ELECTRICIAN

NSQF (LEVEL - 5)

4th Semester

TRADE THEORY

SECTOR: Electrical

Directorate General of Training

**DIRECTORATE GENERAL OF TRAINING
MINISTRY OF SKILL DEVELOPMENT & ENTREPRENEURSHIP
GOVERNMENT OF INDIA**

NATIONAL INSTRUCTIONAL MEDIA INSTITUTE, CHENNAI

Sector : Electrical

Duration : 2 - Years

Trade : Electrician 4th Semester - Trade Theory - NSQF (LEVEL - 5)

Rs.260/-

FOREWORD

The Government of India has set an ambitious target of imparting skills to 30 crores people, one out of every four Indians, by 2020 to help them secure jobs as part of the National Skills Development Policy. Industrial Training Institutes (ITIs) play a vital role in this process especially in terms of providing skilled manpower. Keeping this in mind, and for providing the current industry relevant skill training to Trainees, ITI syllabus has been recently updated with the help of Mentor Councils comprising of various stakeholder's viz. Industries, Entrepreneurs, Academicians and representatives from ITIs.

National Instructional Media Institute (NIMI), Chennai has come up with instructional material to suit the revised curriculum for **Electrician 4th Semester Trade Theory NSQF (LEVEL - 5)** in **Electrical** sector under Semester Pattern required for ITIs and related institutions imparting skill development. The NSQF (LEVEL - 5) will help the trainees to get an international equivalency standard where their skill proficiency and competency will be duly recognized across the globe and this will also increase the scope of recognition of prior learning. NSQF (LEVEL - 5) trainees will also get the opportunities to promote life long learning and skill development. I have no doubt that with NSQF (LEVEL - 5) the trainers and trainees of ITIs, and all stakeholders will derive maximum benefits from these IMPs and that NIMI's effort will go a long way in improving the quality of Vocational training in the country.

The Executive Director & Staff of NIMI and members of Media Development Committee deserve appreciation for their contribution in bringing out this publication.

Jai Hind

RAJESH AGGARWAL
Director General / Addl. Secretary,
Ministry of Skill Development & Entrepreneurship,
Government of India.

New Delhi - 110 001

PREFACE

The National Instructional Media Institute (NIMI) was established in 1986 at Chennai by then Directorate General of Training (D.G.T), Ministry of Labour and Employment, (now under Directorate General of Training (D.G.T), Ministry of Skill Development and Entrepreneurship) (MSDE) Government of India, with technical assistance from the Govt. of the Federal Republic of Germany. The prime objective of this institute is to develop and provide instructional materials for various trades as per the prescribed syllabi (NSQF) under the Craftsman and Apprenticeship Training Schemes.

The instructional materials are created keeping in mind, the main objective of Vocational Training under NCVT/NAC in India, which is to help an individual to master skills to do a job. The instructional materials are generated in the form of Instructional Media Packages (IMPs). An IMP consists of Theory book, Practical book, Test and Assignment book, Instructor Guide, Audio Visual Aid (Wall charts and Transparencies) and other supporting materials.

The trade theory book provides related theoretical knowledge required to enable the trainee to do a job. The test and assignments will enable the instructor to give assignments for the evaluation of the performance of a trainee. The wall charts and transparencies are unique, as they not only help the instructor to effectively present a topic but also help him to assess the trainee's understanding. The instructor guide enables the instructor to plan his schedule of instruction, plan the raw material requirements, day to day lessons and demonstrations.

IMPs also deals with the complex skills required to be developed for effective team work. Necessary care has also been taken to include important skill areas of allied trades as prescribed in the syllabus.

The availability of a complete Instructional Media Package in an institute helps both the trainer and management to impart effective training.

The IMPs are the outcome of collective efforts of the staff members of NIMI and the members of the Media Development Committees specially drawn from Public and Private sector industries, various training institutes under the Directorate General of Training (DGT), Government and Private ITIs.

NIMI would like to take this opportunity to convey sincere thanks to the Directors of Employment & Training of various State Governments, Training Departments of Industries both in the Public and Private sectors, Officers of DGT and DGT field institutes, proof readers, individual media developers and coordinators, but for whose active support NIMI would not have been able to bring out this materials.

Chennai - 600 032

R. P. DHINGRA
EXECUTIVE DIRECTOR

ACKNOWLEDGEMENT

INTRODUCTION

This manual for trade Theory is intended for use in the ITI class room. It consists of a series of lessons that are to be completed by the trainees during the Third semester of course is the **Electrician trade under Electrical Sector. It is National Skills Qualifications Framework NSQF (LEVEL - 5),** supplemented and supported by instructions/information to assist the trainees in performing the exercises. The syllabus for the 4th Semester **Electrician NSQF (LEVEL - 5)** Trade under **Electrical Sector** Trade Practical is divided into Seven modules.The allocation of time for the various modules is given below:

Module 1 - Electronic Practice	15 Exercises	175 Hrs
Module 2 - Control Panel Wiring	5 Exercises	100 Hrs
Module 3 - AC/DC Motor Drives	3 Exercises	50 Hrs
Module 4 - Inverter and UPS	6 Exercises	75 Hrs
Module 5 - Power Generation and Substation	7 Exercises	50 Hrs
Module 6 - Transmission and Distribution	7 Exercises	50 Hrs
Module 7 - Circuit Breakers and Relays	5 Exercises	25 Hrs
Total	48 Exercises	525 Hrs

The syllabus and the content in the modules are interlinked. As the number of workstations available in the electrical section is limited by the machinery and equipment, it is necessary to interpolate the exercises in the modules to form a proper teaching and learning sequence. The sequence of instruction is given in the schedule of instruction which is incorporated in the Instructor's Guide. With 25 practical hours a week of 5 working days 100 hours of practical per month is available.

The procedure for working through the 48 exercises for the 4th semester with the specific objectives to be achieved as the learning out comes at the end of each exercise is given in this book.

The symbols used in the diagrams comply with the Bureau of Indian Standards (BIS) specifications.

This manual on trade Theory forms part of the Written Instructional Material (WIM), which includes manual on trade practical and assignment/test.

CONTENTS

ASSESSABLE / LEARNING OUTCOME

On completion of this book you shall be able to

- **Detect the faults and troubleshoot inverter, stabilizer, battery charger emergency light and UPS etc.**

- **Plan, assemble and install solar panel**

- **Erect overhead domestic service line and outline various power plant layout.**

- **Examine the faults and carryout repairing of circuit breakers.**

- **Identify the control and functional switches in C.R.O and measure the DC and AC voltage, frequency time period.**

- **Construct and test a half and fullwave rectifiers with and without filter circuits.**

- **Draw and wire up the control panel for forward/ reverse operation of induction motor.**

- **Control speed and reverse the direction of rotation of different type of three phase induction motor using VVVF control /AC drive**

ELECTRICIAN 4TH SEMESTER SYLLABUS

Fourth Semester Duration: Six Month

Week No.	Learning outcome Reference	Professional Skills (Trade Practical) With Indicative Hours	Professional Knowledge (Trade Theory)
79	• Assemble simple electronic circuits and test for functioning.	160. Determine the value of resistance by colour code and identify types. (10 Hrs) 161. Test active and passive electronic components and its applications. (15 Hrs)	Resistors - colour code, types and characteristics. Active and passive components. Atomic structure and semiconductor theory.
80-81	• Assemble simple electronic circuits and test for functioning.	162. Determine V-I characteristics of semiconductor diode. (10 Hrs) 163. Construct half wave, full wave and bridge rectifiers using semiconductor diode. (10 Hrs) 164. Check transistors for their functioning by identifying its type and terminals. (10 Hrs) 165. Bias the transistor and determine its characteristics. (10 Hrs) 166. Use transistor as an electronic switch and series voltage regulator. (10 Hrs)	P-N junction, classification, specifications, biasing and characteristics of diodes. Rectifier circuit - half wave, full wave, bridge rectifiers and filters. Principle of operation, types, characteristics and various configuration of transistor. Application of transistor as a switch, voltage regulator and amplifier.
82-83	• Assemble simple Electronic circuits and test for functioning.	167. Operate and set the required frequency using function generator. (12 Hrs) 168. Make a printed circuit board for power supply. (10 Hrs) 169. Construct simple circuits containing UJT for triggering and FET as an amplifier. (12 Hrs) 170. Troubleshoot defects in simple power supplies. (16 Hrs)	Basic concept of power electronics devices. IC voltage regulators Digital Electronics - Binary numbers, logic gates and combinational circuits.
84-85	• Assemble simple electronic circuits and test for functioning.	171. Construct power control circuit by SCR, Diac, Triac and IGBT. (15 Hrs) 172. Construct variable DC stabilized power supply using IC. (10 Hrs) 173. Practice on various logics by use of logic gates and circuits. (15 Hrs) 174. Generate and demonstrate wave shapes for voltage and current of rectifier, single stage amplifier and oscillator using CRO. (10 Hrs)	Working principle and uses of oscilloscope. Construction and working of SCR, DIAC, TRIAC and IGBT. Principle, types and applications of various multivibrators.
86-87	• Assemble accessories and carry out wiring of control cabinets and equipment.	175. Design layout of control cabinet, assemble control elements and wiring accessories for: (i) Local and remote control of induction motor. (15 Hrs) (ii) Forward and reverse operation of induction motor. (10 Hrs)	Study and understand Layout drawing of control cabinet, power and control circuits. Various control elements: Isolators, pushbuttons, switches, indicators, MCB, fuses, relays, timers and limit switches etc.

ELECTRICIAN 4TH SEMESTER SYLLABUS

Fourth Semester Duration: Six Month

Week No.	Learning outcome Reference	Professional Skills (Trade Practical) With Indicative Hours	Professional Knowledge (Trade Theory)
		(iii) Automatic star-delta starter with change of direction of rotation. (15 Hrs) (iv) Sequential control of three motors. (10 Hrs)	
88-89	• Assemble accessories and carry out wiring of control cabinets and equipment.	176. Carry out wiring of control cabinet as per wiring diagram, bunching of XLPE cables, channeling, tying and checking etc. (15 Hrs) 177. Mount various control elements e.g. circuit breakers, relays, contactors and timers etc. (10 Hrs) 178. Identify and install required measuring instruments and sensors in control panel. (10 Hrs) 179. Test the control panel for its performance. (15 Hrs)	Wiring accessories: Race ways/ cable channel, DIN rail, terminal connectors, thimbles, lugs, ferrules, cable binding strap, buttons, cable ties, sleeves, gromats and clips etc. Testing of various control elements and circuits.
90-91	• Perform speed control of AC and DC motors by using solid state devices.	180. Perform speed control of DC motor using thyristors / DC drive. (18 Hrs) 181. Perform speed control and reversing the direction of rotation of AC motors by using thyristors / AC drive. (18 Hrs) 182. Construct and test a universal motor speed controller using SCR. (14 Hrs)	Working, parameters and applications of AC / DC drive. Speed control of 3 phase induction motor by using VVVF/AC Drive.
92-94	• Detect the faults and troubleshoot inverter, stabilizer, battery charger, emergency light and UPS etc.	183. Assemble circuits of voltage stabilizer and UPS. (15Hrs) 184. Prepare an emergency light. (10 Hrs) 185. Assemble circuits of battery charger and inverter. (15 Hrs) 186. Test, analyze defects and repair voltage stabilizer, emergency light and UPS. (15 Hrs) 187. Maintain, service and troubleshoot battery charger and inverter. (10 Hrs) 188. Install an Inverter with battery and connect it in domestic wiring for operation. (10 Hrs)	Basic concept, block diagram and working of voltage stabilizer, battery charger, emergency light, inverter and UPS. Preventive and breakdown maintenance.
95	• Erect overhead domestic service line and outline various power plant layout.	189. Draw layout of thermal power plant and identify function of different layout elements. (5 Hrs) 190. Draw layout of hydel power plant and identify functions of different layout elements. (5 Hrs)	Conventional and nonconventional sources of energy and their comparison. Power generation by thermal and hydel power plants.

ELECTRICIAN 4TH SEMESTER SYLLABUS

Fourth Semester Duration: Six Month

Week No.	Learning outcome Reference	Professional Skills (Trade Practical) With Indicative Hours	Professional Knowledge (Trade Theory)
		191. Visit to transmission / distribution substation. (10 Hrs) 192. Draw actual circuit diagram of substation visited and indicate various components. (5 Hrs)	
96	• Plan, assemble and install solar panel. • Erect overhead domestic service line and outline various power plant layout.	193. Prepare layout plan and Identify different elements of solar power system. (05 Hrs) 194. Prepare layout plan and Identify different elements of wind power system. (05 Hrs) 195. Assemble and connect solar panel for illumination. (15 Hrs)	Various ways of electrical power generation by non-conventional methods. Power generation by solar and wind energy. Principle and operation of solar panel.
97	• Erect overhead domestic service line and outline various power plant layout.	196. Practice installation of insulators used in HT/LT line for a given voltage range. (5 hrs) 197. Draw single line diagram of transmission and distribution system. (5 Hrs) 198. Measure current carrying capacity of conductor for given power supply. (5 hrs) 199. Fasten jumper in pin, shackle and suspension type insulators. (10 Hrs)	Transmission and distribution networks. Line insulators, overhead poles and method of joining aluminum conductors.
98	• Erect overhead domestic service line and outline various power plant layout.	200. Erect an overhead service line pole for single phase 230 V distribution system in open space. (10 Hrs) 201. Practice on laying of domestic service line. (10 Hrs) 202. Install bus bar and bus coupler on LT line. (5 Hrs)	Safety precautions and IE rules pertaining to domestic service connections. Various substations. Various terms like - maximum demand, average demand, load factor, diversity factor, plant utility factor etc.
99	• Examine the faults and carry out repairing of circuit breakers.	203. Identify various parts of relay and ascertain the operation. (5 Hrs) 204. Practice setting of pick up current and time setting multiplier for relay operation. (5 hrs) 205. Identify the parts of circuit breaker, check its operation. (5Hrs) 206. Test tripping characteristic of circuit breaker for over current and short circuit current. (5 hrs) 207. Practice on repair and maintenance of circuit breaker. (5 hrs)	Types of relays and its operation. Types of circuit breakers, their applications and functioning. Production of arc and quenching.

ELECTRICIAN 4TH SEMESTER SYLLABUS

Fourth Semester Duration: Six Month

Week No.	Learning outcome Reference	Professional Skills (Trade Practical) With Indicative Hours	Professional Knowledge (Trade Theory)
100-101	Project work / Industrial visit Broad Areas: a) Battery charger/Emergency light b) Control of motor pump with tank level c) DC voltage converter using SCRs d) Logic control circuits using relays e) Alarm/indicator circuits using sensors		
102-103	Revision		
104	Examination		

Circuit board soldering and resistor colour coding

Objectives: At the end of this lesson you shall be able to
• **distinguish between eyelet board, lug board and PCB**
• **explain the preparation of components for mounting and method of soldering on boards**
• **explain the inspection of solder joints and defects in soldered joints**
• **explain construction, types, function, colour coding and application of resistors in circuits.**

In assembling of electronic circuits using components, it is required to layout (arrange), mount and wire the components in a systematic manner. In wiring the electronic circuits depending upon the circuit, different types of boards are used.

Type of boards

1 Eyelet board

2 Lug or tag board

3 Printed Circuit Boards (PCB's)

Eyelet Board (Fig 1) : In this, eyelets are riveted on perforated bakelite boards. Refer Fig 1. In this type of board, eyelets can be riveted only to a limited number, depending on the lay-out of the circuits.

EYELET BOARD
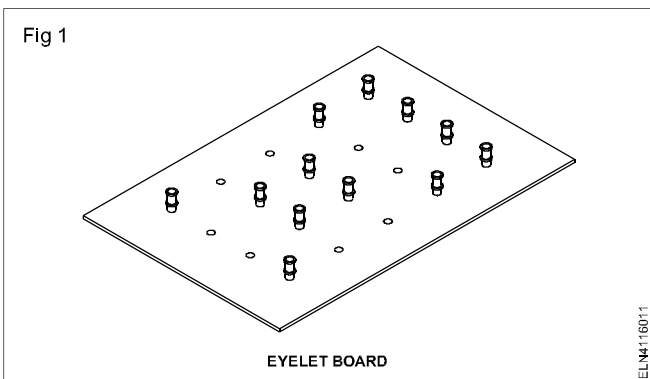
Lug or tag board (Fig 2) : In this type of boards, brass lugs are riveted in rows on insulated board like bakelite. In this type, components are to be arranged, and circuits are to be made without altering the lug position.
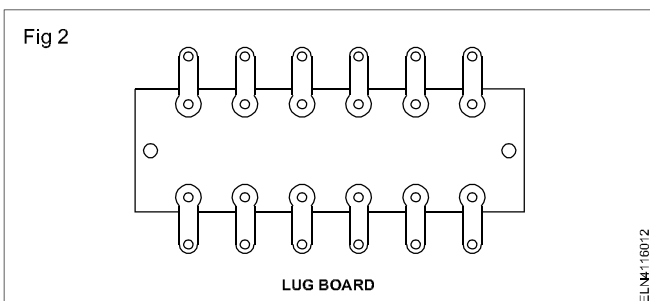
LUG BOARD

PCB (Printed circuit board) : A printed circuit board in which inter connecting wires are replaced by a thin conducting surface called copper on silver foil which is moulded in one side of the insulated board. The insulating board is generally made up of phenolic (or) paper or fibre glass or epoxy.

The required circuit pattern on the laminated board is made by process called "etching". Etching is the process of removing the portion of the metal foil, leaving behind only the required portion refer Fig 3.

PRINTED CIRCUIT BOARD
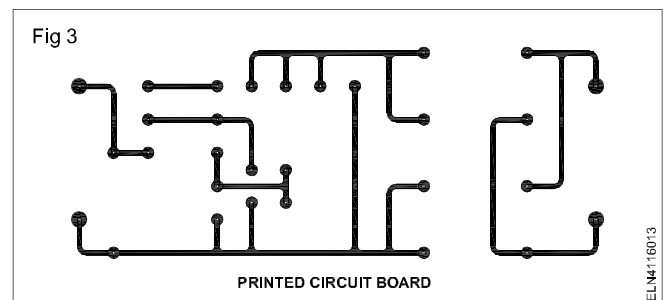
For general purpose, printed circuit boards are readily available to design and develop electronic circuits. They are also called as matrix boards. A strip type matrix board is shown in Fig 4.

GENERAL PURPOSE PCB
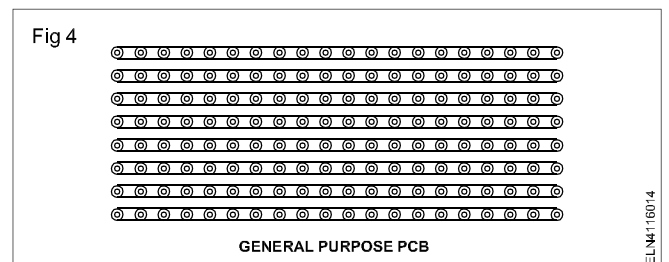
Securing and fixing of components: Mounting of components on eyelet board / lug board / tag board or PCB involves 4 main activities, namely,

1 Preparation of component leads and surfaces to be soldered.

2 Shaping the components leads.

3 Bending and trimming the excess length before soldering.

4 The order of mounting and soldering.

1 **Preparation of components leads and surfaces etc.:** Dust, oil, oxide layer paint or any protective coating on the component leads and surfaces must be removed at places where soldering has to be done.

2 **Shaping the components:** The shape to which the components leads are to be bent depends up on the manner in which the component is to be mounted. Care should be taken to reduce the thrust on the component.

1

Depending on the type of component lead, and the space available on the PCB, component can be mounted either vertically (or) horizontally as in Fig 5.

Fig 5

HORIZONTAL MOUNTING OF COMPONENTS

VERTICAL MOUNTING OF COMPONENTS

PCB

PCB

CAPACITOR

CAPACITOR

TAKES MORE SPACE BUT MORE STABLE

TAKES LESS SPACE BUT LESS STABLE

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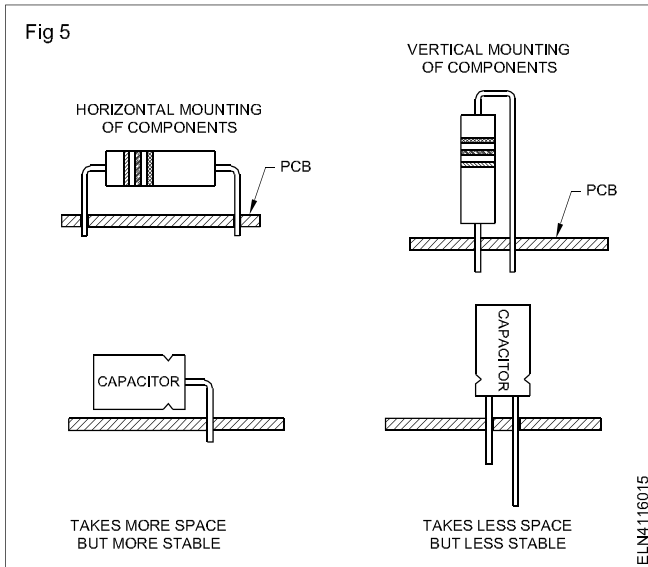
3 Bending and trimming : Once the components leads are inserted into the holes of PCB, lead length in excess (0.5 mm to 3 mm), from the PCB surface should be trimmed, using side cutting pliers as in Fig 6.

Fig 6

TRIM LEAD

3 – 5mm

ELN4116016
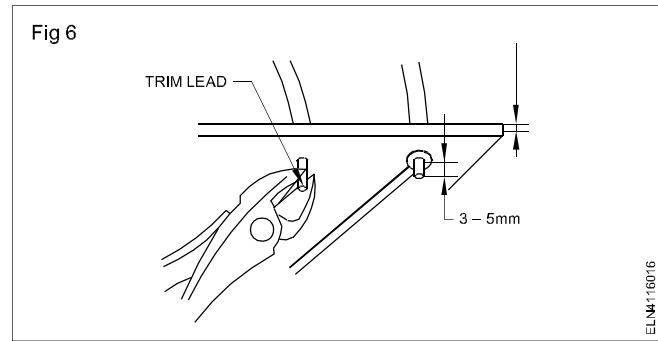
After cutting the excess lead length, the component lead must be bend and terminated, on PCB.

4 Order of mounting: Mount the components in the order as per layout, and should be easy to trace the circuit, as per connection diagram.

The technique used for soldering is explained in subsequent lesson.

Soldering technique

Objectives : At the end of this lesson you shall be able to
• **list the critical factors and stages in soldering**
• **list the steps involved in selecting and preparing the materials**
• **list the different shapes of tips and inspection of soldering iron**
• **state the functions of soldering iron stand and inspection of soldering iron**
• **state the technique of soldering electronic components and effect of residual flux**
• **state the defects in soldering joints.**

Soldering

Soldering is the process of joining two metals for a permanent joint/connections. The bonding of two metals done by using alloy of two metals-lead and tin called solder in different ratios to solder electronic component like resistors, capacitor, transistor etc.

Soldering a joint: Selection and preparation of the soldering materials and cleaning the surfaces to be soldered are the most time consuming phase of making a solder joint. Heating the joint and applying solder is the least time consuming but, all these steps contribute heavily for the good soldered joint.

Critical factor during soldering

1 Controlling the temperature of the workpiece.

2 Limiting the time that a workpiece is to be held at soldering temperature.

These factors are specially critical while soldering electronic components like resistors, capacitors, transistors, ICs etc., Failure of correct time and coordinate the heating of the joint and add solder, will result in a poor quality joint and may even damage the components.

Stage in soldering: The soldering process can be divided into several distinct stage or phases as given below:

1 Selection and preparation of materials

2 Cleaning the surfaces to be soldered

3 Heating the joint and adding solder

4 Cooling the joint

5 Cleaning the joint

6 Inspecting the joint.

1 Selection and preparation of materials

Selection of soldering iron wattage : Soldering irons are available in different wattage ratings starting from 10 watts to several 100 watts. The wattage of a soldering iron specifies the amount of heat it can produce. As a thumb rule, higher the physical dimension of the workpiece, higher should be the wattage rating of the soldering iron. Some of the suggested wattage of soldering iron are given below:

i) For soldering, less temperature sensitive component such as, resistors on lug boards or tag boards, use 25 to 60W iron. For soldering on printed circuit boards, use 10 to 25 W iron.

ii) For soldering highly temperature sensitive components such as, diodes, transistors and integrated circuits, use 10 to 25 watts iron.

Selection of soldering iron tip: To ensure that the joint is heated to the required temperature ideally,

– the area of the tip face should be approximately equal to the area of the joint to be soldered

– the tip should be long enough to allow easy access to the joint.

- the tip should not be too long, as this may result in the low temperature at the tips working face.

In most soldering irons, the tip can be easily removed and can be replaced.

Selection of tip shape: Suggested soldering tip shapes and their application are given below;

Type of soldering tip shape	Application
Wires, resistor and the passive components on lug boards	CHISEL TIP
All miniature electronic components except ICs on to lug boards and printed circuit boards (PCB)	BEVEL TIP
Integrated circuits (ICs) on to printed circuit boards (PCBs)	CONICAL TIP

Selection of solder and flux: For electronic soldering applications, solder of tin and lead of 60/40 proportion is used. This solder proportion has a melting point of 200°C which is the required temperature for general purpose soldering irons.

For electrical purpose, resin core solders are used.

For ease of application, the flux used in addition to the cored flux in solder, should be in paste form.

Flux is a chemical substance which has acidic properties. Therefore, it is advised not to touch the flux by hand. Use a stick or a thin stiff brush to apply flux on the work pieces. Hands should be washed after soldering work.

Soldering stand: Soldering stand plays an important role of retaining the soldering iron tip temperature around the required soldering temperature. The soldering stand should not allow the external temperature to cool the bit. At the same time the stand should not contain all the heat generated.

Soldering stands are specially designed as in Fig 1 to fulfill the above requirements. Such a design also prevents accidental burn injuries to the user of the soldering iron and the stand remains stable mechanically.

Fig 1
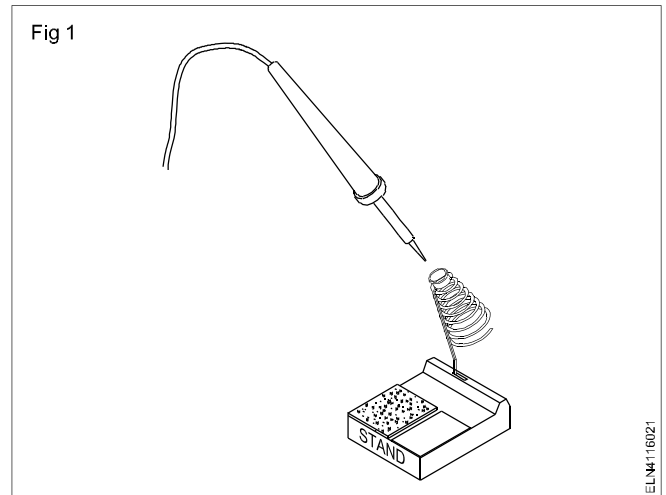
Inspection of soldering iron: Most soldering irons are powered by AC main voltage. This voltage level is high and can give shock if one is careless. Soldering irons will generally have lengthy mains cable. While using the iron, the mains cable gets twisted and will have to bear physical stain. Because of this strain, the insulation of cable may get cut. This may lead to live wires protruding out. The live wires give severe electrical shocks if it touches the user.

Hence, a thorough inspection of the soldering iron cable is a must before using it.

Preparation of soldering iron for soldering: The soldering bit tip should be cleaned, heated and tinned before starting the soldering work.

Cleaning the surfaces to be soldered: Before joining two pieces of metal by soldering, the joining surfaces should be cleaned to remove foreign matters over the surface. Also the jointing surfaces should be free from grease grit or oil. this could be achieved by using either a knife or by a sand paper and cloth.

2 **Heating the joint and adding solder:** Tips for heating and applying solder to a joint to be soldered are given below:

– Do not apply too much flux on a joint in one place. Apply a small amount of flux around the joint. Do not allow the flux to flow outside the area to be soldered.

– Place the iron tip at the joint such that the tip gets maximum contact with parts to be joined as in Fig 2

Fig 2

A. COMPONENT LEAD TO IRON CONTACT AREA
B. IRON TO LUG / TERMINAL / PCB CONTACT AREA
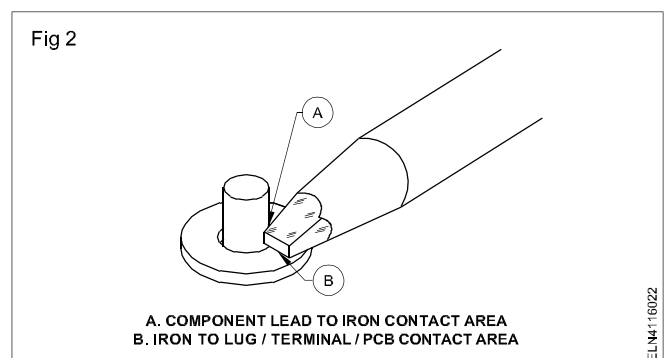
Slowly feed the solder into the joint starting close to the soldering tip and moving towards the edge of the joint as in Fig 3

Fig 3
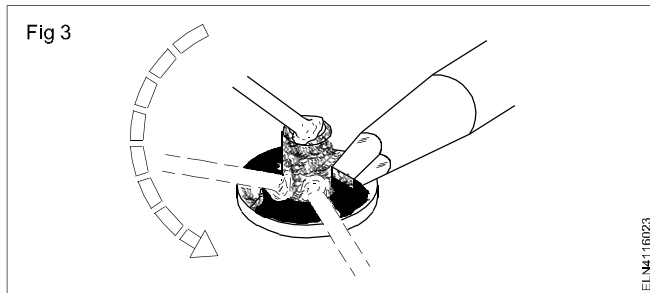
Continue applying the solder to the joint until complete wetting of the joint has been achieved and the joint has a concave fillet as in Fig 4

Fig 4
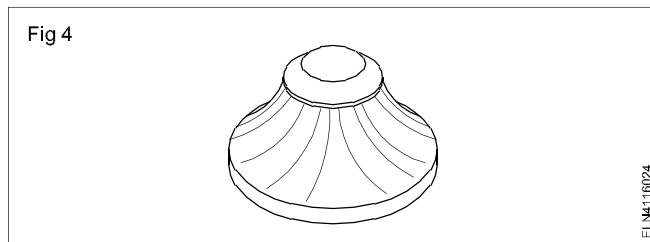
After enough solder has been applied and solder wire removed, keep the soldering iron tip on the joint for a moment to ensure that all the flux on the joint has reached the soldering temperature. This will allow majority of the acids within the joint to break down, which otherwise will corrode the joint after a period of time.

Generally the time taken to make a good soldered joint is between 3 to 7 seconds from applying the soldering iron to and removing the soldering iron.

3 **Cooling the joint:** Tips for cooling a solder joint are given below:

–   Allow the joint to cool without assistance, do not blow air from your mouth or from any other source to cool the joint. Forced cooling, cools the joint much earlier than it has to, resulting in a dry and brittle solder joint which will lead to mechanical and electrical defects of the joint.

–   Do not move any part of the joint while it is cooling. This disturbs the chemical bonding taking place. Movement of the joint while it is cooling results in a dry joint.

4 **Cleaning the joint :** When a solder joint is made, the amount of flux applied should be just sufficient to make a good joint. But, quite often, there will be a brown waxy substance left on the joint. This is nothing but the flux residue. In its original state this residue is corrosive. Hence, the flux residue or excess flux must be removed from the joint before soldering can be considered as complete.

If the flux residue and excess flux are not properly removed, their corrosive nature of the flux will gradually destroy the component leads and the circuit board. The flux residue is also sticky and, if not removed, will collect dust and debris leading to circuit failure.

Removal of flux residue requires the use of solvents. The type of solvent depends on the flux used.

Iso Propyl Alcohol (IPA) is one of the solvents used for removing residual flux. It is available either undiluted or pre-mixed with water and can be obtained in pump sprays, aerosols, cans and drums depending on the quantity and style of use.

Cleaning using water/IPA solution: Determine the right method of application. (spray or liquid). Apply the solvent to the soldered joint. Use a clean brush, or some other type of stiff brush, to gently scrub the joint as in Fig 5, to help dissolve the residue, taking care to avoid splashing the mixture.

Fig 5

SOLUTION SOAKED BRUSH

SOLDER PAD
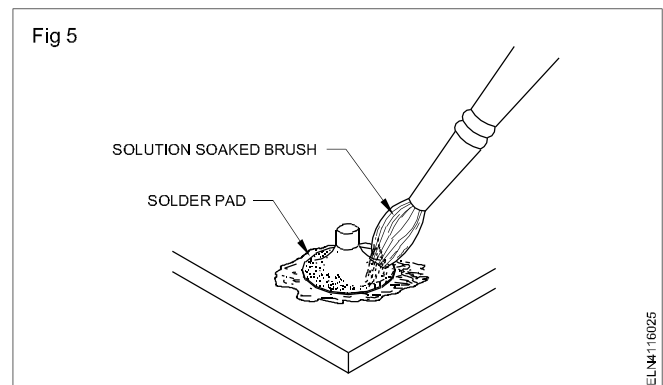
When the residue has been dissolved, dry the joint with a lint-free cloth to remove as much of the dissolved residue as possible.

Inspection of soldered joints: Soon after making a solder joint, as a quick check, the following features of the solder joint should be checked:

1   Soldered joint must be bright and shiny.

2   Soldered joint must be smooth and symmetrical.

Surface colour - The surface of a correctly soldered joint will be glossy, silvery and uniform in colour.

Surface texture - The surface texture of a correctly soldered joint will be smooth, even and non-grainy. There shall be no signs of pitting on the surface of the solder.

Common soldering defects: Defects in solder joints can be grouped as follows:

1   Temperature defects

2   Wetting defects

3   Solder quantity defects

4   Mechanical defects.

Temperature defects: Temperature defects are caused by excessive or insufficient heating of the joint during the soldering process.

Defects due to excessive heating: The solder on an overheated joint will have grainy tenure, dull grey colour and pitted.

Too much heat can lead to one or more of the following defects:

– Overheating of the resin flux, causes the flux to char and lose its ability to remove oxides. Lumps of charred flux gets trapped in the solder forming pits and voids.

– Overheating of the solder, causes excessive alloying between the copper parts of the connection and the tin content of the solder. This in turn causes localized depletion of the tin and results in a brittle joint.

– Excessive oxidisation of the solder. The oxidised solder forms a poor bond with the other parts of the joint.

Defects due to insufficient heating: Too little heat can lead to one or more of the following defects:

A defect known as a cold joint. A cold joint occurs when the flux is unable to remove the tarnish from the joint. At low soldering temperature the flux is only partly activated. Therefore, it is less effective in removing tarnish.

Insufficiently heated solder joint results in,

– poor wetting of the joint

– a course solder fillet

– solder steps at the edges

The effects of a cold joint are,

– high electrical resistance

– low mechanical strength

– dry solder joint

A defect known as a dry joint occurs when the solder is too viscous to push the flux away from the component lead. A layer of the flux becomes trapped around the lead. This layer of flux causes a weak bond and hence a poor electrical connection.

Causes of incorrect soldering temperatures

A common indicator of incorrect soldering temperature is the formation of small peaks at the tip of the joint as the iron is pulled away. These peaks will be formed at either too high or too low soldering temperature.

Incorrect soldering temperature may be due to,

– incorrect wattage of the soldering iron

– incorrect soldering tip selection

– insufficient heating of the soldering iron

– poor soldering technique, leading to poor heat transfer from the tip of the iron to the joint.

Wetting defects (Refer Fig 6)

The degree of wetting of a joint depends greatly on the cleanliness of the parts to be joined.

Fig 6
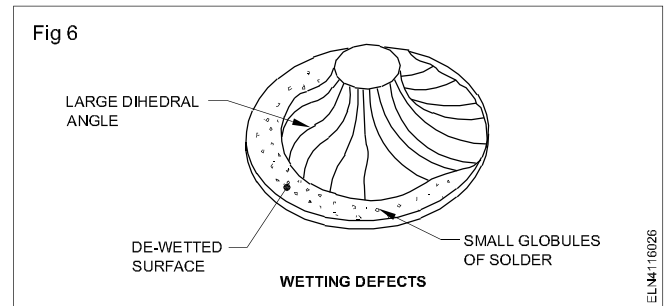
WETTING DEFECTS

Wetting defects are easily recognised by the inability of the solder to cover all the metal surfaces at the joint and the formation of a large dihedral angles as in Fig 6.

On severely tarnished surfaces, the solder will not flow over the tarnished surface(non-wetting) or the solder initially flows over the tarnished surface, but then retreats leaving small globules of solder on the surface (de-wetting) as in Fig 6.

Solder quantity defects(Refer Fig 7 and 8)**:** Solder quantity defects are due to either too little or too much solder applied to a connection.

Too little solder results in a small size of the solder fillet as in Fig 7. The small solder fillets makes a joint weak.

Fig 7

TOO SMALL SOLDER QUANTITY DEFECTS
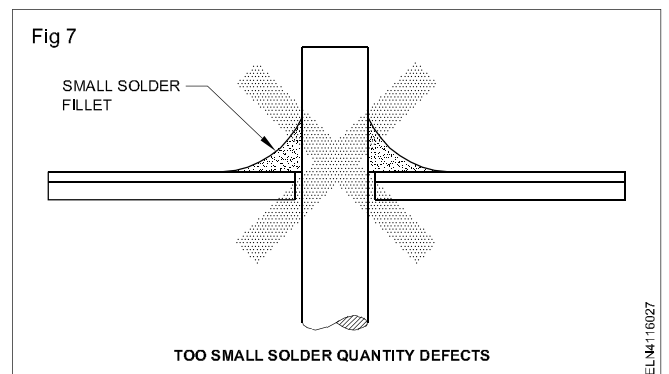
Too much solder results in convex solder fillets as in Fig 8. This defect is recognised by the large size and the convex shape of the fillets.

Fig 8

TOO LARGE SOLDER QUANTITY DEFECTS
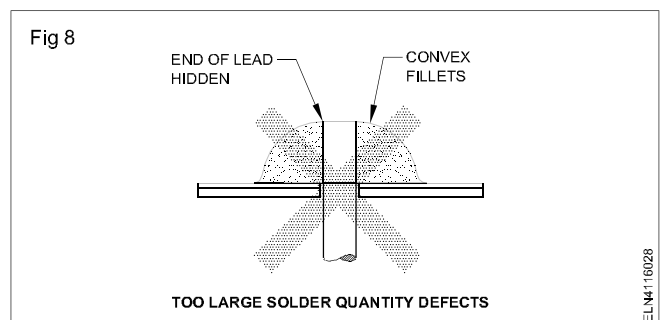
Mechanical defects: Mechanical defects of a solder joint are caused by;

– the movement of parts of a joint while the solder is cooling.

Movement during cooling causes severe dislocation of the crystalline structure of the solder. This results in a weak joint which may fracture later and cause high electrical resistance or an intermittent fault when the circuit is in use. A joint moved before cooling will have a frosted appearance with fractures.

– stresses imposed on the joint as it cools.

Stresses on the joint are usually as a result of inadequate stress relief bends in the leads of components. A stressed joint usually breaks due to the expansion and contraction of components while in use, due to temperature variations.

Blowing on the soldered joint to attempt to speed up cooling will introduce several additional cooling stresses.

Connections that have been disturbed as they cool usually have a frosted appearance.

Never forget the rule, if the quality or reliability of the joint is in doubt, de-solder the joint and re-solder it fresh.

Resistors: These are the most common passive component used in electronic circuits. A resistor is manufactured with a specific value of ohms (resistance). The purpose of using a resistor in circuit is either to limit the current to a specific value or to provide a desired voltage drop (IR). The power rating of resistors may be from 0.1 W. to hundreds of Watts.

There are four types of resistors

1 Wire-wound resistors

2 Carbon composition resistors

3 Metal film resistors

4 Carbon film resistors

1 Wire-wound resistors

Wire-wound resistors are manufactured by using resistance wire (nickel-chrome alloy called Nichrome) wrapped around an insulating core, such as ceramic porcelain, bakelite pressed paper etc.Fig 9, shows this type of resistor.The bare wire used in the unit is generally enclosed in insulating material. Wire wound resistors are used for high current application. They are available in wattage ratings from one watt to 100 watts or more. The resistance can be less than 1 ohm and go up to several thousand ohms. They are also used where accurate resistance values are required.

Fig 9

WIRE-WOUND FIXED RESISTOR
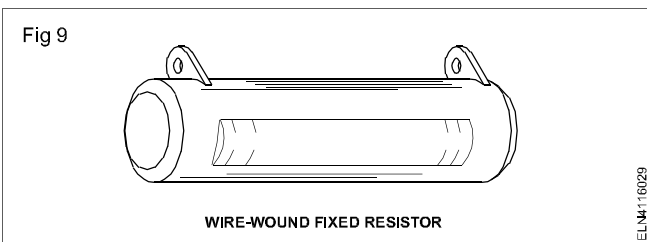
One type of Wire-wound resistor is called as fusible resistor enclosed in a porcelain case. The resistance is designed to open the circuit when the current through it exceeds certain limit.

2 Carbon composition resistors

These are made of fine carbon or graphite mixed with powdered insulating material as a binder in the proportion needed for the desired resistance value. Carbon-resistance elements are fixed with metal caps with leads of tinned copper wire for soldering the connection into a circuit. Fig 10 shows the construction of carbon composition resistor.

Fig 10

MOLDED
RESISTANCE ELEMENT

TINNED LEADS

CARBON COMPOSITION RESISTOR
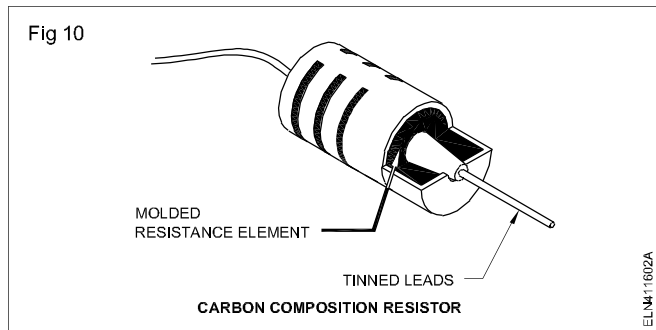
Carbon resistor are available in values of 1 ohm to 22 megohms and of different power ratings, generally 0.1, 0.125, 0.25, 0.5 and 2 watts.

3 Metal film resistors (Fig 11)

Fig 11

METAL FILM RESISTOR
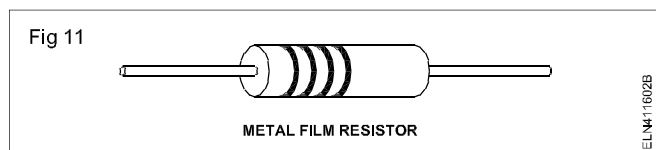
Metal film resistors are manufactured by two processes. Thick film resistors are pasted with metal compound and powdered glass which are spread on the ceramic base and then backed.

Thin film resistors are processed by depositing a metal vapour on a ceramic base. Metal film resistors are available from 1 ohm to 10 MΩ, upto 1W. Metal film resistors can work from 120°C to 175°C.

4 Carbon film resistors (Fig 12)

Fig 12

GROOVED CARBON FILM

LEADS

END CAP   CERAMIC CORE

(a) CONSTRUCTION   (b) A CARBON-FILM RESISTOR

CARBON – FILM RESISTOR
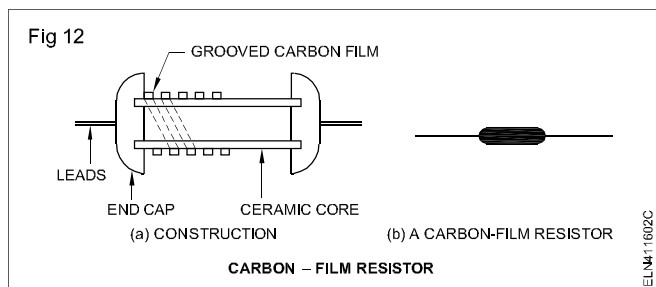
In this type, a thin layer of carbon film is deposited on the ceramic base/tube. A spiral groove is cut over the surface to increase the length of the foil by a specialised process.

Carbon film resistors are available from 1 ohm to few Meg ohm and up to 2W and can work from 85°C to 155°C.

All the above four types of resistors are coated with synthetic resin to protect them against mechanical damages and climatic influences, It is therefore, difficult to distinguish them from each other externally.

Specification of resistors: Resistors are specified normally with the four important parameters

1 Type of resistor

2 Nominal value of the resistors in ohm (or) kilo ohm (or) mega ohm.

3 Tolerance limit for the resistance value in percentage.

4 Loading capacity of the components in wattage

Example

100 ± 10% , 1W, where as nominal value of resistance is 100Ω.

The actual value of resistance may be between 90 Ω to 110 Ω, and the loading capacity is maximum 1 watt.

The resistors can also be classified with respect to their function as

1 Fixed resistors

2 Variable resistors

Fixed resistors : The fixed resistors is one in which the nominal value of resistance is fixed. These resistors are provided with pair of leads. (Fig 10 to 12)

Variable resistors (Fig 13) : Variable resistors are those whose values can be changed. Variable resistors includes those components in which the resistance value can be set at the different levels with the help of sliding contacts. These are known as potentiometer resistors or simply as a potentiometers.

Fig 13

(a)

FLAT KEYWAY
SHAFT
X
Y TERMINALS
Z

(b)

CARBON COMPOSITION RESISTOR ELEMENT
SPRING WIPER CONTACT
ROTATING ARM
SHAFT

① ② ③

VARIABLE CARBON-RESISTANCE   (a) EXTERNAL VIEW
(b) INTERNAL VIEW OF CIRCULAR RESISTANCE ELEMENT
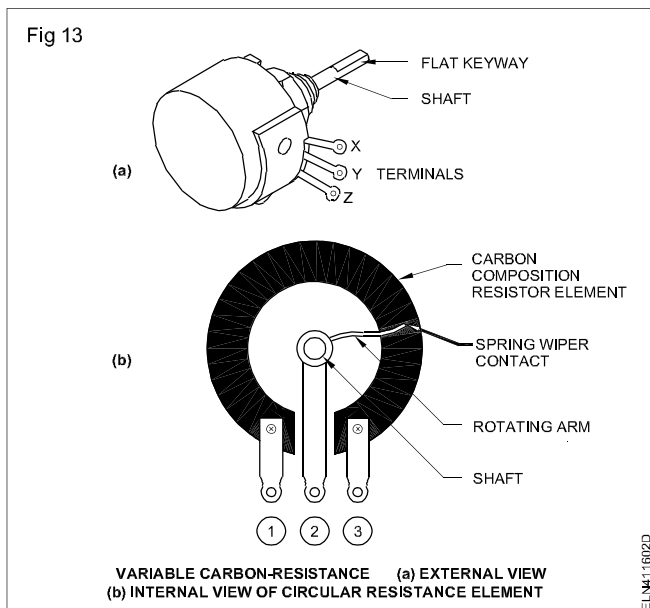
It is provided with 3 terminals as shown in Fig 13 and 14. They are available with carbon tracks (Fig 13) and wire wound (Fig 14) types. Trimmer potentiometers (or) resistor which can be adjusted with the help of a small screw driver. (Fig 15).

Fig 14

WIRE-WOUND VARIABLE RESISTOR

Fig 15

TRIMMER RESISTOR
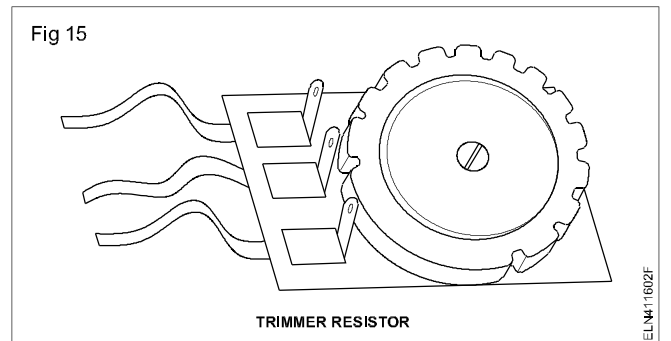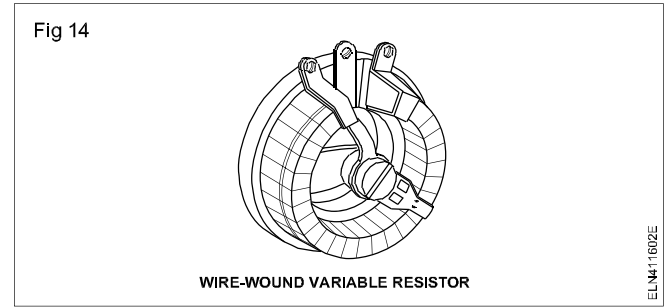
Resistance depends upon temperature, voltage, light: Special resistors are also produced whose resistance varies with temperature, voltage, and light.

PTC resistors (Sensistors) : Since, different materials have different crystal structure, the rate at which resistance increases with raising temperature varies from material to material. In PTC resistor (positive temperature coefficient resistor), as the temperature increases, the resistance increases non linearly. For example, the resistance of PTC at room temperature may be of nominal value 100 Ω when the temperature rises say 10°C, it may increase to 150 Ω and with further increase of another 10°C, it may increases to 500 Ω.

NTC Resistors (Thermistors) : In case of NTC resistors (Negative temperature co-efficient resistors) as the temperature increases, the value of resistance decreases non-linearly, For example, NTC resistor, which has nominal value of resistance is 500 Ω at room temperature may decrease to 400 Ω with the rise of 10°C temperature and further decrease to 150 Ω when the temperature rises to another 10°C.

The PTC and NTC resistors can perform switching operation at specific temperature. They are also used for measurements and temperature compensators.

VDR (Varistors) : The VDR (Voltage dependent resistor) resistance falls non-linearly with increasing voltage. For example, a VDR, may have 100 Ω resistance at 10 V, and it may decrease to 90 Ω at rise in 5V. By further increasing the voltage to another 5V, the resistance may fall to 50 Ω. The VDRS are used in voltage stabilisation, arc quenching and over voltage protection.

Light dependent resistor (LDR): The LDRs are also known as photo- conductors. In LDRs the resistance falls with increase in intensity of illumination. The phenomena is explained as the light energy frees some electron in the materials of the resistors, which are then available as extra conducting electrons. The LDR shall have exposed surface to sense the light. These are used for light barriers in operating relays. These are also used for measuring the intensity of light.

Marking codes for resistors

Commercially, the value of resistance and tolerance value are marked over the resistors by colour codes (or) letter and digital codes.

Resistance and tolerance value of colour coded resistors.

The colour codes for indicating the values to two significant figure and tolerances are given in Table 1 as per IS:8186.

Table 1

Values to two significant figures and tolerances corresponding to colours

Colour	First Band/ Dot	Second Band/ Dot	Third Band/ Dot	Fourth Band/ Dot
	First Figure	Second Figure	Multiplier	Tolerance
Silver	—	—	10^{-2}	± 10 %
Gold	—	—	10^{-1}	± 5 %
Black	—	0	1	—
Brown	1	1	10	± 1 %
Red	2	2	10^2	± 2 %
Orange	3	3	10^3	—
Yellow	4	4	10^4	—
Green	5	5	10^5	—
Blue	6	6	10^6	—
Violet	7	7	10^7	—
Grey	8	8	10^8	—
White	9	9	10^9	—
None	—	—	—	± 20 %

The two significant figures and tolerances colour coded resistors have 4 bands of colours coated on the body as in Fig 16.

The first band shall be the one nearest to one end of the component resistor. The second, third and four colourbands are shown in Fig 16.

Fig 16
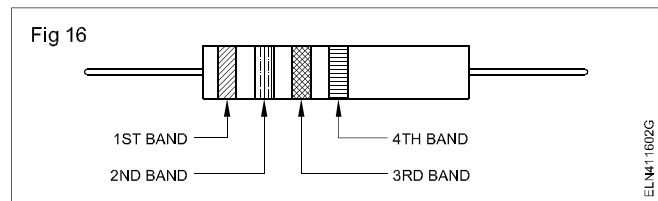
The first two colour bands indicate the first two digits in the numeric value of resistance. The third colour band indicates the multiplier.The first two digits are multiplied by the multiplier to obtain the actual resistance value. The forth colour band indicates the tolerance in percentage.

Example

Resistance value : If the colour band on a resistor are in the order- Red, Violet, Orange and Gold, then the value of the resistor is 27,000 ohms with +5% tolerance.

First colour	Second colour	Third colour	Fourth colour
Red	Violet	Orange	Gold
2	7	$1000(10^3)$	±5%

Tolerance value: The fourth band (tolerance) indicates the resistance range within which is the actual value falls. In the above example, the tolerance is ±5%. ±5% of 27000 is 1350 ohms. Therefore, the value of the resistor is any value between 25650 ohms and 28350 ohms. The resistors with lower value of tolerance (precision) are costlier than normal value of resistors.

For less than ten ohms, the third band will be either golden or silver.

The colours are,

    Gold - 10^{-1} =   1/10 = 0.1

    Silver - 10^{-2} =   1/100 = 0.01

Example (Refer Fig 17)

Colour of Ist Band	Colour of 2nd Band	Colour of 3rd Band
Orange	White	Gold
3	9	1/10

thus, the value of resistor is 39/10 or 3.9 ohms.

Fig 17
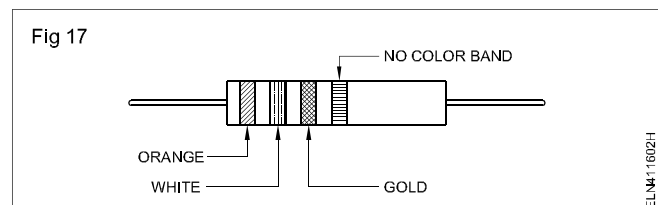
Large value resistances are expressed in kilo ohms and megohms. Letter 'k' stands for kilo and M stands for mega. One kilo equals 1000 (10^3) and one mega equals 1000000 (10^6). The resistance values are expressed as

1000 ohms	=	1 k
1800 ohms	=	1k 8
100 ohms	=	0.1 k
10000 ohms	=	0.1 M
1500000 ohms	=	1 M 5.

Preferred values for resistors: It is not possible to manufacture all values of resistors right from one ohm to a million ohms. So only a set of preferred values of resistors are generally made. Also in the manufacturing process, in which thousands of resistors are made in a day, it is not possible to adjust every ordinary resistor to an exact value. The term 'tolerance' denotes the acceptable deviation in the resistance value of a resistor. The usual specified tolerances are ±5%, ±10% and ±20% for the ordinary resistors. The precision resistors may have selected tolerances as close as ±0.1%. In each tolerance range, a set of preferred values are available refer Table 2.

Table 2

Preferred series of values for resistors with ordinary tolerances

E 24 Series Tolerance ±5 percent	E12 Series Tolerance ± 10 percent	E 6 Series Tolerance ±20 percent
1.0	1.0	1.0
1.1	—	—
1.2	1.2	—
1.3	—	—
1.5	1.5	1.5
1.6	—	—
1.8	1.8	—
2.0	—	—
2.2	2.2	2.2
2.4	—	—
2.7	2.7	—
3.0	—	—
3.3	3.3	3.3
3.6	—	—
3.9	3.9	—
4.3	—	—
4.7	4.7	4.7
5.1	—	—

Table 2 contd.

E 24 Series Tolerance ±5 percent	E12 Series Tolerance ± 10 percent	E 6 Series Tolerance ±20 percent
5.6	5.6	—
6.2	—	—
6.8	6.8	6.8
7.5	—	—
8.2	8.2	—
9.1	—	—

Letter and digit code for resistance values: In this system of coding, numbers and letter are used. Generally three or four, or five characters consisting of

1 Two figures and letters

2 Three figures and letter,

3 Four figures and letters are used as the case may be.

The letter R.K. and M. shall be used for multipliers of the resistance values expressed in ohms R = (10°) = 1, k = 10^3 = 1000, M = 10^6 = 1 000000

For example (Fig 18)

0.1Ω is coded as R10 and 1200 Ω or 1.2k Ω is coded as 1.2 kΩ similarly 1500000 Ω or 1.5 M Ω is coded as 1 M 5.

For symmetrical tolerance in percentage the following letter shall be used for indicating tolerance of the resistance ±5% = J, ±10% = K, ±20% = M

For example (Refer Fig 18)

1 1.5 Ω ±10% 1 W is letter coded as K 1R51W

2 330 Ω ±20% 0.5 W is letter coded as M 330R 0.5W

3 2.7 K Ω ±5% 2W is letter coded as J 2K72W

4 1M Ω ±20% 1 W is letter coded as M 1M1W

Fig 18

LETTER CODING OF RESISTORS
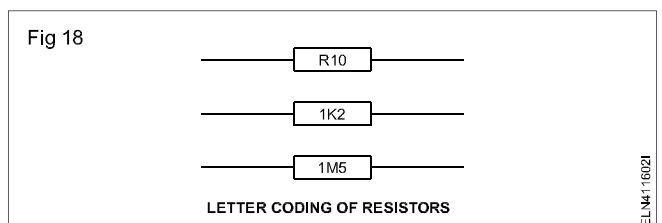
Semiconductor theory-Active and passive components

Objectives: At the end of this lesson you shall be able to
• **explain atom conductor, semiconductor, insulator and atomic structure**
• **state the function of N and P type semiconductor, PN junction, depletion region**
• **state the coding of semiconductor devices and its meaning**
• **explain active and passive components, symbols - uses.**

Atom

The very tiny fundamental unit of an element which is capable of independent existence is the atom. An atom of any element consists of a central core called Nucleus. A number of small particles called electrons move around the central core.

The nucleus contains protons and neutrons. A proton in the nucleus possess a positive electrical charge. An electron in an atom possess negative electrical charge. In normal state, the atom is electrically neutral, that is the number of electrons is equal to the number of protons in the nucleus.

For stability of materials (solids), the valence (outer most) shell of an atom should contain either 8 or more number of electrons, if it is to be complete. The above stability keeps the atoms and the molecules together in a solid state.

There are three important kinds of bonding amongst the atoms and the molecules of a solid. They are i) ionic ii) covalent and iii) metallic bonds.

Examples of solids under different bondings are,

Ionic bond   :   sodium chloride

Covalent bond   :   silicon and germanium

Metallic bond   :   metals like copper

Difference between conductors insulators and semi conductors: We are familiar with conducting and insulating materials. Conducting materials are good conductors of electricity. Insulating materials are bad conductors of electricity. There is another group of materials called as semiconductors, such as germanium and silicon. These are neither good conductors nor good insulators.

The conductors on valence electrons are always free. In an insulator the valence electrons are always bound. Whereas in semi conductors the valence electrons are normally bound but can be set free by supplying a small amount of energy. Several electronic devices are made using semi conductor materials.

Semi conductors - Atomic structure: Germanium (Ge) and silicon (Si) are examples of semi conductors. Fig 1a shows a germanium atom. In the centre is a nucleus with 32 protons. 32 revolving electrons are distributed

themselves in different orbits. There are 2 electrons in the first orbit, 8 electrons in the second orbit, and 18 electrons in the third orbit. The fourth orbit is the outer or valence orbit which contains 4 electrons.

Fig 1b shows a silicon atom. It has 14 protons in the nucleus and 14 electrons in 3 orbits. There are 2 electrons in the first orbit and 8 in the second orbit. The remaining 4 electrons are in the outer or valence orbit.
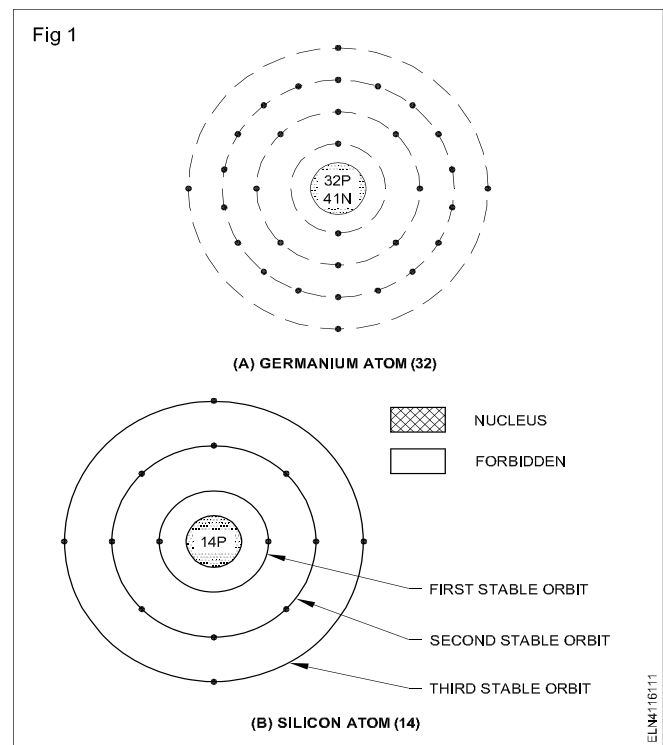
In semiconductor materials, the atoms are arranged in an orderly pattern called a crystal lattice structure. If a pure silicon crystal is examined we find that the four electrons in the outer (valence) shell of an atom is shared by the neighbouring atoms as in Fig 2.
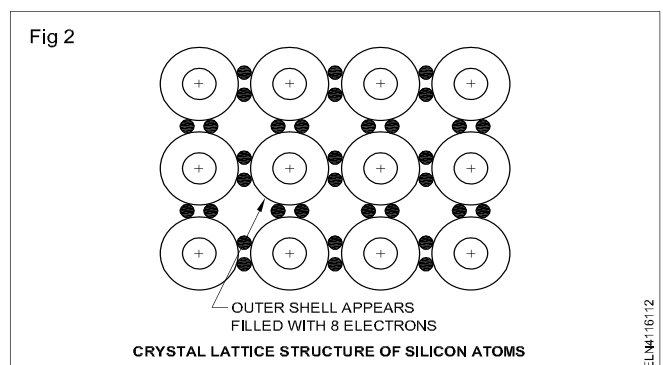
The union of atoms sharing the valence electrons is called a **covalent band**.That means a valence electron being shared by two adjacent atoms. Each atom appears to have a full outer shell of eight electrons.

Types of semiconductors : A pure semiconductor is called an intrinsic semiconductor. For example, a silicon crystal is an intrinsic semiconductor because every atom in the crystal is a silicon atom. One way to increase conductivity in a semiconductor is by **'doping'**. This means adding impurity atoms to an intrinsic semiconductor. The doped semi-conductor is known as an extrinsic semiconductor.

The residual heat at room temperature (300K) is sufficient to make a valence electron of an intrinsic semiconductor to move away from the covalent bond and then the covalent bond is broken, and the electron becomes a free electron to move in the crystal. This is shown in Fig 3.

Fig 3
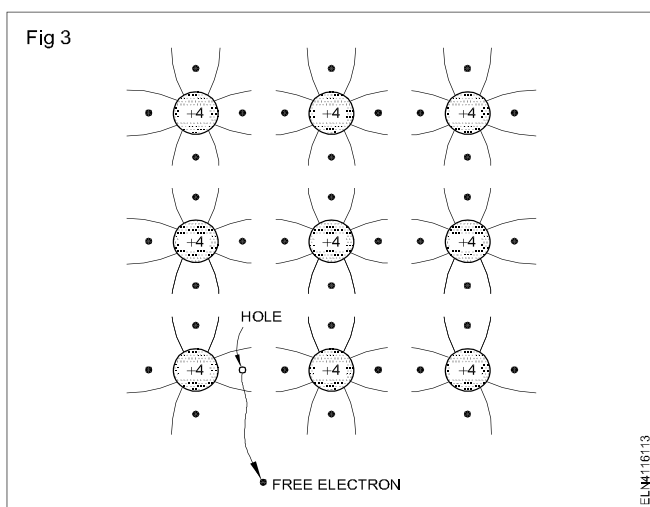
When an electron breaks a covalent bond and moves away, a vacancy is created in the broken covalent bond. This vacancy is called a 'hole'. A hole has a positive charge. When a free electron is liberated, a hole is created.

N - type semiconductor : A semiconductor with excess of electrons is called N-type. To obtain excess free electrons the element doped with the semiconductor material is arsenic, or antimony or phosphorus. Each of these atoms has five electrons in its outer orbit. (Fig 4)

Fig 4

FORMATION OF 'N' TYPE SEMICONDUCTOR
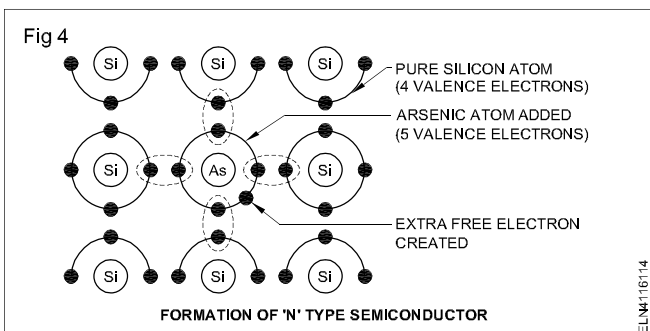
Because the outer orbits of the atoms can hold eight electrons, no hole is available for the fifth electron in the arsenic atoms to move into. It, therefore, becomes a free

electron. The number of such free electrons is controlled by the amount of arsenic added to the crystals.

In N-type, the free electrons are called the **majority** carriers, and the holes **minority** carriers.

P-type semiconductor : To obtain more holes, a pure silicon crystal is doped with elements such as aluminum or boron or gallium. The atoms of each of these elements have three electrons only in their outer orbit. Adding gallium to pure silicon crystals allows the atoms of the two elements to share seven electrons. (Fig 5)

Fig 5

FORMATION OF 'P' TYPE SEMICONDUCTOR
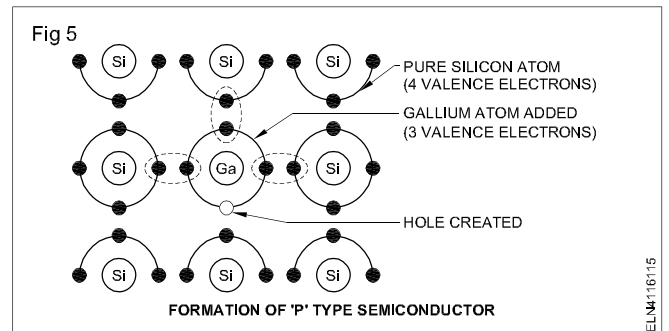
A hole is created in the place of the eighth electron. Now that the number of holes exceeds the number of free electrons the substance becomes 'P' type material. The holes in P-type are the **majority** carriers, and the free electrons are the minority carriers.

PN Junction : A PN junction is formed by combining P and N type materials. The surface where they meet is called the PN junction. A PN junction is illustrated in Fig 6.

Fig 6
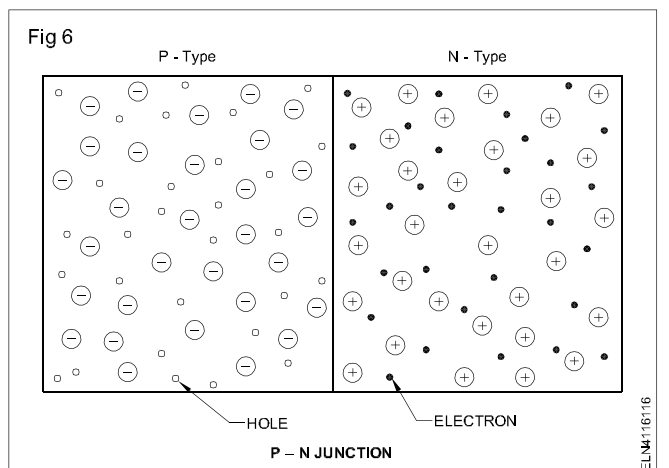
P – N JUNCTION

The free electrons in the N-regions diffuse across the junctions into the P-region. The free electrons lose energy and recombine with the holes in the P-regions.This recombination eliminates a free electron and a hole. When the electron moved from the N-region and diffused across the junction, it leaves the atom to be a positive ion.

The positive ion is not balanced by a negative charge in the N-region. The hole is eliminated in the P-region by recombination. The elimination of the hole and its positive charge leaves the atom to be a negative ion in the P-region.

The ions in the crystal structure are fixed and cannot move. Thus, a layer of fixed charges is formed on the two sides of the junctions. This is shown in Fig 7.

Fig 7
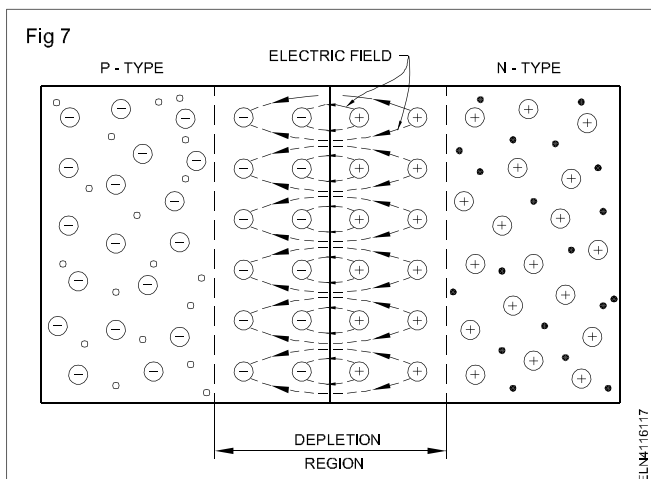
There is a layer of positively charged ions on the N-side and on the P-side of the junction there is a layer of negatively charged ions. An electric field is created across the junction between the oppositely charged ions. This is called a junction field. The junction field is also known as 'barrier'. The distance between the sides of the barrier is the 'width' of the barrier.

Depletion region : The carrier in the vicinity of the junction are involved in forming the junction. Once the junction field is established, no carriers can move through the junction. Hence the junction field is called 'depletion region' or 'space charge region'. This layer is called the depletion layer, because there are neither free electrons nor holes present. This depletion region prevents further movement of electrons from the N-material to the P-material and thus an equilibrium is reached.

The intensity of the field is known as 'barrier height' or 'potential' hill'. The internal voltage set up due to positive and negative ions at the junction is called barrier potential. If any more electrons have to go over from the N-side to P-side, they have to over come this barrier potential. This means, only when the electrons on the N-side are supplied with energy to overcome the barrier potential they can go over to the P-side.

In order to cancel the barrier potential and the electrons to cross over a potential difference of 0.7 V is required for a silicon diode and 0.3 V for a germanium diode. The barrier voltage is more for silicon because its lower atomic number allows more stability in the covalent bonds. The barrier potential decreases at higher temperatures.

Old system : Some earlier semiconductor diodes and transistors have type numbers, consisting of two or three letters followed by group of one, two or three figures. The first letter is always 'O', indicating a semi-conductor device.

The second (and third) letter(s) indicate the general class of the device.

A   –   diode or rectifier

AP   –   photo-diode

AZ   –   voltage regulator diode

C   –   transistor

CP   –   phototransistor

The group of figures in a serial number indicating a particular design or development.

Present system : This system consists of two letters followed by a serial number. The serial number may consists of three figures of one letter and two figures depending on the main application of the device.

The first letter indicates the semiconductor material used.

A   Germanium

B   Silicon

C   Compound materials such as gallium arsenide

R   Compound materials such as cadmium sulphide

The second letter indicates the general function of the device.

A   detection diode, high speed diode, mixer diode

B   variable capacitance diode

C   transistor for I.F. applications (not power types)

D   power transistor for A.F. applications (not power types)

E   tunnel diode

F   transistor for A.F. applications (not power types)

G   multiple of dissimilar devices, miscellaneous devices

L   power transistor for a.f. applications

N   photo-coupler

P   radiation sensitive device such as photo-diode, photo-transistor, photo-conducive cell, or radiation detector diode

Q   radiation generating device such as light-emitting diode

R   controlling and switching devices (e.g. thyristor) having a specified breakdown characteristic (not power types)

S   transistor for switching applications (not power types)

T   controlling and switching power device (e.g. thyristor) having a specified breakdown characteristic.

U   power transistor for switching applications

X   multiplier diode such as varactor or step recovery diode

Y   rectifier diode, booster diode, efficiency diode

Z   voltage reference or voltage regulator diode, transient suppressor diode.

The remainder of the type number is a serial number indicating a particular design or development, and is in one of the following two groups.

a Devices intended primarily for use in consumer applications (radio and television receivers, audio-amplifiers, tape recorders, domestic appliances, etc.) The **serial number** consists of three figures.

b Devices intended mainly for applications other than (a) e.g. industrial, professional and transmitting equipments.

The serial number consists of one letter (Z,Y,X,W etc) followed by two numbers (digits)

The International System follows letters 1N, 2N, 3N etc followed by four numbers.

1N   indicates single junction

2N   indicates two junction

3N   indicates three junctions.

The number indicates internationally agreed manufacturer's code e.g. 1N 4007, 2N 3055, 3N 2000.

Again, manufacturers use their own codes for semiconductor devices. Manufacturers in Japan use 2SA, 2SB, 2SC, 2SD etc. followed by a group of numbers e.g. 2SC 1061, 2SA 934, 2SB 77. Indian manufacturers have their own codes too.

Passive and active electronic components

Introduction: The Components used in electronic circuits can broadly grouped under two headings.

– passive components

– active components

Passive components: Components like resistors, capacitors, and inductors used in electronic circuit are called as passive components. These components by themselves are not capable of amplifying or processing an electrical signal. However these components are equally important in electronic circuit as that of active components, without the aid of passive components, a transistor (active components) cannot be made to amplify electrical signal.

Circuits formed with passive components obey the electrical circuits laws such as ohm's law, Kirchoff's Laws etc.,

Resistors: The components whose purpose to introduce resistance in the circuit is called as resistors. Other details of resistors are dealt in earlier lessons.

Capacitor: The components whose purpose to introduce capacitance in the circuit is called as capacitor. The unit of capacitance is 'FARAD'. Commercially capacitors are available in Microfarad (μF), Nanofarad (nF) and Picofarads (pF).

The colour coding of capacitors and resistors are same. Where as, in the case of fixed capacitors, the colour coded unit shall be in Picofarads.

For letter coding, incase of capacitor, the letter 'p', 'n', 'μ' shall be used as multipliers. Where p = 10^{-12}, n= 10^{-9} and μ = 10^{-6} farads, and letter code for tolerance on capacitor is the same as in resistor.

Inductor: The ability of the conductor to induce voltage in itself, when the current changes in it is called as self inductance (or) simply inductance. A coil introduced in a circuit to have inductance is called as inductor. Different type of inductors are shown in Fig 8. The unit of inductance is "Henry". Commercially a coil may have inductance in Millihenry (10^{-3}H), or in Microhenry (10^{-6}H).

Fig 8

b) AIR-CORE INDUCTOR

a) SHIELDED INDUCTOR

c) IRON-CORE INDUCTOR
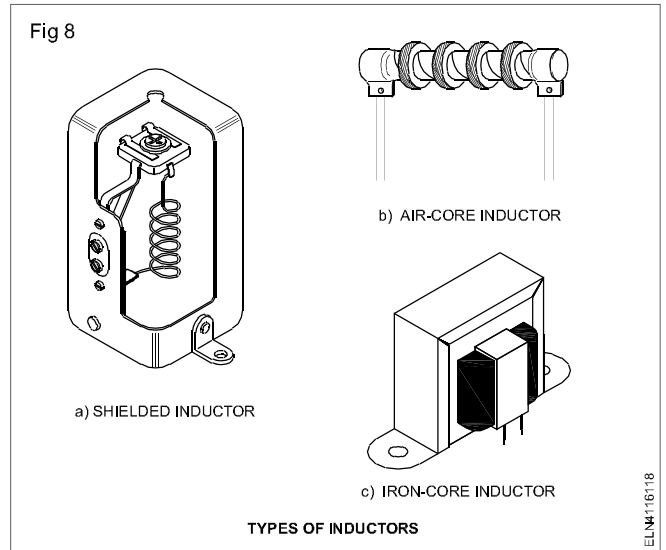
TYPES OF INDUCTORS

While specifying the inductance the following factors to be considered

• nominal value of inductance in Henry / Millihenry / Microhenry.

• tolerance in percentage (±5/10/20%)

• type of winding like single layer, double layer, multilayer and pie (p) etc.

• type of core like air core, iron core, ferrite core

• type of application like audio frequency (AF), Radio frequency (RF) coupling coil, filter coil etc.,

In an electronic circuit some time, it is also required to vary the inductance.

The inductance of a coil can be varied by:-

• providing tapped inductive coil, as in Fig 9 or

• adjusting the core of a coil as in Fig 10.

However, all inductor coils have inherent resistance due to the resistance of the winding wire in the coil. Further the maximum current that can be safely carried by an inductor depends upon the size of the winding wire used.

Fig 9

(a)   (b)

Fig 10

CORK

COIL
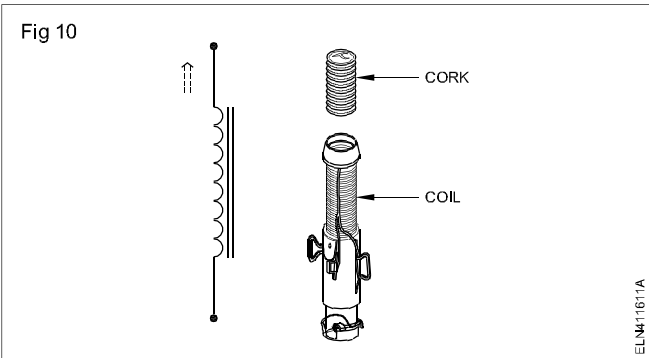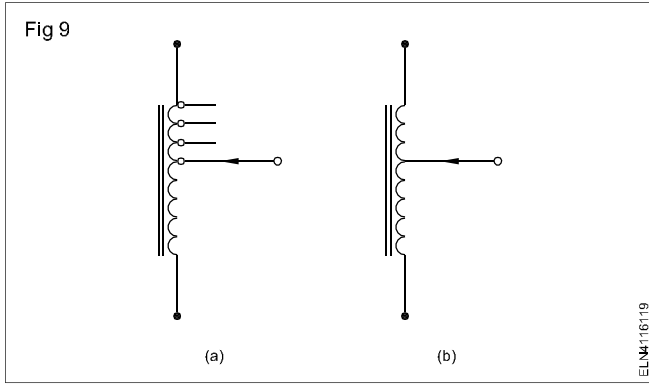
Active components

In electronic circuit, the components, other than passive are known as active components. Namely, transistors, diodes, SCRs Vacuum tubes etc.,

Active components : In electronic circuits, components other than resistors, capacitors and inductors are also used. Namely, transistors, diodes, vacuum tubes, SCRs, diacs, zener-diode (Fig 11) etc. The application of electrical circuit laws (Ohm's law etc.) in the circuit containing the above components will not give correct results. i.e. these components do not obey. Ohm's law, Kirchoff's law etc. These components are called active components.

The different active components and the method of representing them by symbols in the circuit diagram are given below (Fig 11)

Fig 11

b) SYMBOL OF DIODE

a) PHYSICAL APPEARANCE OF DIODES
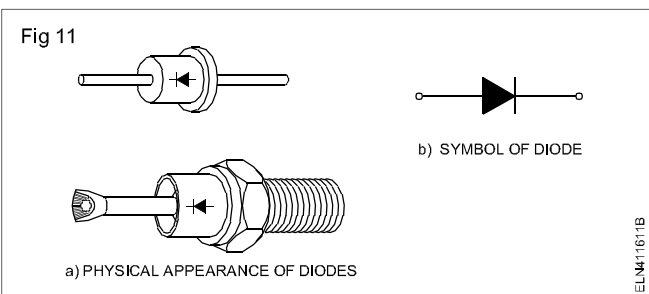
The different types of diodes (Fig 12) used for specific purposes are represented by the symbols given.

Transistor : Figure 13a shows the physical appearance of transistors. There are two symbols to represent a transistor. (Fig 13b). The selection of a symbol is based on either the NPN or the PNP type of transistor.

Fig 12

K o————|◄————o A   A o————►|————o K   A o————►|————o K

LED

a) ZENER DIODE   b) PHOTOCONDUCTIVE   c) LIGHT EMITTING
                            DIODE   DIODE

Fig 13

TO-92   TO-05   TO-03

MOUNTING
HOLE

METAL HEAT
SINK

a) TRANSISTOR

C   C

B   B

E   E
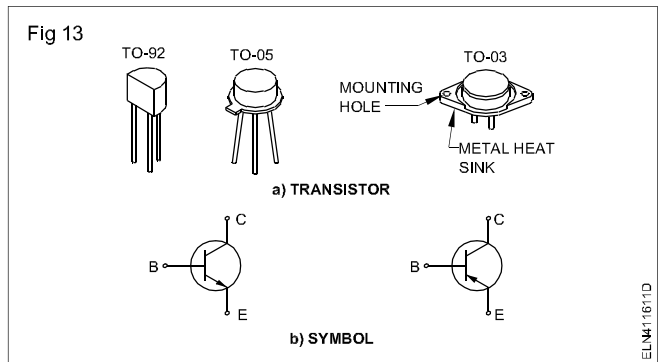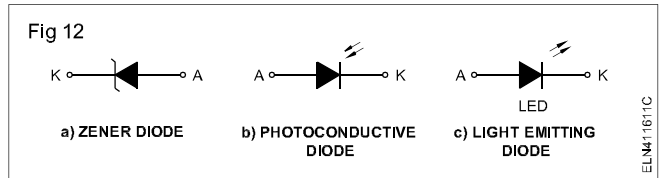
b) SYMBOL

SCR (Silicon controlled rectifier) : Figure 14a shows the physical appearance of one type of SCR and the symbol is shown in Fig 14b. SCRs are also called thyristors and used as switching devices.

Fig 14

TO-220

MOUNTING
HOLE

METAL HEAT
SINK

K

G

A

a) PHYSICAL APPEARANCE OF SCR   b) SCR SYMBOL
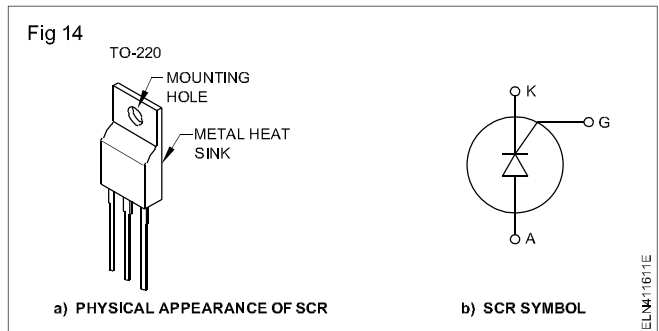
Diac : A diac (Fig 15a) is a two-lead device like a diode. It is a bidirectional switching device. Its symbol is shown in Fig 15b.

Fig 15

MT1

MT2

DIAC
SYMBOL

(a)   (b)
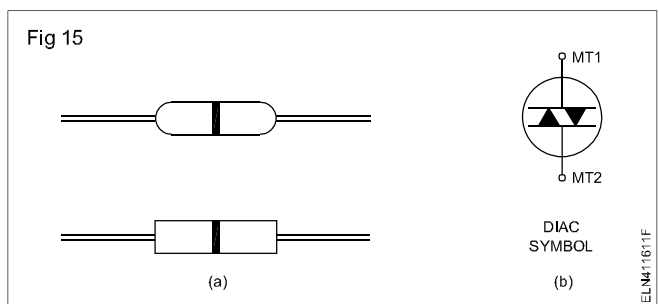
Triac : A triac is also a semiconductor device with three leads like two SCRs in parallel. The triac can control the circuit in either direction. (Fig 16)

Bridge rectifier or diode bridge : It is a single package of four semiconductor diodes connected in bridge circuit. The input AC and the output DC leads are marked and terminated as shown in the Figure 17.

UJT (Uni-junction transistor) : It has two doped regions with three leads and has one emitter and two bases (Fig 18).

Fig 16

TO-220

MT1

G

MT2

b) TRIAC SYMBOL

a) TRIAC

ELN41161'G

Fig 17

(a)

(b)

+

L ▶|◀ N

AC INPUT

-DC OUTPUT   +DC OUTPUT

AC INPUT

c) STANDARD DIODE BRIDGE SYMBOL

(d)

ELN41161'H

Fig 18

TO-05

E

B2

B1

a) PHYSICAL APPEARANCE   b) SYMBOL OF UJT

ELN41161'I
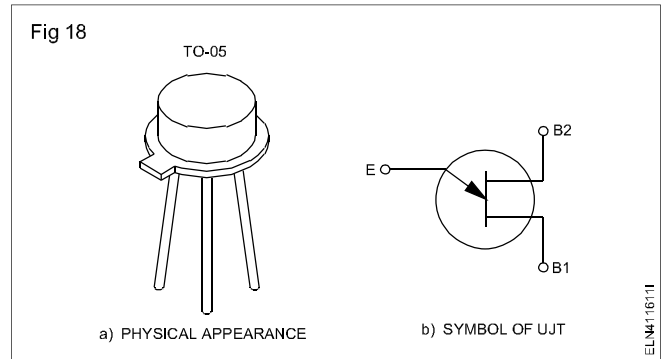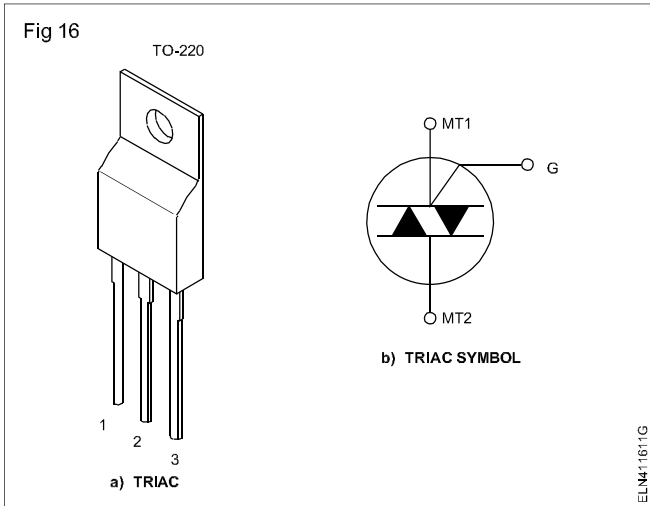
FET (Field effect transistor) : Fig 19a give a pictorial view of the component, and the related symbol to represent the field effect transistor is shown in Fig 19b. The selection of the symbol is based on whether the FET is a 'N' channel or a 'P' channel one.

Fig 19

TO-05

D

G

S

'N' CHANNEL FET

D

G

S

'P' CHANNEL FET

(a)

(b)

ELN41161'J
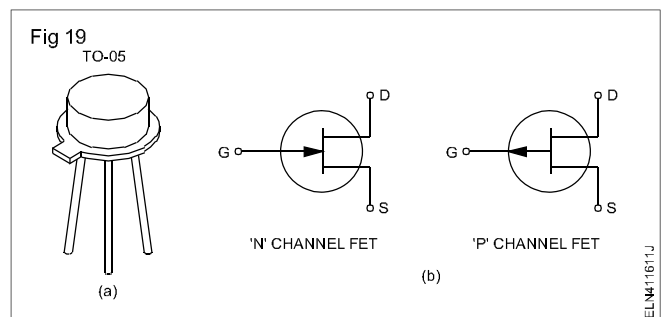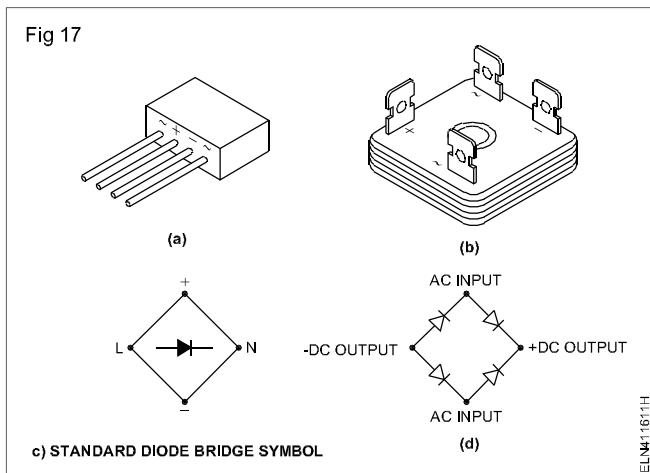
In the active components few basic components discussed have and many more advanced components associated with modern circuits are in use.

PN Junction - semi conductor diodes

Objectives: At the end of this lesson you shall be able to
• **explain diffusion in PN junction and barrier potential**
• **explain forward and reverse biasing of PN junction and semi conductor diodes and its VI characteristics**
• **state the applications specifications and classification of diodes**
• **state the different industry standards for diode numbering and finding equivalents of diode**
• **state the method of testing diode and identifying the polarity**
• **state special diodes and their functions and PIV.**

PN junction: A diode is made by combining P and N materials. The surface at which these materials meet is the PN junction.

Diffusion occurs when P and N materials are joined together.(Fig 1) some electrons in the N material, near the junction, are attracted to the holes in the P material, thus leaving holes in the N material. The diffusion of electrical charges produces a potential difference in a small area near the junction (Fig 2).As a result, the material will conduct in one direction but not in the opposite direction. For this reason, the area in which this emf exists is called a barrier.

Fig 1
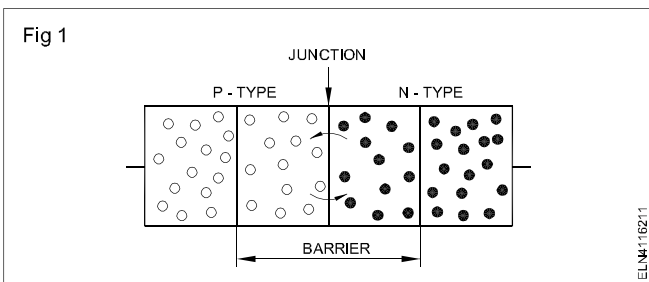
The internal barrier potential (V_b) : Although it is an internal contact potential that cannot be measured directly, the effect can be overcome by 0.3V for a **Ge** junction or 0.7 V for **Si**. The barrier voltage is more for **Si** because its lower atomic number allows more stability in the covalent bonds as already stated.

The PN junction, with the depletion zone magnified, shows the iron that has +ve and -ve charges produce the internal contact potential V_b at the barrier. (Fig 2)

A PN device is knows as a diode. The diode and its symbol are in Fig 3. This type of construction permits the current to flow in one direction but not in the opposite direction.

Biasing the PN junction

Forward Bias : A forward-biased PN junction is in Fig 4 The positive terminal is connected to the P-side and the negative terminal of the DC supply is connected to the N-side of the junction.

Fig 2

Fig 3
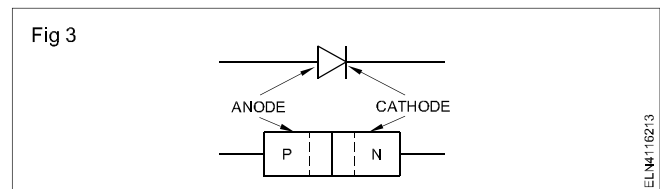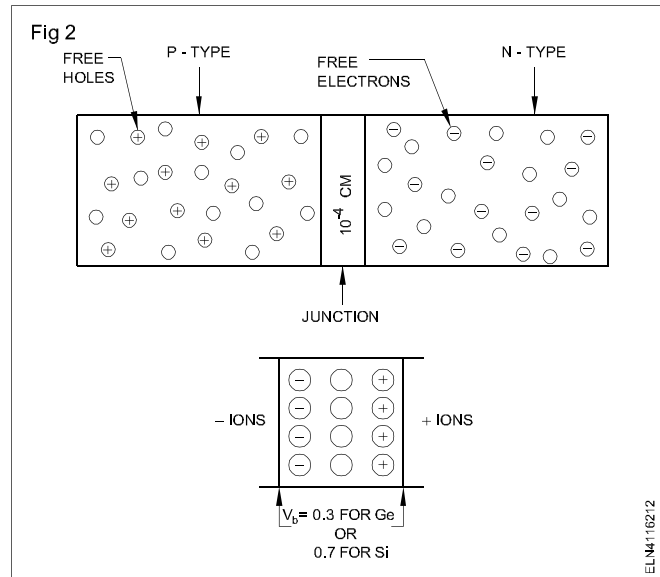
A current will flow through the diode as in the Fig 4. The positive terminal for the battery attracts electrons from P material, leaving an excess of holes. Because electrons are drifting away from the junction, the excess holes tend to accumulate near the junction. At the same instant, electrons from the negative terminal of the battery are attracted to the less negative N material of the diode. This action overcomes the barrier at the junction and allows the electrons to move into the excess holes of the P material, the result is a continuous flow of electrons in one direction. The voltage required to move the charge carries in forward bias conduction called the barrier voltage.

Reverse Bias: If the polarities of the DC supply are as shown in Fig 5, the PN junction is said to be reverse-biased. That is, the P side is connected to the negative and the N-side is connected to the positive terminals of the supply. Fig 5 shows the battery connection reversed (reverse bias). At the same instant, a shift in electrons in the P material causes the positive holes to appear further

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away from the junction near the end for the diode, which is connected to the negative terminal of the battery. This action produces a wider barrier at the PN junction through which the electrons cannot flow. (A very small current leakage may however occur).

Fig 4

a) PN JUNCTION IN FORWARD BIAS

b) SCHEMATIC DIAGRAM

Fig 5

a) PN JUNCTION IN REVERSE BIASED

b) SCHEMATIC DIAGRAM
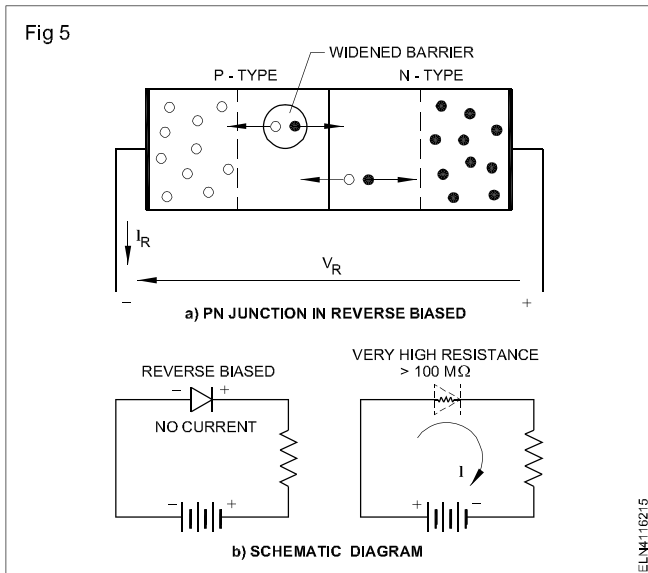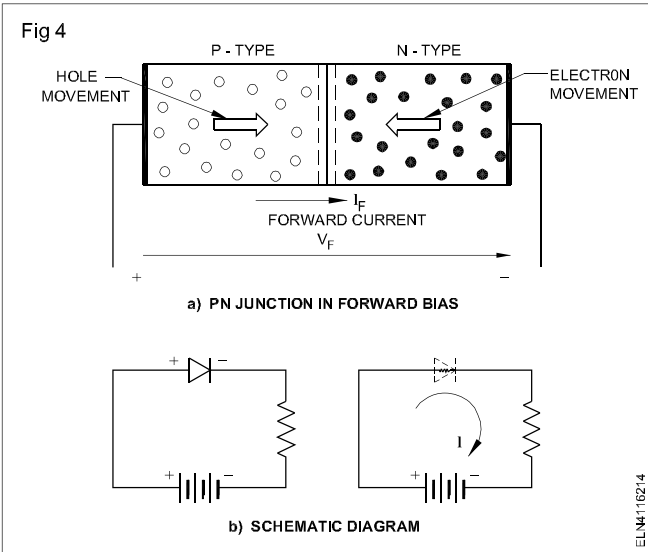
V-I characteristic of PN junction : The static current voltage characteristic is in Fig 6.

Fig 6

CHARACTERISTICS OF DIODES
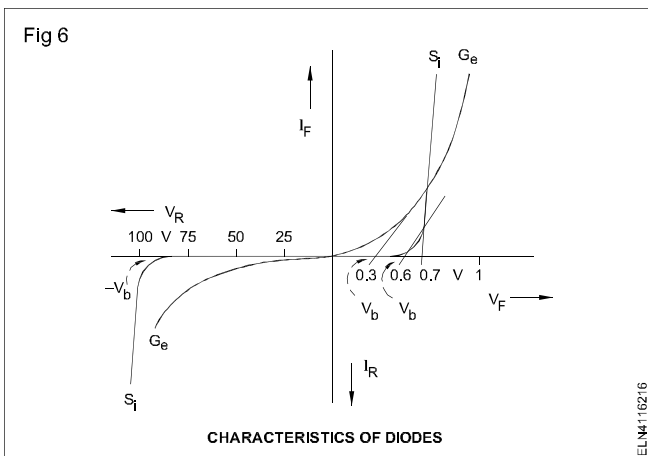
The current in the forward direction increases rapidly upon reaching the forward voltage V_b which is known as the barrier potential or the junction potential and the barrier potential for germanium is 0.3 V and for silicon it is 0.7 V.

The behaviour of the PN junction is limited by the maximum forward current, as too much of current may destroy a diode due to the excess heat generation.

The current in the reverse direction of the junction is very small. Upon reaching —V_b in the reverse direction, the reverse current suddenly increases. —V_b in the reverse direction where the current starts increasing is called the knee potential or breakdown voltage. Normally the diode should not be operated in this region. The knee voltage depends on the type of diode which varies from 3V to 20 kV or more.

Application of diodes : Semi conductor diodes are used for various applications. Some of the major areas of application are listed below.

• Modulation and demodulation in communication receivers.

• Switching high speed digital circuits

• Low power and high power rectification

• As surge protectors in EM relay and other circuits.

• For clipping, clamping wave-forms.

For different applications, diodes of different current carrying capacity, different PIV capacity and so on are required. Therefore, manufacturers make diodes to cater to varied applications with different specifications. Before using a diode for a particular application, it is a must to find out whether the voltage, current, and temperature characteristics of the given diode match the requirement or not.

Important specifications of a diodes

The material : The diode is made-of dopped semi-conductor material. This could be Silicon or Germanium or Selenium.This is important because the cut-in voltage depends upon the material the diode is made-of. For example, in Ge diodes the cut-in voltage is around 0.3V, whereas in Si diodes the cut-in voltage is around 0.7V.

Maximum safe reverse voltage : Denoted as V_R or V_r that can be applied across the diode. This is known as peak-inverse-voltage or PIV. If a higher reverse voltage than the rated PIV is applied across the diode, it will become defective permanently.

Maximum average forward current : I_f or I_F that a diode can allow to flow through it without getting damaged.

Forward voltage drop : V_F or V_f that appears across the diode when the maximum average current, I_f flows through it continuously

Maximum reverse current : I_{vr} that flows through the diode when the maximum reverse voltage, PIV is applied.

Maximum forward surge current : I_s that can flow through the diode for a defined short period of time.

The maximum junction temperature: The temperature upto which the diode junction can withstand without mal functioning or getting damaged.

Manufacturer's code of Diodes : The diodes are printed with a type number. When this type number is referred to in the manufacturer's manual, the detailed specifications for a particular type, number of the diode, can be obtained.

To bring standardization for the diodes and other components manufactured by different manufacturers. The Manufacturer and Standards Associations have set certain International Standards for the benefit of users of the components. The principal industry standard numbering systems are dealt with here.

1 **The JEDEC type code:** The EIA in USA maintains a register of 1N, 2N, types familiarly known as JEDEC types, which have world wide acceptance.

1N is used as a prefix for semiconductors with one junction. For example all 1N components refer to diodes because diodes have one junction. Similarly, prefix 2N is used with components with two junctions and so on.

2 **The PRO-ELECTION type code :** The Association International pro-electron in Europe maintains a register of Pro-electron type which have wide acceptance in Europe.

Components in the Pro-electron system have,

* two letter and numeral code for consumer devices (Example, BY127 and so on)

* three letter and numeral code for industrial devices. (Example, ACY17 and so on).

The first letter in the pro-electron type code indicates the type of semiconductor material used in making the device. Example, device numbers starting with A are made of germanium. Refer to diode data book for further details and examples.

The second and third letter indicate the applications of the component. Example, in the type code BY127, the second letter Y indicates that it is a rectifier diode.

The numeral after the second or third letter is the code number of its detailed voltage, current and temperature specification.

3 **The JIS type code:** In Japan, the JIS, (Japanese Industrial Standards) code is used. This system of component numbering is almost universal. In this system, all component numbers start with 2S, followed by a letter and several numbers. Example. 2SB364.

The letters after the S has the following significance:

A = pnp hf

B = pnp if

C = npn hf

D = npn if

Some components will have a type number which does not match with any of the above said International Standards. Then, these type numbers are particularly known to the individual manufacturer. These codes are generally referred to as manufacturer's house code. However, these type numbers may conform to one or more of the International Standards. Almost all standard diode data books lists popular manufacturers house codes.

Diode equivalent: There are several occasions, especially while servicing electronic circuits, it may not be possible to get a replacement for a diode of a particular type number. In such cases one can obtain a diode having specification closest to the one to be replaced. Such diodes are referred to as equivalents.

Example: In a circuit, diode 1N 4007 is found to be defective, and if 1N4007 is not available in stock, then instead of 1N4007, BY 127 can be used as it is the equivalent for 1N4007.

Some data books give these lists of equivalents.

Classification of Diode

1 Based on their current carrying capacity/power handling capacity, diodes can be classified as

* **low power diode**

    It can handle power of the order of several milliwatts only

* **medium power diode**

    It can handle power of the order of several watts only

* **high power diode**

    It can handle power of the order of several 100's of watts.

2 Based on their principal application, diodes can be classified as,

* **Signal diode**

    Low power diodes are used in communication circuits such as radio receivers etc. for signal detection and mixing

* **Switching diode**

    Low power diodes are used in switching circuits such as digital electronics etc. for fast switching ON/OFF of circuits

- **Rectifier diode**

    Medium to high power is used in power supplies for electronic circuits for converting AC to DC voltage.

3. Based on the manufacturing techniques used, diodes can be classified as,

- **point contact diode**

    A metal needle is connected with pressure on to a small germanium (Ge) or silicon (Si)

- **Junction diode**

    They are made by alloying or growling or diffusing P and N materials on a semiconductor substrate.

Types of diode packaging : The type of packaging given to diodes is mainly based on the current carrying capacity of the diode. Low power diodes have either glass or plastic packaging. Medium power diodes have either plastic or metal can packaging. High power diodes will invariably have either metal can or ceramic packaging. High power diodes are generally of stud-mounting type.

Testing diodes using ohmmeter: A simple ohmmeter can be used to quickly test the condition of diodes. In this testing method, the resistance of the diode in forward and reverse bias condition is checked to confirm its condition.

Recall that there will be a battery inside an ohmmeter or a multimeter in the resistance range. This battery voltage comes in series with the leads of the meter terminals as in Fig 7.In Fig 7 the lead A is positive, lead B negative.

> If the polarity of the meter leads are not known at first, the polarity of the meter leads can be determined by using a voltmeter across the ohm meter terminals.

If the positive lead of the ohmmeter, lead A in the Fig 7 is connected to the anode of a diode, and the negative (lead B) to the cathode, the diode will be forward-biased. Current will flow, and the meter will indicate low resistance.

On the other hand, if the meter leads are reversed, the diode will be reverse-biased. Very little current will flow because a good diode will have very high resistance when reverse biased, and the meter will indicate a very high resistance.

While doing the above test, if a diode shows a very low resistance in both the forward and reverse biased conditions,

Fig 7
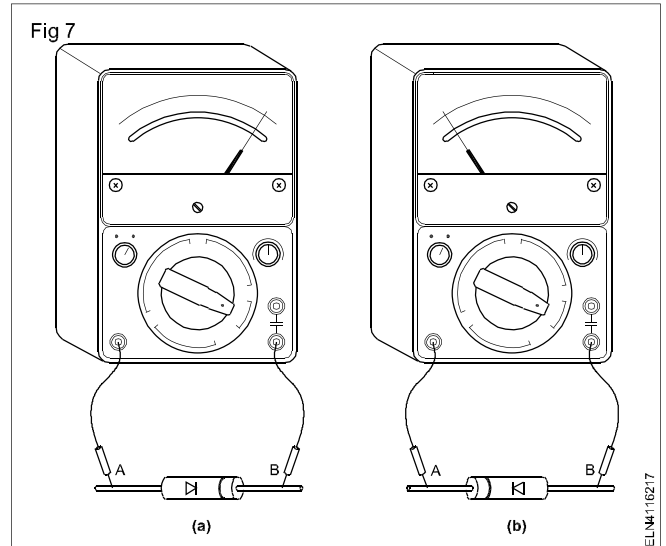
then, the diode under test must have got damaged or more specifically shorted. On the other hand, a diode is said to be open if the meter shows very high resistance both in the forward and reverse biased conditions.

Polarity marking on the diodes: The cathode end of a diode is usually marked by a circular band or by a dot or by plus (+) sign. In some diodes the symbol of the diode, which itself indicates the polarities, is printed on the body of the diode.

Special diodes: All diodes are basically PN junction diodes and are made according to the application. There are many special purpose diodes are in use in which zener diodes widely used for voltage regulation.

Zener diode: This diode specially designed for voltage regulation. A wide range of voltage regulated zener diodes are available.

It is a PN junction diode doped heavily for regulation purpose. It has a normal VI characteristic when it is forward biased. But the characteristic are changed abruptly when it is connected in reverse bias.

In the reverse bias condition a leakage current in the order of Microamps will flow. When the reverse voltage reaches to a particular designed voltage a sudden breakdown known as avalanche breakdown happens.

When a heavy current flows at constant voltage, the voltage continue to remain constant. Further increase in voltage, the current suddenly increases. Fig 8 shows the reverse characterises of zener diode.
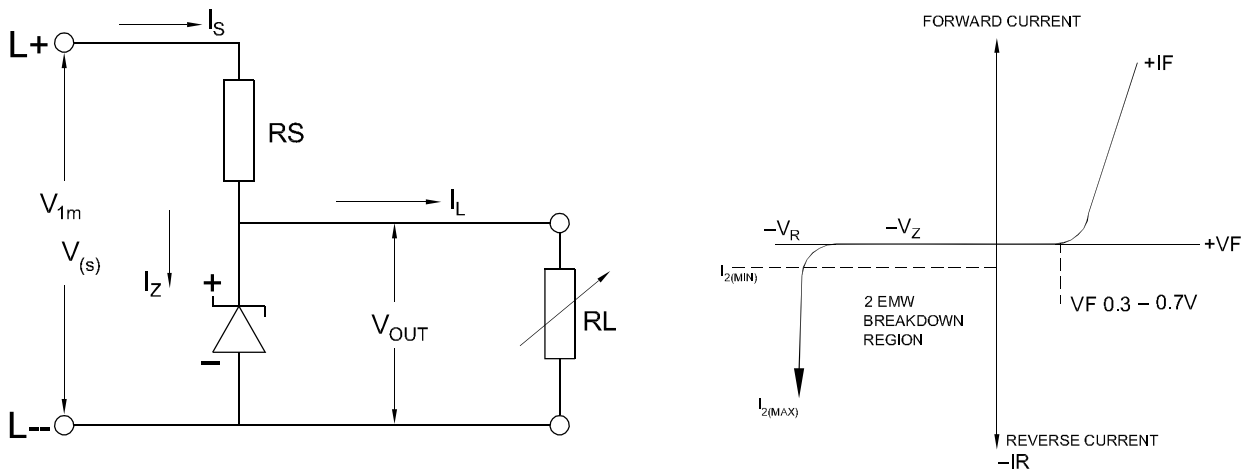
Fig 8

Few more special diodes listed below in Table 1

Sl.No	Name	Purpose	Symbol
1	LED	Light emitting diode - exhibits light in conduction	
2	TUNEL or ESAKI	Un effected by change in temperature	
3	SCHOTTKY	Fast switching	
4	VARICAP	Varactor -Variable capacitance diode or tuning diode	
5	SCHOKLEY	Constant current diode	
6	PHOTO DIODE	Light dependent diode	
7	IMPATT DIODE	Heavily doped PN layers	
8	PIN DIODE	Low capacitance switching	

Rectifiers

Objectives: At the end of this lesson you shall be able to
• **state the purpose of rectifier in power supply circuit**
• **explain the working of half-wave, full-wave and bridge rectifier circuit**
• **state the need of filter circuit to rectifier circuits**
• **state the different types filter circuit for rectifiers and their working.**

Most of the electronic equipment, both entertainment and professional, need DC voltage for operation. The power supply converts AC supply voltage into DC. Diodes are used as rectifier in a power supply circuit.

Half wave rectifier: This simplest form of AC to DC converter is by using one diode such an AC to DC converter is known as half-wave rectifier as in Fig 1.
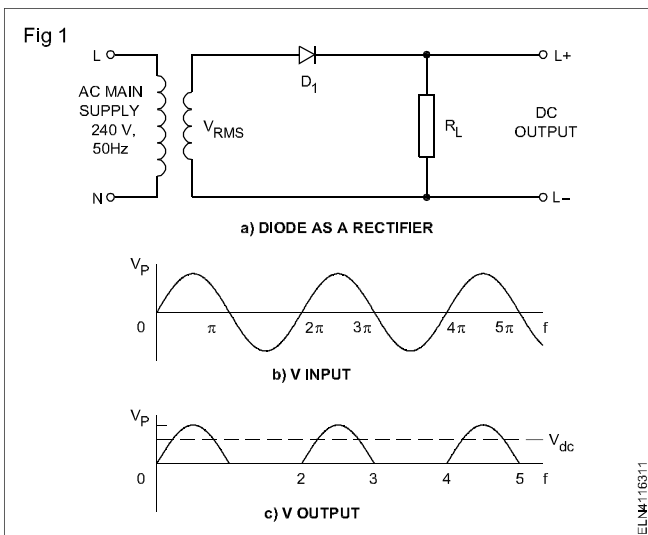
A diode D_1 and a load resistance R_L in series are connected across the secondary of a step down transformer (Fig 1(a). The transformer steps up or steps down the supply voltage as needed. Further the transformer isolates the power line and reduces the risk of electrical shock. During the positive half-cycle of the input line frequency, (Fig 1b) the diode anode is made positive with respect to the cathode. The diode D_1 conducts because it is forward-biased. Current flows from the positive end of the supply through diode D_1 and R_L to the negative terminal of the input. During this period of time, a voltage is developed across R_L. The polarity of the voltage is as indicated in Fig 1C.

During the negative half cycle of AC input line frequency, the diode is reverse-biased. Practically no current flows through the diode and the load R_L and there is no voltage output.

DC output: The voltage drop across the forward biased diode is low, because the resistance of the forward-biased diode is very low. Ge diode drops 0.3V and Si diode drops

0.7V. Ignoring the small voltage drop across the diode. We can find the relationship between AC input and DC output voltage.

The AC input wave-form is shown in Fig 1b.

$$V_{rms} = 0.707 \ V_p$$

$$V_p = \frac{V_{rms}}{0.707}$$

In Fig 1C, the DC output is shown. The diode produces only half cycle of the Ac input. The average value of this half wave is the DC output voltage.

$$V_{dc} = \quad 0.318 \ V_p$$

$$= 0.318 \quad x \ \frac{V_{rms}}{0.707}$$

$$= \quad 0.45 \ V_{rms}$$

For example if the input AC voltage is 24 volts the output DC of the half wave rectifier will be $V_{dc} = 0.45 \ x \ 24 = 10.8$ V

The DC load current is $I_{dc} = \frac{V_{dc}}{R_L}$

Ripple frequency: From Fig 1 it is evident that the frequency of the rectified pulsating DC is same as the frequency of the input AC signal. This is true for all half-wave rectifiers.

Peak inverse voltage: Fig 1(a) shows the half-wave rectifier at the instant the secondary voltage is at its maximum negative peak.

In this condition, since the diode is reverse biased, it behaves as an open switch as in Fig 2b. Since the diode is reverse biased, there is no voltage across the load R_L. Therefore, from Kirchhoff's Voltage law, all the secondary voltage appears across the diode as shown in Fig 2a. This is the maximum reverse voltage that appears across the diode in the reverse biased condition. This voltage is called the peak reverse voltage or more commonly as the peak inverse voltage (PIV). Therefore, in a half-wave rectifier the

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peak inverse voltage across the diode is equal to the -ve peak value of the secondary voltage $V_{s(peak)}$. Since the -ve peak voltage and +ve peak voltage in a sinusoidal wave is same in magnitude, the peak inverse voltage (PIV) across the diode in a halfwave rectifier can be taken as a $V_{s(peak)}$.

Fig 2

(a)   (b)

ELN4116312
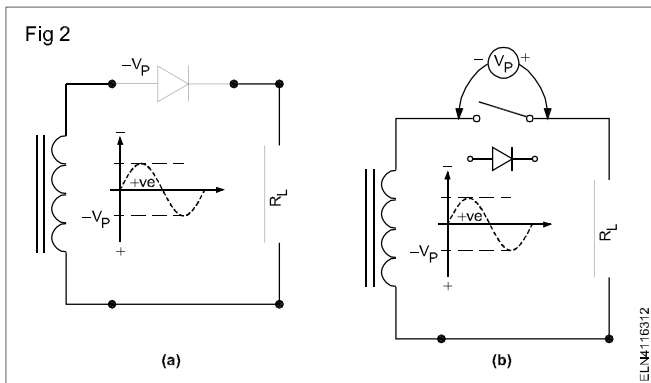
In the example considered earlier, the PIV across the diode will be,

$$V_{s(peak)} = \frac{V_{s(rms)}}{0.707} = \frac{24}{0.707} = 33.9 = 34 \text{ volts}$$

To avoid break down of the diode used, the PIV appearing across the diode of the designed HW rectifier must be less than the PIV rating of the diode. For instance, in the above example to avoid break down of the diode, the PIV rating of the diode should be greater than 34 volts.

However this condition changes when a filter capacitor is used in the output DC circuit.

Full wave rectifier (FW): A full wave rectifier circuit is in Fig 3. The secondary winding of the transformer is centre-tapped. The secondary voltage is divided equally into two halves, one end of the load R_L is connected to the centre tap and the other end of R_L to the diodes.

It is seen that two half-wave rectifiers are conducting on alternate half cycles of the input Ac.

During the positive half cycle of the secondary voltage, diode D_1 is forward-biased and diode D_2 is reverse-biased. (Fig 3b) The current flows through the load resistor R_L, diode D_1 and the upper half of the secondary winding.

During the negative half cycle of secondary voltage, diode D_2 is forward-biased and diode D_1 is reverse-biased. Therefore, current flows through the load resistor RL diode D_2 and the lower half of the secondary winding. (Fig 3c)

The load current is in the same direction during both the half-cycles of the AC input. The output of the full-wave rectifier is shown in Fig 3d.

DC output : Since a full wave rectifier is nothing but a combination of two half-wave rectifiers, the average or DC value of a full wave rectifier is naturally twice the output of

a half wave rectifier driven by the same secondary voltage.

Fig 3

(a)

(b) INPUT   OUTPUT

(c) INPUT   OUTPUT

(d) CONDUCTION BY THE DIODE

ELN4116313
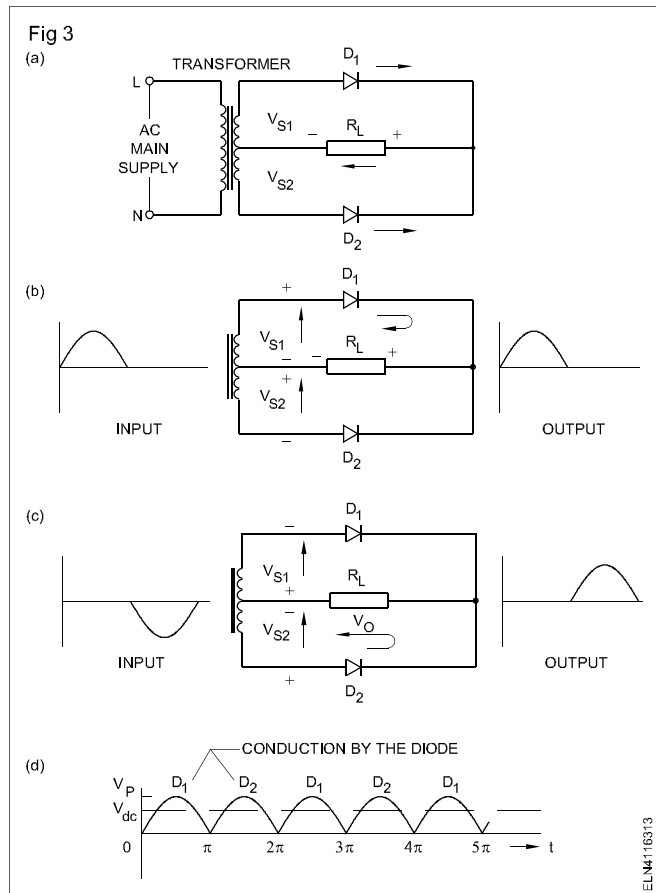
From Fig 3 it is evident that the average of DC value of a full wave rectified output is

$$V_{dc} = 0.318 \, V_{s(peak)} + 0.318 \, V_{s(peak)}$$

$$V_{dc} = 0.636 \, V_{s(peak)}$$

where, $V_{s(peak)}$ is the equal peak voltage between the centre-tap and any one end A or B of the transformer secondary.

In terms of $V_{s(rms)}$ V_{dc} of full wave rectifier is given by,

$$Vs_{(rms)} = 0.707 \, V_{s(peak)}$$

$$\text{Therefore, } V_{dc} = 0.636 = \frac{V_{s\,(rms)}}{0.707} = 0.9 \, V_{s\,(rms)}$$

Example

Suppose the secondary voltage of the transformer is 24-0-24V(rms), the Dc output voltage of a full wave rectifier using this transformer will be,

For a two diode full wave rectifier

$$V_{dc} = 0.9 \, V_{s(rms)}$$

Therefore, in the given example

V_{dc} = 0.9 x $V_{s(rms)}$ = 0.9 x 24 = 21.6 volts

Ripple frequency in a full wave rectifier: From Fig 3c it can be seen that two cycles of output occur for each input cycle of AC voltage. This is because, the full wave rectifier has inverted the negative half cycle of the input voltage. As a result, the output of a full wave rectifier has frequency double the input AC frequency. If mains AC supply is used as input to a full wave rectifier, the mains frequency is 50 Hz, the output frequency of the pulsating DC will be 100 Hz.

> **Note: This increased ripple frequency has certain advantages when the pulsating DC is smoothed. This will be dealt with in further lesson.**

Peak inverse voltage: Fig 4 shows the full wave rectifier at the instant the secondary voltage reaches its maximum positive value.

Fig 4
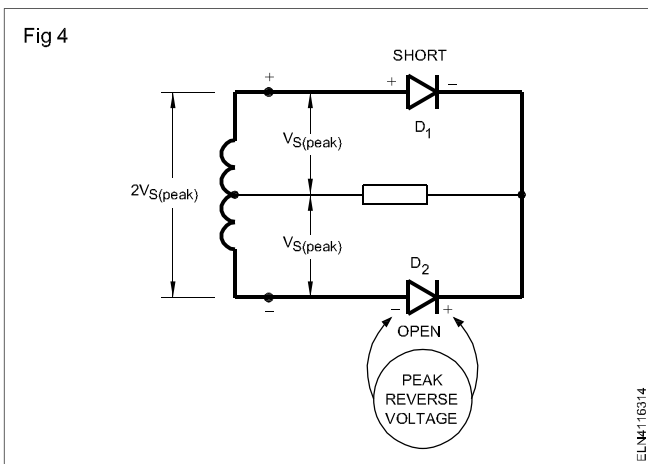
Applying Kirchhoff's law around the outside loop, we get,
$2V_{s(peak)}$ - Reverse voltage(PIV)

across D_2 + Forward voltage across D_1 = 0

Neglecting the small forward voltage across D_1 we have, $2V_{s(peak)}$ = PIV across D_2 + 0 = 0

or PIV across D_2 = $2V_{s(peak)}$

From the above it can be seen that each diode in a fullwave rectifier must have PIV rating greater than the peak value of the full secondary voltage. $2V_{s(peak)}$

In the example considered earlier, the PIV of diodes should be $2 V_{s(peak)}$.

$$V_{s(peak)} = \frac{V_{s(rms)}}{0.707} \quad = \quad 2 V_{s(peak)} = \frac{2 \times V_{s(rms)}}{0.707}$$

$$= \frac{2 \times 24}{0.707} = 68 \text{ volts (approx.)}$$

Current rating of diodes in a full wave rectifier : If the load, R_L connected in the fullwave rectifier is, say 10Ω the DC current through it will be,

$$I_{dc} = \frac{V_{dc}}{10 \, \Omega}$$

In the example considered above, V_{dc} = 21.6 volts

Therefore, $I_{dc} = \frac{21.6}{10} = 2.16$ amps.

It is interesting to note this current I_{dc} is shared by the two diodes D_1 and D_2. This is because each diode conducts only for one half cycle. Therefore, the DC current through each diode is half the total DC load current I_{dc}. Hence, the maximum current through each diode with 10Ω load will be 2.16/2 = 1.08 amps. From this it follows that the current rating (If(max)) of each diode need only be half the maximum/rated load current.

NOTE: In a halfwave rectifier, since there is only one diode, the current rating of the diode used should be the maximum current through the load unlike in the case of a full wave rectifier in which the current rating of the diodes used is only half the maximum current through the load.

Example: In a two diode full wave rectifier, with a load current requirement of 1.8 amps, what should be the current ratings of the diodes used?

Since it is a two diode full wave rectifier, the current rating of each diode should be = 1/2 the total load current.

Therefore I_f(max) of diodes should be = 1.8 amps/2 = 0.9 amps.

It is fine if a diode of 1 amp current rating is used for this rectifier circuit.

Disadvantages of TWO DIODE full wave rectifier : The full wave rectifier using two diodes and centre tap transformer has the following disadvantages

• A centre-tapped transformer that produces equal voltages on each half of the secondary winding is difficult to manufacturer and, hence, expensive.

• Centre-tapped transformers are generally bulkier than ordinary transformers, and, hence, occupy larger space.

• In a two diode full wave rectifier, only half of the secondary voltage is made use at a time although it works in both +ve and -ve half cycles.

Bridge rectifier : It is a full-wave rectifier. The circuit is in Fig 5a. In the bridge rectifier four diodes are used. There is no centre tap on the secondary of the transformer.

Fig 5

(a)

(b)

(c)

(d)
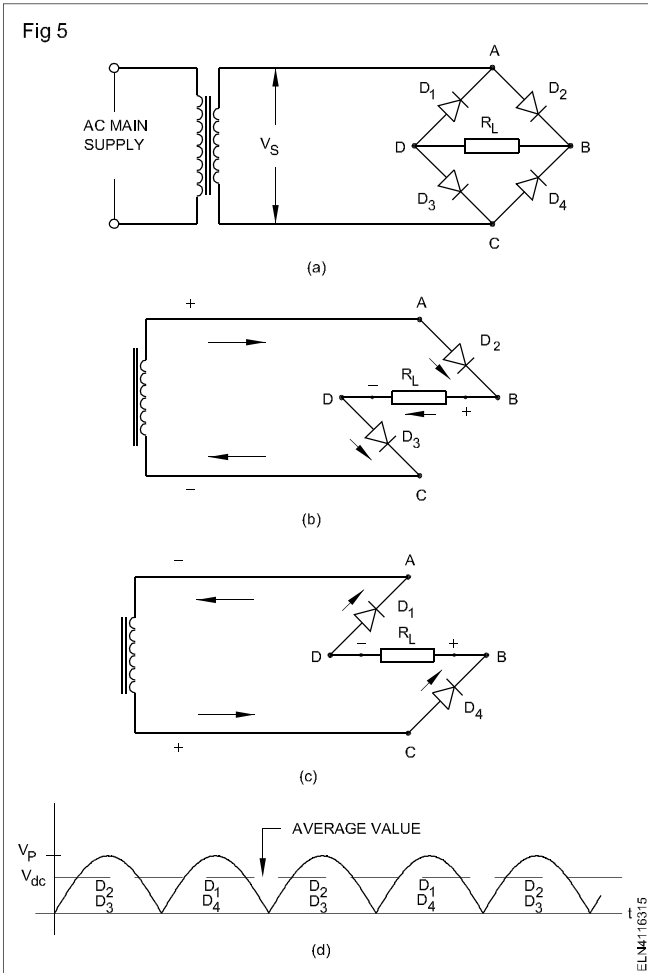
During the positive half of the secondary voltage, diodes D_2 and D_3 are forward-biased. Hence current flows through diode D_2 load resistance R_L and D_3 to the other end of the secondary. This is illustrated in Fig 5b. During the negative half of the secondary voltage, diodes D_1 and D_4 are conducting. The current flows through diode D_4, resistor R_L and diode D_1 to the other end of the secondary. This is illustrated in Fig 5c.

In both cases the current flows through the load resistor in the same direction. Hence, a fluctuating DC is developed across the load resistor RL. This is shown in Fig 5d.

DC output: Fig 6 shows the input AC and the output pulsating DC wave-form of a bridge rectifier.

This wave-form is similar to that of the full wave rectifier using a centre-tap transformer. Hence, the average DC value of the output is,

$V_{dc} = 0,636 \ V_{s(peak)}$

or $V_{dc} = 0.9 \ V_{s(rms)}$

where, Vs(rms) is the full secondary AC rms voltage.

NOTE: In a two -diode full wave rectifier $V_{s(rms)}$ refers to only half for the total secondary voltage whereas in a bridge rectifier $V_{s(rms)}$ refers to full secondary voltage.

Fig 6
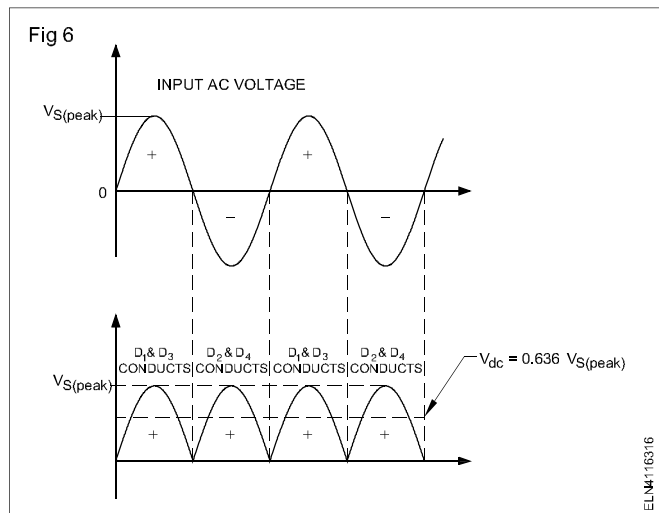
Example: In Fig 5, if the transformer secondary voltage $V_{s(rms)}$ is 24 volts, the rectified DC voltage V_{dc} across the load R_L will be,

From equation ....2, V_{dc} for a bridge rectifier is given by, $V_{dc} = 0.9 \ V_{s(rms)}$

In the given example, $V_{s(rms)}$ = 24 volts

Therefore, V_{dc} = 0.9 x 24 = 21.6 volts

NOTE: Using the same transformer, a two-diode full wave rectifier would have given only 10.8 volts which is half of that of bridge rectifier output.

Ripple frequency - Bridge rectifier: The pulsating DC output of a bridge is similar to the two diode full wave. Hence as in a two diode fullwave rectifier, the output ripple frequency of the bridge rectifier is also twice the input AC frequency.

Peak inverse voltage - Bridge rectifier: Fig 7 shows a bridge rectifier at the instant the secondary voltage has reached its maximum value.

Fig 7
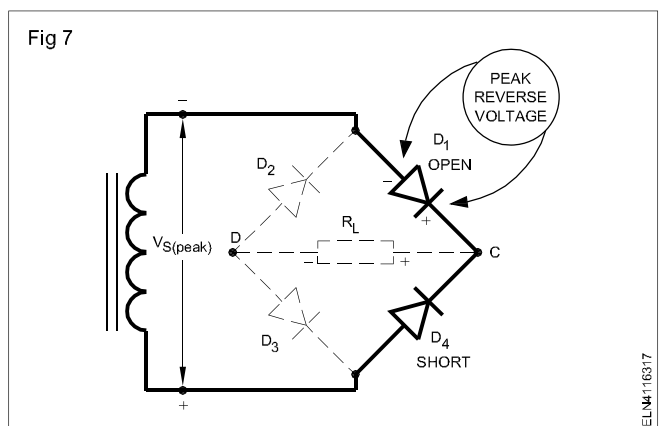
Diode D_4 is ideally short (as it is conducting) and D_1 is ideally open. summing the voltages around the outside loop and applying Kirchhoff's law,

$V_{s(peak)}$ - PIV across D_1 + 0 = 0

or   PIV across D_1 = $V_{s(peak)}$

Therefore, the peak inverse voltage across D_1 is equal to the peak secondary voltage $V_{s(peak)}$

In a similar way, the peak inverse voltage across each diode will be equal to the peak secondary voltage $V_{s(peak)}$ of the transformer secondary. Hence the PIV ratings of the diodes used should be greater than $V_{s(peak)}$

Example

In Fig 7 if the transformer secondary voltage $V_{s(rms)}$ is 24 volts, find the minimum PIV of diodes used. In a bridge rectifier PIV across the diodes is same and is equal to $V_{s(peak)}$

Therefore, in the given example,

$$PIV = V_{sd(peak)} = \frac{V_{s(rms)}}{0.707} = \frac{24}{0.707} = 34 \text{ volts}$$

Current rating of diodes in bridge rectifiers : As in the case of a two diode fullwave rectifier even in a bridge rectifier is in Fig 5, diode pairs D_1, D_3 and D_2 D_4 carry half the total load current1. This is because each diode pair is conducting only during one half of the AC input cycle.

The only disadvantage of bridge rectifiers, D_1, D_3 and D_2, D_4 is that, this circuit uses four diodes for full wave rectification instead of two as in two-diode fullwave rectifier. But this disadvantage is compensated by the simple transformer requirement of the bridge rectifier and higher DC output level. Hence, bridge rectifiers are the most popular AC to DC rectifiers for most applications.

Encapsulated bridge rectifiers are available as a single pack with two terminals for AC input and two terminals for DC output.
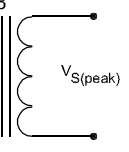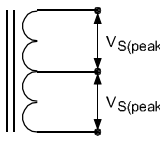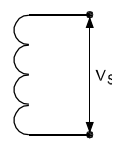
The following table provides data for a normally used diode having the current rating of one ampere.

Maximum ratings

Rating	Symbol	Type Number							Unit
		IN 4001	IN 4002	IN 4003	IN 4004	IN 4005	IN 4006	IN 4007	
Peak repetitive reverse voltage Working peak reverse voltage DC blocking voltage	$V_{RM(rep)}$ $V_{RM(wkg)}$ V_R	50	100	200	400	600	800	1000	Volts
Non-repetitive peak reverse voltage (half wave, single phase, 50 Hz peak)	$V_{RM (nonrep)}$	75	150	300	600	900	1200	1500	Volts
RMS reverse voltage	Vr	35	70	140	280	420	560	700	Volts
Average rectified forward current (Single phase, resistive load, 50Hz, T_A = 75°C)	Io			1.0					Amp
Non-repetitive (Half sine wave t=10m sec)	IFM			30					
Maximum thermal resistance junction temperature to ambient (lead length = 25 mm)	TJA			85					
Maximum Operating and storage junction temperature range	$T_j T_{stg}$			-65 to 175					

Other diode specifications can be obtained from the data book).

A comparison of half-wave, fullwave and bridge rectifier is given below in a tabular form

	Half wave	Full wave	Bridge
Number of diodes required	1	2	4
Transformers peak output voltage	Fig 8 $V_{S(peak)}$	$V_{S(peak)}$ $V_{S(peak)}$	V_S
DC output voltage in terms of $V_{s(peak)}$	$0.318 Y_{s(peak)}$	$0.636V\ V_{s(peak)}$	$0.636V\ V_{s(peak)}$
DC output voltage in terms of $V_{s(rms)}$	$0.45\ V_{s(rms)}$	$0.9\ V_{s(rms)}$	$0.9 V_{s(rms)}$
Diode current rating	$I_{L(max)}$	$0.5 I_{L(max)}$	$0.5 I_{L(max)}$
Peak inverse voltage	$V_{s(peak)}$	$2V_{s(peak)}$	$V_{s(peak)}$
Ripple frequency	f_{input}	$2f_{input}$	2_{finput}

Filter circuits : Alternating current is rectified to provide a steady DC voltage similar to the output of a battery as shown in Fig 9a. But the output of rectifiers in a pulsating DC as in Fig 9b.

Fig 9

a) PURE DC OUTPUT OF BATTERIES

b) PULSATING DC OUTPUT OF RECTIFIERS

PEAK TO PEAK RIPPLE

TIME

c) A FILTERED HALFWAVE OUTPUT
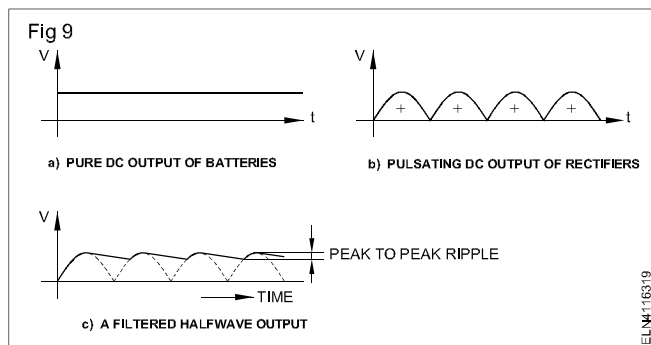
Pulsating DC voltages cannot be used in most of the electronic circuits. For example a buzzing sound will be obtained from a radio if these pulsations are not removed in the output of the rectifiers. The circuits used to filter off or reduce the pulsation in the DC output of rectifiers are known as smoothing circuits or popularly as Ripple filters.

Ripple : The small voltage fluctuations in the output of a filter like those shown in figure 9c are called Ripple.

Filter circuit components : Filter circuits are normally combinations of capacitors, inductors and resistors.

Types of filter circuits : The different filter circuits in use are

1   Capacitor input filter.

2   RC filter

3   Series inductor filter

4   Choke input LC filter

5   π filter.

1   **Capacitor filter** : A capacitor filter is the most simplest and cheapest filter. Here a large value capacitor C is connected across the load resistor RL as in Fig 10a. The capacitance offers a low reactance path to the AC components of current and offers very high resistance to DC. So all the DC current passes through the load.

Working : When the rectifier output voltage is increasing the capacitor charges to the peak voltage Vm. After reaching the positive peak the rectifier output voltage tries to fall. Observe the wave form in Fig 10b. At point 'B' the capacitor has $+V_m$ volts across it. Since the source voltage becomes slightly less than Vm, the capacitor will try to send current back through the diode, which reverse biases the diode.

The diode disconnects the source from load. The capacitor starts to discharge through the load. Thus the voltage across load will not fall to zero. The capacitor continues to discharge until the source voltage becomes more than the capacitor voltage at point C. The diode again starts conducting and the capacitor is again charged to peak value V_m. During the charging period for the capacitor the rectifier supplies the charging current I_c through capacitor as well as the load current I_L. Thus the current is maintained through the load always.

Fig 10
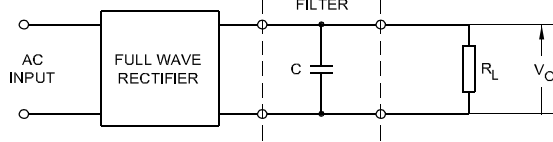
a) CAPACITOR FILTER
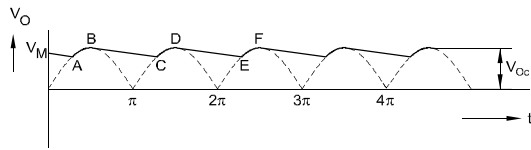
b) WAVE FORM OF OUTPUT OF CAPACITOR FILTER
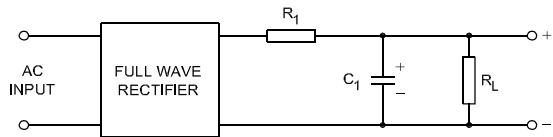
c) SERIES INDUCTOR FILTER
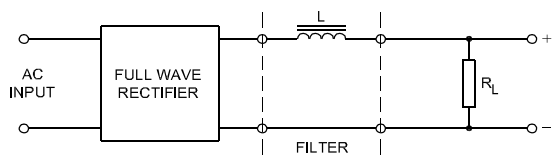
d) SERIES INDUCTOR FILTER
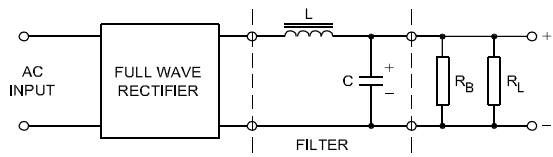
e) CHOKE INPUT - LC FILTER
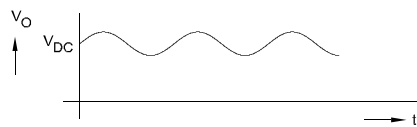
f) OUTPUT WAVE FORM OF A RC FILTER
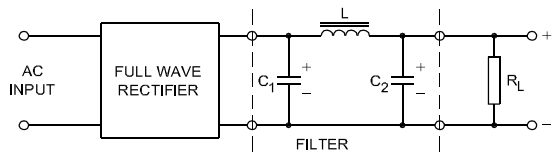
g) TT FILTER CIRCUIT

The rate at which the capacitor discharges between points B and C in Fig 10b depends upon the time constant $R_L C$. longer this time constant is, the steadier is the output voltage.

Calculation of Ripple : While designing a filter circuit the following methods can be used to calculate theoretically the ripple voltage in the output of the filter circuit.

Method 1

Knowing the required load current, I_L, for a given value of frequency f and capacitance C, the peak-to-peak ripple voltage can be found using the formula,

$$V_{rip(p-p)} = \frac{I_L}{F_r C} \ldots \ldots (2)$$

Where

$V_{r(p-p)}$ = peak-to-peak ripple voltage in volts

I_L = required Dc load current, in Amps

F_r = ripple frequency, in Hz

C = capacitance in Farads

Fixing the permissible $V_{r(p-p)}$ and knowing f and I_L the required value for C can also be found using this formula

Method 2

Another method of expressing the ripple in the output DC is by ripple factor r defined as,

$$Ripple\ factor, r = \frac{V_{r(rms)}}{V_{dc}}$$

where,

r = ripple factor (dimension less)

$V_{r(rms)}$ = rms value for ripple voltages.

V_{dc} is the measured dc voltage at the output.

2 RC filter

A simple RC filter circuit is in Fig 10c. It consists of a resistor R_1 and capacitor C_1 connected as shown . The resistor R_1 help the filtering provided by the capacitor by lengthening the discharge time of the capacitor.

3 Series inductor filter

The figure 10d shows a series inductor filter circuit. An inductor is a device which has the fundamental property of opposing any change in current flowing through it. This property is used in the series inductor filter.

Working : Whenever the current through an inductor tends to change, a back emf is induced in the inductor which prevents the current from changing its value. The operation of a series inductor filter depends upon the current through it. Therefore this filter can be used together with a full wave rectifier only. further an increase in load current result in reduced ripple.

4 Choke-input LC filter

A choke input filter consists of an inductor L in series and a capacitor C in shunt with load as shown in Figure 10e.

Working : An LC filter combines the features of both the series inductor filter and shunt capacitor filter. The choke (iron-core inductor) allows the DC component to pass through easily because it offers no resistance to DC. While the capacitor allows AC ripples to pass through but

blocks DC. As a result all the DC current passes through the load resistor R_L. The output wave form of a LC filter is an shown in Figure 10f.

Bleeder resistor : An inductor functions better when large steady current flows. For optimum functioning of choke filter a bleeder resistance R_B , which by passes the fluctuating current is included in the circuit as shown in Fig 10e.

5 PI-Filter (π filter)

This circuit is shown in Fig 10g. It is also called as a capacitor input filter. This circuit uses one inductor and two electrolytic capacitors. It is called capacitor-input filter because C_1 is the first filtering component. It is also called PI filter because the circuit looks like π (Greek letter)

Working : The rectifier output first goes to C, which alternately charge and discharges as in the case of a capacitor filter. The capacitor C_2 also provides a similar filtering action. The inductor opposes the changes in both the output of C_2 and in the current drawn by the load. Also the LC filters are capable of removing the voltage spikes at the input.

Transistors

Objectives: At the end of this lesson you shall be able to
• **explain the construction of bipolar transistors**
• **explain the classification and working of PNP and NPN transistors**
• **state the important packages and type number systems of transistor**
• **explain the methods of testing transistor.**

Introduction: Transistor is an active device which can be compared to the heart of modern electronics. It accepts small electrical signal either in the form of current or voltage at the input and then amplifies (increase the amplitude) and provides a large signal at the output as in Fig 1. Transistors are used in almost all electronic gadgets such as radio, TV, tape recorder, computer etc.,

Fig 1
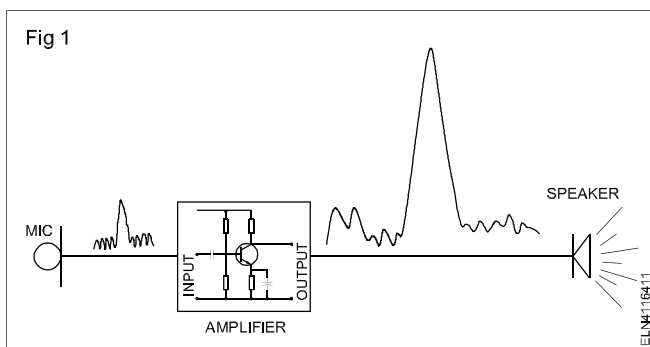
Before the transistors were invented (1947), certain devices are used known as vaccum tubes or valves which were used in amplifiers.

Compared with the present day transistors the vacuum tubes were big in size, consumed more power, generated lot of unwanted heat and were fragile. Hence vaccum tubes became obsolete as soon as transistors came to market.

Transistors were invented by walter H. Brazil and John Barlow of Bell Telephone Laboratories on 23rd Dec. 1947. Compared to vaccum tubes transistors have several advantages. Some important advantages are listed below.

• Very small in size

• Light in weight

• Minimum power loss in the form of heat

• Low operating voltage

• Rugged in construction

• Long life and cheap.

To satisfy the requirements of different applications, several types of transistors in different types of packaging are available. As in diodes, depending upon the characteristics, transistors are given a type number such as BC 107, 2N 6004 etc., The characteristics data corresponding to these type numbers are given in Transistor data books.

Transistor are available as bi polar, field effect and unijunction etc.,

A bipolar junction transistor uses two opposite polarity of doped semiconductor i.e. 'N' type and 'P' type.

A field-effect transistor uses electrostatic field of charged carriers for its working.

An unijunction transistor uses a single junction of 'P' and 'N' type semiconductor.

Construction of bipolar junction transistors : The bipolar junction transistor is a three-element device (emitter, base, collector) made up of silicon or germanium materials by various methods like point contact, grown junction, alloy junction, diffusion junction and epitaxial. The construction of the transistor and the symbols, NPN and PNP, are shown in Fig 2.

Fig 2

a) pnp - TRANSISTOR
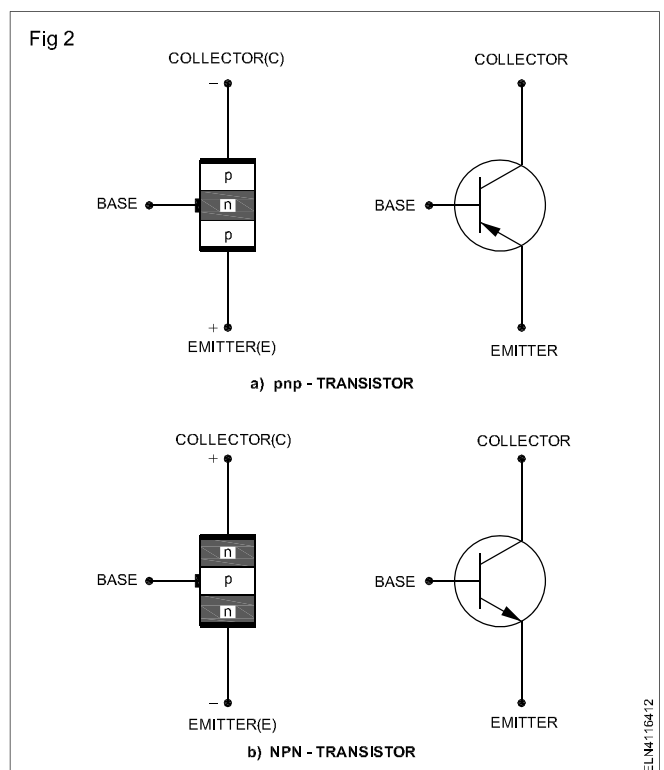
b) NPN - TRANSISTOR

A transistor is represented with the symbol shown. The arrow at the emitter shows the current flow through the transistor.

In most of the transistors, the collector region is made physically larger than the emitter region since it is required to dissipate more heat. The base is very lightly doped and is very thin. The emitter is heavily doped. The doping of the collector is more than that of the base but less than of the emitter.

Classification of transistors

1 Based on the semiconductor used

• Germanium transistors

• Silicon transistors

Like in diodes, transistors can be made, using any one of the above two important semiconductors. However, most of the transistors are made using silicon. this is because, silicon transistors work better over a wide temperature range (higher thermal stability) compared to germanium transistor.

Method of finding the semi conductor used in Transistor

Transistor data books give information about the semi conductor used in any particular transistor.

In the absence of data, still a quick check can be made with an ohmmeter to determine whether a transistor is made from silicon or germanium. In the test of a PNP transistor in Fig 3 first connect the ohmmeter negative lead to the collector and the positive lead to the emitter. With this hook-up a high resistance reading from the emitter to the collector will be shown.

Fig 3

OHMMETER TEST RESULTS PROVE WHETHER THE PNP TRANSISTOR UNDER TEST IS MADE FROM GERMANIUM OR SILICON
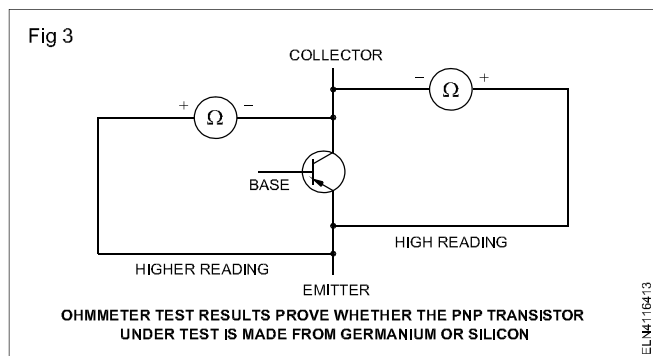
Then reverse the ohmmeter lead connections, and the resistance reading will go even higher. If it is possible to read the ohms on the meter scale, it is germanium transistor. If the reading is in the megohms-to-infinity range, it is a silicon transistor.

2 Based on the way the P and N junctions are organised as in Fig 4

• NPN transistor

• PNP transistor

Both NPN and PNP transistors are equally useful in electronic circuits. However, NPN transistors are preferred for the reason that NPN has higher switching speed compared to PNP.

Fig 4

a) pnp - TRANSISTOR
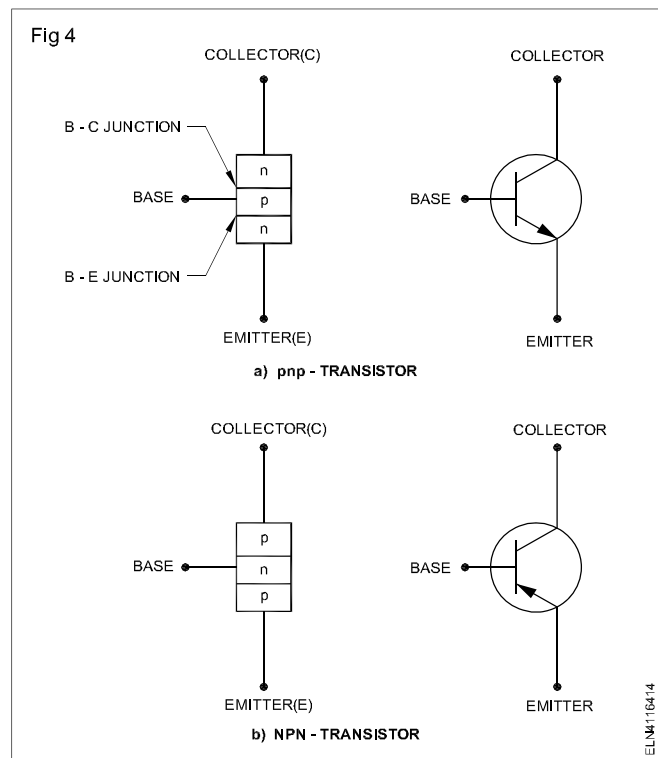
b) NPN - TRANSISTOR

Operation of NPN transistor : During the normal operation of the transistor for amplifications the emitter base junction must be forward-biased, and the base collector junction must be reverse-biased, as in Fig 5.

Fig 5
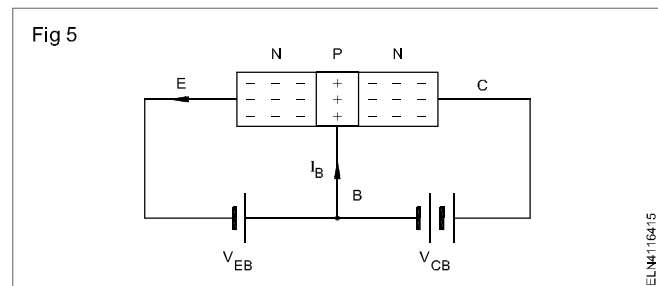
If V_{EB} is greater than the barrier potential (0.3 V for germanium and 0.7 V for silicon), the electrons in the emitter are repelled by the negative polarity of V_{EB} and sent to the base. After filling a few holes in the base, these electrons can flow in either of the two directions. A few of the electrons are attracted to the positive terminal of V_{EB}, producing base current I_B. Many electrons in the base and collector are attracted by the high position potential of V_{CB}, producing collector current I_c. Emitter current I_E is equal to base and collector currents.

$$I_E = I_B + I_c$$

Working of PNP transistor: For proper operation of a PNP transistors as amplifier the base emitter junction must be forward-biased and the collector-base junction must be reverse-biased as in Fig 6.

Holes which are the majority carries are injected from the emitter into the base region. By the reverse biasing of the base-collection junction, the collector region is made negative with respect to the base, and hence holes, which

carry a positive charge, penetrate into to base and flow across the collector junction and flow into the external applied voltage.

Fig 6
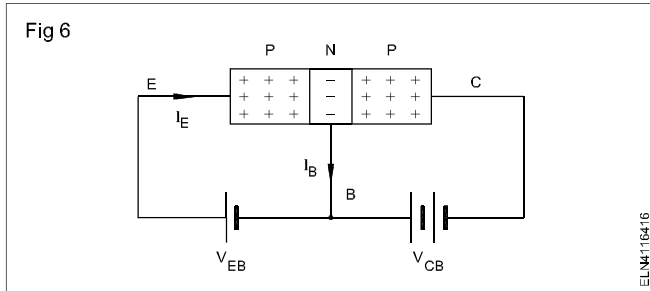
Method of identifying PNP and NPN transistors : Whether a transistor is PNP or NPN can be found with the help of transistor data book.

In the absence of data the following procedure may be adopted to identify the type of transistor whether it is PNP or NPN.

PNP identification : To identify the type of transistor first, make sure which is the positive lead and which is the negative lead from the ohmmeter. If necessary, take of the back for the instrument and check the polarity of the battery against the lead connections (positive to positive, negative to negative).

To test the transistor for its type:

1   Hook the positive lead from the ohmmeter to the base of the transistor. Fig 7

2   Connect the negative lead from the ohmmeter first to one transistor lead, then to the other.

3   If both readings shows high resistance, hook the negative ohmmeter lead to the base of the transistor. (Fig 7)

4   Connect the positive lead from the ohmmeter first to one transistor lead, then to he other.

5   If both readings show low resistance, then it is a PNP transistor.

Fig 7
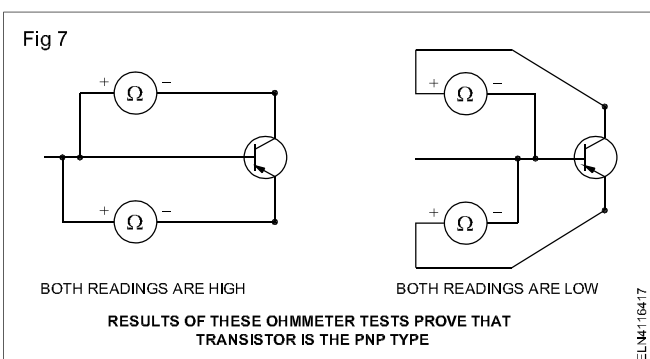
NPN identification : Suppose the ohmmeter tests show high resistance with the negative ohmmeter lead connected to the base of the transistor and the other lead is switched from transistor lead to transistor lead. See Fig 8 for reference.

Fig 8
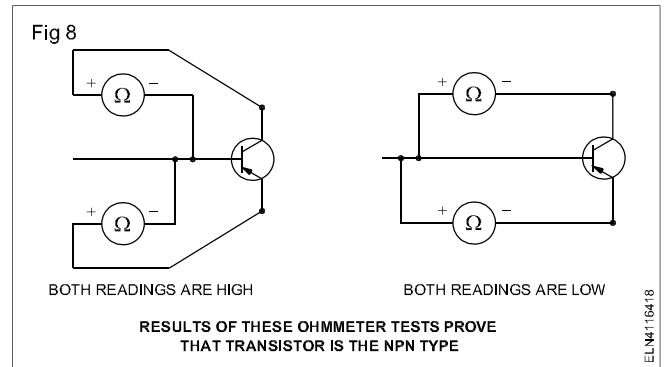
Continue testing as follows:

1   Reverse the ohmmeter leads, connecting the positive lead to the base of the transistor.

2   Connect the negative lead from the ohmmeter first to one transistor lead, then to the other.

3   If the readings show low resistance, then it is a NPN transistor.

3   Based on the power handling capacity of transistors, they are classified as

1   Low power transistors less than 2 watts

2   Medium power transistors is 2 to 10 watts

3   High power transistors more than 10 watts

Low power transistors, also known as small signal amplifiers, are generally used at the first stage of amplification in which the strength of the signal to be amplified is low. For example to amplify signals from a microphone, tape head, transducers etc.,

Medium power and high power transistors, also known as large signal amplifiers are used for achieving medium to high power amplification. For example, signals to be given to loudspeakers etc. High power transistors are usually mounted on metal chassis or on a physically large piece of metal known as heat sink. The function of heat sink is to, take away the heat from the transistor and pass it to the surrounding air.

Transistor data books give information about the power handling capacity of different transistor.

4   Based on the frequency of application

•   Low frequency transistor (Audio Frequency of A/F transistors)

•   High frequency transistor (Radio frequency of R/F transistors)

Amplification required for signals of low or audio range of frequencies in Tape recorders, PA systems etc., make use of A/F transistors. Amplifications required for signals of high and very high frequencies as, in radio receivers, television receivers etc., use R/F transistors.

Transistors data books give information for any particular transistor as to whether it is a AF of RF transistor.

5 Based on the manufacturing method

- Grown junction
- Alloy junction
- Planar contact
- Epitaxial
- Mesa

The aim of each manufacturing process is to yield transistors most suitable for a particular type of application.

Transistor data books generally do not give information about the adopted manufacturing process of transistor. However, the relevant details can be obtained from the transistor manufacturer.

6 Based on the type of final packaging

- Metal
- Plastic
- Ceramic

Metal packaged transistors are generally used in medium and high power amplifications. Plastic packaging is generally used for low power amplification. Some plastic packages come with a metal heat sink. Such transistors are used for medium power amplification. Ceramic packaging is used for special purpose very high frequency applications, for higher temperature stability etc.,

Some examples of packaging type codes used with transistors are, TO-3, TO-92- SOT-25 and so on.

Transistor data books give information about the type of packaging and its case outline.

Three lead devices such as transistors, SCRs, triacs etc., are cased in packages numbered as TO (transistor outline) or SOT (semi-conductor outline for transistors) followed by a number. A number of packages after designs are rarely used by circuit designers and have become obsolete.

Testing of transistor : A transistor can be tested for all specifications shown in the data book. But verification of almost all specifications, except a few requires an elaborate step up and can damage the transistor permanently.

The condition of a transistor with two diodes connected back to back will be as shown in Fig 9(a) & (b)

Fig 9

a) NPN   b) PNP
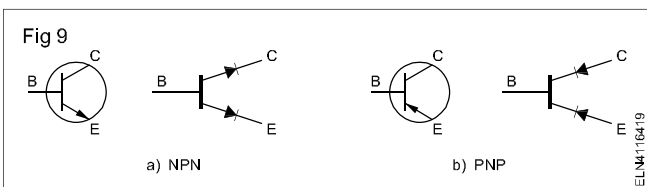
An ohmmeter can be used to check the junction either for an open circuit or a short circuit. The short is indicated by R practically zero ohms. A very high R of many megohms,

in the direction of infinite ohms, means an open circuit. Power must be off in the circuit for ohmmeter readings. Preferably, the device is out of the circuit to eliminate any parallel paths that can affect the resistance readings for a transistor, low resistance from base to emitter or base to collector indicate forward bias and when the ohm-meter/multimeter leads are transferred the resistance should be very high indicate reverse bias.

Probable possibilities are

1   When the ratio of reverse to forward R is very high, the junction is good.

2   When both the forward and reverse R are very low, close to zero, the junction is short-circuited.

3   When both the forward and reverse R are very high, close to infinity, the junction is open.

4   When both junctions are good transistor is good.

5   For a transistor without terminal details, base can be identified easily by identifying between collector and emitter terminal.

> **Normally for any power transistor, collector is connected to the metallic part/case to dissipate excess heat generated.**

6   With a high voltage multimeter (MOTWANE multimeter with 9 V cell in Ω x 100 range), emitter base junction shows some reverse resistance due to zener action which should be treated as high resistance for all purpose.

A germanium transistor has very low forward resistance for each of junction and a high resistance in the reverse direction, while a silicon transistor has moderate forward resistance and infinity reverse resistance.

Fig 10

a) NPN TRANSISTOR
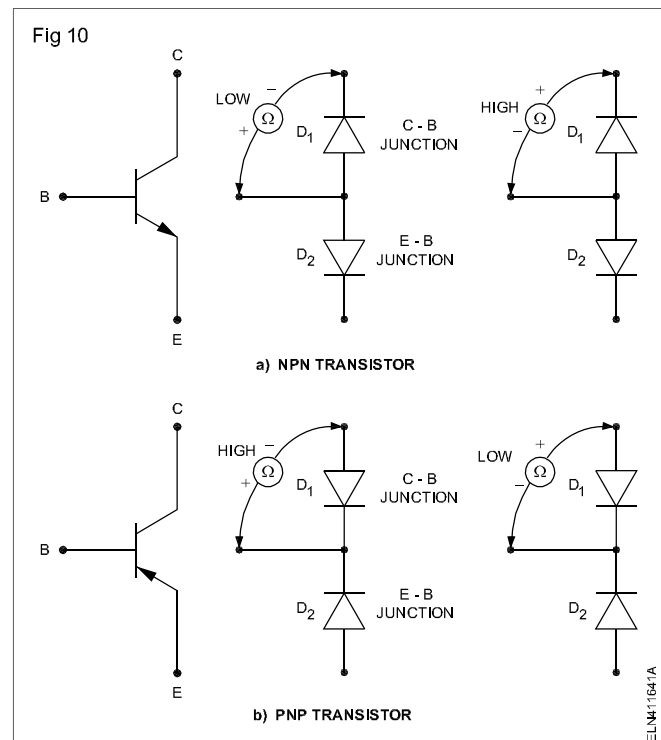
b) PNP TRANSISTOR

Fig 10a shows a NPN transistor and Fig 10b shows a PNP transistor. The imaginary diodes1 and 2 can be tested as similar to testing any diode. When a diode is tested, if the ohmmeter shows high resistance in one direction and low resistance in another direction, then the diode corresponding to that diode junction can be regarded as GOOD. One important point to note in a transistor is that, both the diodes of the transistor should be GOOD to declare the transistor as GOOD.

When testing, a transistor using ohmmeter, it is suggested to use the middle ohmmeter range (Rx 100) because, ohmmeters in low range can produce excessive current and ohmmeters in high range can produce excessive voltage which may be sufficient to damage small signal transistors.

Transistor biasing and characteristics

Objectives: At the end of this lesson you shall be able to
• **state the need and type of transistors biasing**
• **state the reason for shifting Q point due to temperature and β_{dc} changes**
• **state the necessity and importance of transistor characteristics**
• **state the importance of DC load line and meaning of Q point in transistors characteristics.**

Need of biasing of transistor

Before any one rides a motor cycle or drives a car, he has to start the engine and keep the engine running. In simple terms biasing transistors is similar to keeping the transistor started before making the real use of it. Once the transistor is started, like the engine of a car, it can be made to amplify, like covering the distance by driving the car.

Before an AC signal is fed to a transistor, it is necessary to set up an operating point or the quiescent(Q) point of operation. Generally this Q point is set at the middle of the DC load line. Once the Q point is set, then the incoming AC signals can produce fluctuations above and below this Q point as in Fig 1.
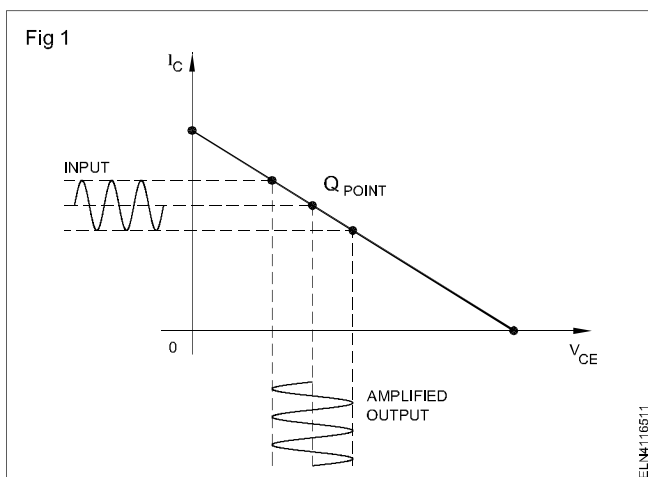
For the normal operation of a transistor amplifier circuit, it is essential that there should be

a) a forward bias on the emitter-base junction and

b) reverse-bias on the collector-base junction

In addition, the amount of bias required is important for establishing the Q point which is dictated by the mode of operation desired.

If the transistor is not biased correctly, it would

1) work inefficiently and

2) produce distortion in the output signal.

It is desirable, that once selected, the Q point should remain stable i.e. should not shift its position due to temperature rise which cause variation in β (V_{BE}) or leakage currents.

Further the amplitude variations in current and voltage of the input signal must not drive the transistor either into saturation of cut off.

Stable Q point: A set Q point of a transistor amplifier may shift due to increased temperature and transistor β value changes. Therefore, the objective of good biasing is to limit this shifting of the Q point or to achieve a stable Q point.

The Q point is nothing but a point in the output characteristic of the transistor. This point corresponds to a particular value of I_B, I_C and V_{CE}. Further, the collector current I_C depends both on I_B and β of the transistor. If I_B changes, I_C also changes, and hence, the Q point changes. If β changes, again I_C changes, and hence, the Q point gets shifted.

Shifting of Q point due to temperature: Remember that a transistor is a temperature sensitive device. Any increase in the junction temperature results in leakage current. this increased leakage current in turn increases the temperature and the effect is cumulative. This chain reaction is called thermal run away. If this thermal run away is not stopped, it may result in the complete destruction of the transistor due to excessive heat. In transistors, due to this increased leakage current, the base current increases, and hence, the Q point gets shifted. This change in the set Q point affects the performance of the amplifier resulting in distortion.

Shifting of Q point due to β_{dc} changes: Practically two transistors of the same type number may have different value of β. this is due to the manufacturing process of transistors. Hence, when a transistor is replaced or changed, due to different β of the replaced transistor, the Q point again gets shifted.

Therefore, a stable biasing is one which does not shift the Q-point even if temperature varies and/or the β of the transistor changes.

Different methods for transistor biasing: There are several ways to bias a transistor for linear operation. This means, there are several ways of setting up a Q point near the middle of the dc load line.

The methods used for providing a bias for transistors are 1 fixed bias or base bias

2 self-bias or emitter bias or emitter feed back bias

3 voltage divider bias

Fixed bias or base bias: The circuit in Fig 2 provides a fixed bias by means of the power source V_{cc} and the base resistor R_B

Fig 2
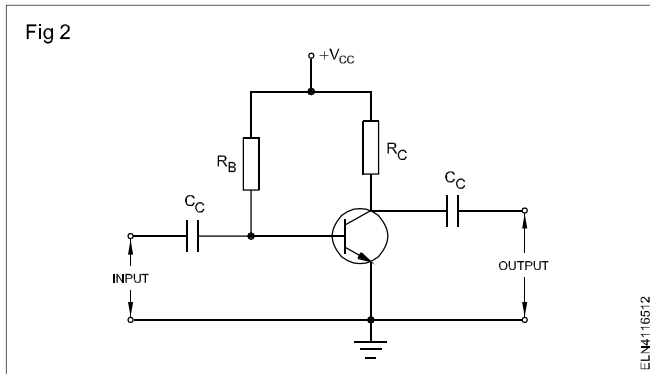
Self-bias arrangements are not practicable for small values of current because the DC Q point changes due to

– poor Beta sensitivity

– bias voltages and current do not remain constant during transistor operation due to temperature variation.

Hence, in a base-biased transistor, it is impossible to set up a stable Q point. Therefore, base biasing of transistors is not generally done in linear amplifier circuits. However, base biasing is commonly used in digital circuits (discussed in further lessons) where transistor are used as a switch and not as a linear amplifier.

2 SELF BIAS or EMITTER BIAS or emitter feedback bias: Fig 3 shows a emitter-biased transistor. This type of biasing compensates for the variations in temperature and keeps the Q point fairly stable.

Fig 3
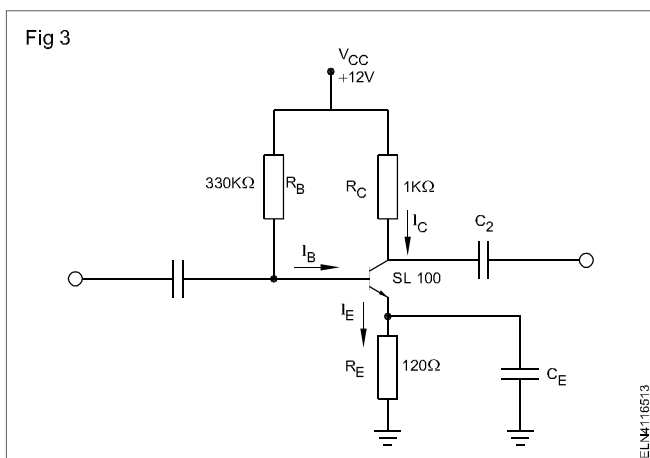
Let the temperature rise-causing rise in I_c and consequently rise in I_c. Then the current in R_E increases. The increased current in R_E increases the DC voltage drop across R_E, reduces the net emitter to the base bias, and the base current, and hence reduces the collector current. Thus the

presence of the self-biasing resistor R_E reduces the increase in Ic and improves the operating point stability.

However if β_{dc} increases, the collector current increase. This inturn increases the voltage at the emitter. This increased emitter voltage decreases the voltage across the base-emitter junction and therefore, the base current reduces. This reduced base current results in less collector current, which partially offsets the increase in I_c due to increase β_{dc}.

Emitter bias is also referred to as emitter feedback bias. This is because an output quantity, i.e., the collector current, produces a change in an input quantity i.e., the base current. The term feedback means a portion of the output is given back to the input. In emitter bias, the emitter resistor is the feedback element because it is common to both the output and input circuits.

Referring Fig 3, if we go for further analysis of the circuit we find if we add the voltages around the collector loop, we get,

$$I_C R_C + V_{CE} + I_E R_E - V_{CC} = 0 \ ...... \ (1)$$

Since I_E approximately equals I_c (as I_B is comparatively very small), equation ..(1) can be arranged as,

$$I_C = \frac{V_{CC} - V_{CE}}{R_C + R_E} \ .... \ (2)$$

If we add voltages around the base loop, we get,

$$I_B R_B + V_{BE} + I_E R_E - V_{CC} = 0 \ ...(3)$$

Since $I_E = I_c$ and $I_B = I_c / \beta_{dc}$, we can rewrite the equation as,

$$I_C = \frac{V_{CC} - V_{BE}}{R_B + R_D / \beta_{dc}} \ .... \ (4)$$

From equation...(4), the presence of term β indicates that I_c is dependent on β. The intention f emitter-feedback bias to swamp out the effect β_{dc}. This is possible when R_E is made much larger than R_B / β_{dc}. However, in practical circuits R_E cannot be made very large because, large value of R_E takes the transistor out of the linear operating region. Due to this problem, the emitter-feedback bias is almost as sensitive to changes in β_{dc} as in the base-bias. Therefore, emitter-feedback bias is also not a preferred form of transistor bias and should be avoided.

In emitter-bias, the saturation current will be,

$$I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_E + R_C} \ .... \ (1)$$

When the transistor is saturated, the value of V_{CE} will be between 0.2 to 0.3V. Hence can be neglected for all practical purposes.

In Fig 3, the saturation current is,

$$I_{C(sat)} = \frac{12V}{1000\Omega + 120\Omega} = 10.71 \, mA$$

Note:

$V_{CE(sat)}$ of 0.2 volts is neglected.

When $\beta_{dc} = 100$, equation...(4) gives,

$$I_C = \frac{12V - 0.7V}{120\Omega + 330\,K\Omega/100} = 3.3mA$$

When $\beta_{dc} = 300$, the same equation...(4) gives,

$$I_C = \frac{12V - 0.7V}{120\Omega + 330\,K\Omega/300} = 9.262mA$$

Fig 4 summarizes the calculations by showing the DC load line and the two Q points. As can be seen, a 3:1 change in β_{dc} produces almost a 3:1 change in the collector current. This change is unacceptable as a stable-biased state.

Fig 4
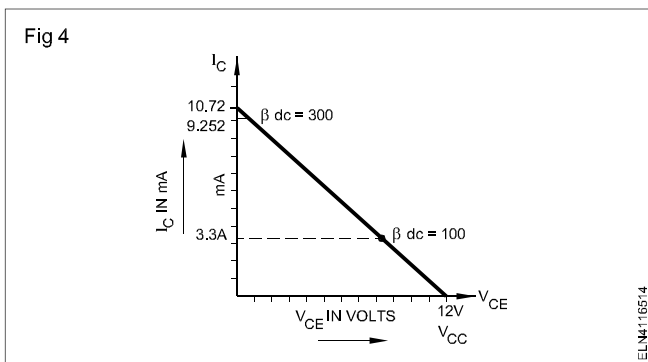
TIP: For linear operation of the transistor, the base resistor RB should be greater than βR_c. A base resistance of less than $\beta_{dc}R_c$ produces saturation in an emitter feedback-biased circuit.

3 VOLTAGE-DIVIDER bias: Collector to base bias: Fig 5 shows a typical voltage-divider bias. This type of biasing is also called the universal bias because, this is the most widely used type of biasing in linear circuits.

Fig 5
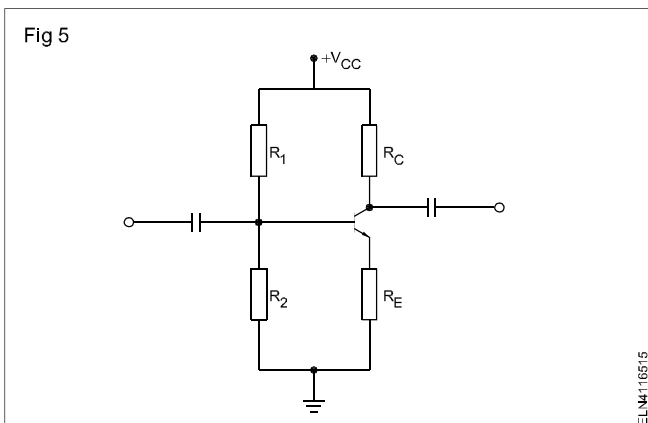
This type of biasing is known as voltage divider bias because of the voltage divider formed by resistors R_1 and R_2. The voltage drop across R_2 should be such that it forward biases the emitter diode.

Emitter current in voltage divider bias : Assume that the base lead is open as shown in Fig 6b. Looking back at the unloaded voltage divider,

$$V_{TH} = \frac{R_2}{R_1 + R_2} = V_{CC}.$$

> **NOTE: V_{TH} is known as the Thevenin's voltage. Refer reference books for Thevinin's theorem.**

Now assume that, the base lead is connected back to the voltage divider as in Fig 6a. then, voltage V_{TH} drives the base of the transistor. In other words, the circuit simplifies to Fig 6a and the transistor acts like the controlled current source.

Fig 6
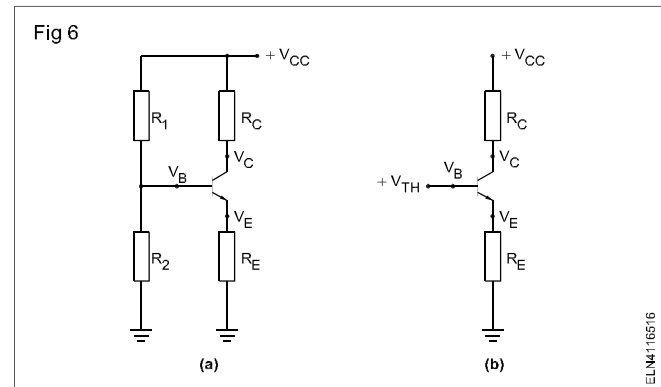
Because the emitter is boot-strapped to the base,

$$I_E = \frac{V_{TH} - V_{BE}}{R_E}$$

The collector current I_c will be approximately equal to I_E.

Notice that β_{dc} does not appear in the formula for emitter current. This means that the circuit is not dependent on variations in β_{dc}. This means that the divider-biased transistor has a stable Q point.

Because of the stable Q point, voltage-divider bias is the most preferred form of bias in linear transistor circuits. Hence, divider bias is used almost universally.

Transistor characteristics

In a transistor there are two PN junctions followed by three voltage parameters V_{BE}, V_{BC}, V_{CE} and three current parameters I_B, I_C, I_E is in Fig 7.

Any change in any one parameter causes changes in all the other parameters. Hence it is not very easy to correlate the effect of one parameter with the others. To have a clear understanding of their relationship a minimum of two characteristics graphs should be plotted for any transistor. They are,

Fig 7
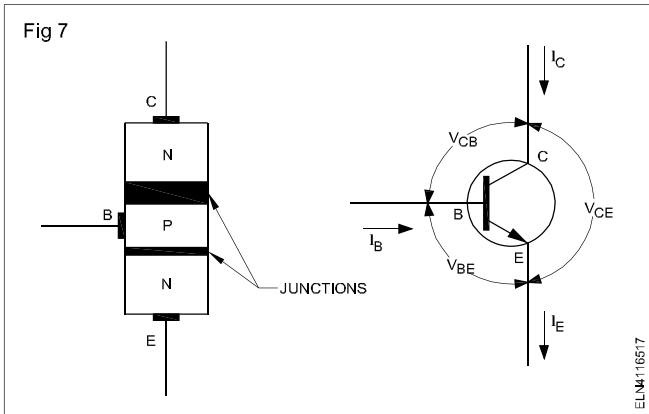
– Input characteristics

– Output characteristics

For simplicity in understanding, consider a common-emitter amplifiers circuit (Fig 8). The two characteristics graphs are in Fig 9 and Fig 10.

Fig 8

Fig 9

INPUT CHARACTERISTICS OF A COMMON EMITTER AMPLIFIER
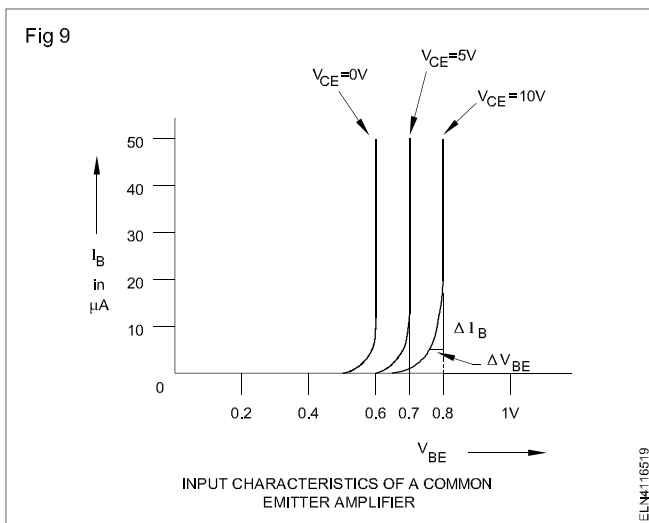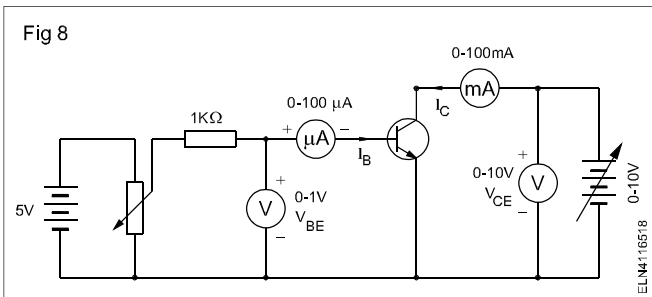
The graph at Fig 9 shows the relationship between the input voltage V_{BE} and input current I_B for different values of V_{CE}

To find the input characteristics from the circuit as in Fig 8 keep V_{CE} = 0 constant; increase V_{BE} at regular steps of 0.1V and note the value of I_B at each step. Repeat the above procedure for different value of V_{CE} say V_{CE} = 5V and 10V.

Input characteristic curves can be obtained by plotting I_B on the Y axis against V_{BE} on the X axis. A typical input characteristic is in Fig 9.

The reason for deviation of the characteristic curve for V_{CE}, 5V and 10V from V_{CE} 0 volt is, at higher values of V_{CE} the collector gathers a few more electrons flowing through the emitter. This reduces the base current. Hence the curve with higher V_{CE} has slightly less base current for a given V_{BE}. This phenomenon is known as early effect.

However for the practical purposes the difference in gap is so small it can be regarded as negligible.

The CE input characteristic curves resemble the forward characteristic of a PN diode. The input resistance can be calculated by using the formula.

$$R_{in} = \frac{V_{BE}}{I_B} = \frac{0.72 - 0.7}{20\,\mu A - 10\mu A} = \frac{0.02}{10\mu A} = 2k\Omega$$
$$(\mu = micro)$$

The voltage gain can be calculated by using the formula:

$$V_{gain} = \frac{V_{CE}}{I_{BE}} = \frac{10\,V - 5\,V}{0.15\,\mu A - 0.65\mu A} = \frac{5\,V}{0.1\mu A} = 50$$

Output CE characteristics: To find the output characteristics, keep I_B=0 micro-amp constant, increase V_{CE} in regular steps of 1V and note the value of I_B at each step. Repeat the above procedure for I_B = 20 micro-amp, 40 micro-amp and 60 micro–amp.

Output characteristics curves can be obtained by plotting I_c on the Y axis against V_{CE} on the X axis. A typical output characteristics curve is shown in Fig 10.

Fig 10

OUTPUT CHARACTERISTICS
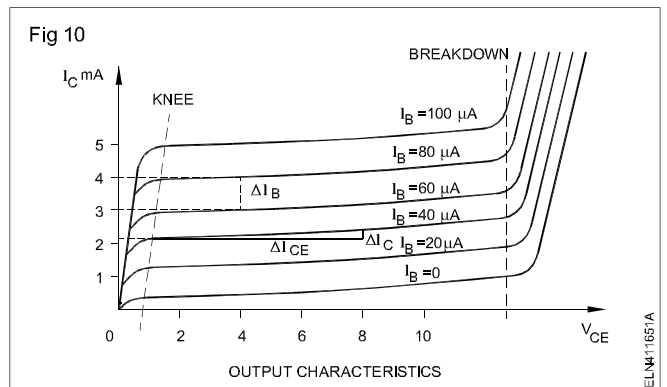
It is seen that as V_{CE} increases from zero, I_c rapidly increases to a near saturation level for a fixed value of I_B. As shown, a small amount of collector current flows even when I_B= 0. It is called leakage current I_{CEO}. Since the main collector current is zero, the transistor is said to be cut-off.

For simplicity in understanding consider on the output characteristic curve where I_B = 40 μA.

The output resistance can be calculated by the formula

$$R_0 = \frac{V_{CE}}{I_C} = \frac{8 - 2}{2.15\,mA - 2mA} = \frac{6}{0.15mA} = 40\,k\,ohms.$$

Current gain can be calculated by the formula

$$Beta\ \beta = \frac{I_C}{I_B} = \frac{4mA - 3\,mA}{80\,\mu A - 60\,\mu A} = \frac{1mA}{20\,\mu A} = 50$$

In the common base configuration, the current gain can be calculated by the formula:

$$Alpha\ \alpha = \frac{I_C}{I_E} = \frac{\beta}{1+\beta} = \frac{50}{1+50} = 0.98$$

Analysis of common emitter output characteristics

Active region : In the active region the collector junction is reverse-biased and the emitter junction is forward-biased. In the active region, the collector current is Beta times greater than the base current. Thus, a small input current I_B produces a large output current I_c.

Saturation regions : In the saturated region, the emitter and collector junctions are forward-biased. When the transistor is operated in the saturated region, it acts as a closed switch having $V_{CE} = 0$ and I_c maximum.

Behaviour of Ic for different values of V_{CE} is explained below:

- When V_{CE} is 0, the collector-base diode is not reverse-biased. Therefore, the collector current is negligibly small and this continues upto knee point.

- For V_{CE} between 0.7V and 1V, say up to knee point voltage the collector diode gets reverse-biased. Once reverse biased, the collector gather all the electrons that reach its depletion layer. Hence the collector current rises sharply and then becomes almost constant.

- Above the knee voltage and below the break down voltage, the collector current does not rise steeply or the current is almost constant even if the value of V_{CE} is increased. Thus the transistor works like a controlled constant current source in this region.

- Assuming that the transistor has a ß$_{dc}$ of approximately 50, the collector current is approximately 100 times the base current as in Fig 4 (1mA is 50 times 20 µA).

- If V_{CE} is further increased, beyond the break down level, $V_{CE(max)}$, the collector-base diode breaks down and normal transistor action is lost. The transistor no longer acts like a current. As the collector-base gets ruptured, the junction is shorted and hence current increases rapidly above the breakdown point as in Fig 10.

Cut off region : In the cut off region, the emitter and collector junctions are reverse-biased. When the transistor is operated in the cut off region, it acts as an open switch, having $V_{CE} = V_{cc}$ and $I_c = 0$

Break down region : When the collector voltage is too large, the collector diode breaks down by a rapid increase of collector current. Usually, a designer should avoid operation in the breakdown region because the excessive power dissipation may destroy the transistor.

For instance, a 2N3904 has a collector break down voltage of 40V. For normal operation, therefore, V_{CE} should be less than 40V.

Maximum power dissipation region : The maximum power dissipation ($P_{o\ max}$), defined as the product of maximum collector current $I_{c\ max}$ and maximum collector emitter voltage $V_{CE\ max}$, restricts the operation to an area on the output characteristic bounded by a hyperbola.

To understand the function of the transistor at active, cut off, saturation regions and breakdown regions, refer to Fig 11.

OUTPUT CHARACTERISTIC WITH LOAD LINE SUPERIMPOSED
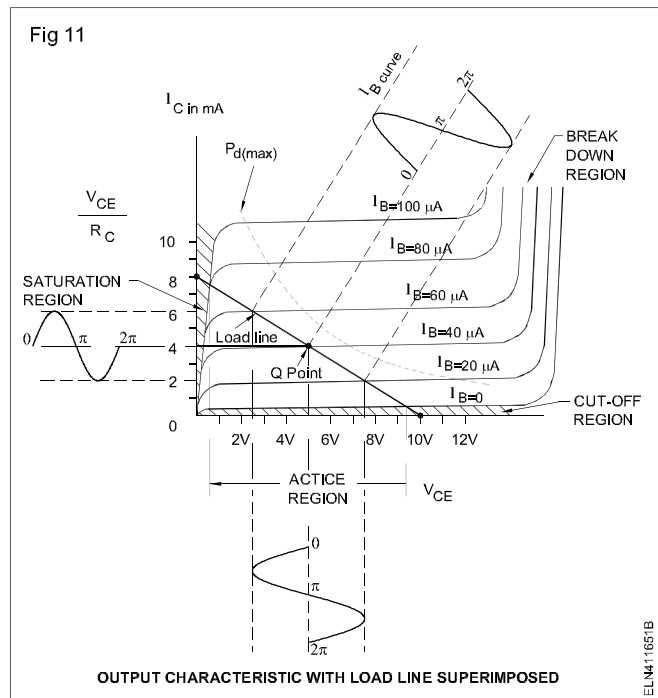
The collector curves are very important because, from these curves the following important information required while designing an amplifier circuit using a particular type of transistor can be obtained;

- DC current gain ß of the transistor at different set DC values of I_B and V_{CE}

- Maximum value of V_{CE} that can be applied for a set value of I_B and I_c.

- Maximum value of I_c that can be made to flow for a set value of I_B

Operation point : The position of the operating point on the DC load line determines the maximum signal that we can get from the circuit before clipping occurs. The operating point or quiescent point is a point on the DC load line which represents the values of I_c and V_{CE} that exist in a transistor circuit when no input signal is applied. The best position for this point is midway between cut-off and saturation point where $V_{CE} = 1/2\ V_{cc}$.

DC load lines of transistors : To have a further insight into how a transistor works and in what region of the collector characteristics does it work better can be seen using DC load lines.

Consider a forward biased transistor as in Fig 12a. Fig 12b shows the collector characteristics of the transistor used.
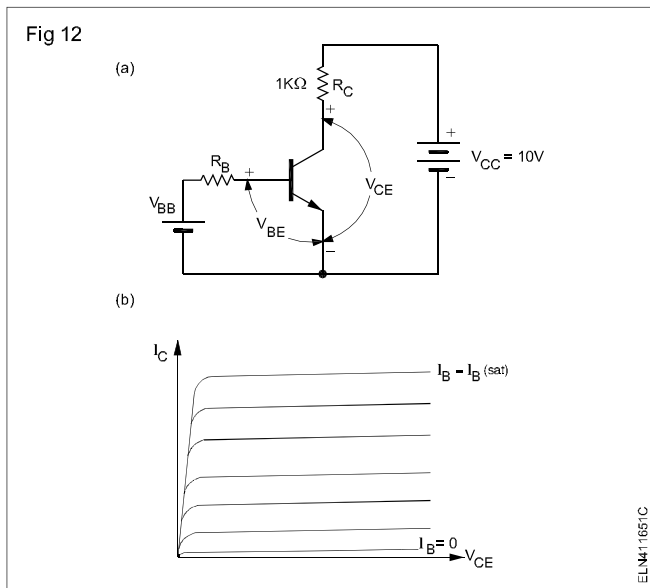
Fig 12

In the circuit at Fig 12a, consider the following two situations,

– Maximum collector current, $I_{c(max)}$

– Minimum collector current, I_c

For situation (1) assume that V_{CE} is zero or collector is at short. In that case, the collector current is limited only by the collector resistor R_c.

Therefore

$$I_C = \frac{V_{CC}}{R_C} \quad \text{at} \quad I_{CE} = 0$$

Under such a condition for the circuit at Fig 12a I_c will be equal to 10V/kΩ = 10mA

Mark this I_c=10mA point along V_{CE}=0 on the collector characteristics of the transistor as shown in Fig 13 at point A.

Fig 13
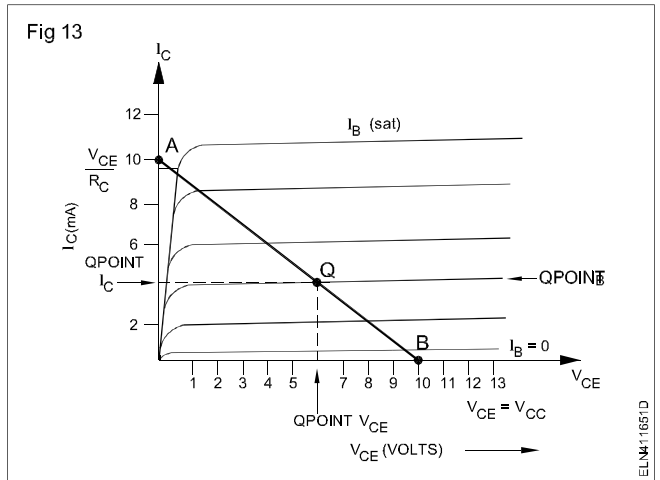
For situation (2), assume that V_{CE} is maximum or collector emitter is open. In that case, the collector current is zero.

Therefore,

$V_{CE} = V_{cc}$ In the circuit at 6a, $V_{CE} = V_{CC} = 10V$

Mark this point of $I_c = 0$ and $V_{CE} = 10$ V on the collector characteristics of the transistor as in Fig 13 at point B.

Connect the two marked points A and B through a straight line as shown in Fig 13. This line is called the load line.

The point at which the load line intersects the $I_B = 0$ is known as the cut off point. At cut off, $I_B = 0$; hence emitter diode is out of forward bias and the transistor action is lost.

The point at which the load line intersects $I_B = I_B(sat)$ is called the saturation point. At this point the base current is maximum and the collector current is also maximum. At saturation, the collector diode comes out of the reverse bias, and hence, the normal transistor action is lost.

For a transistor to work in a normal way, i.e. as a controlled current source, it must not be made to work either in the cut off or in saturation. Therefore the ideal point would be somewhere in the middle of these extreme points on the load line. This middle point is known as Quiescent point or Q-point as in Fig 13. knowing the Q point we can fix up the value of resistors RC and RB of the circuit.

Transistor as a switch, series voltage regulator and amplifiers

Objectives: At the end of this lesson you shall be able to
• **explain the function of the transistor at cut-off and saturation condition**
• **explain the operation of a transistor as a switch and its application**
• **state the working of series voltage regulator using transistor**
• **state the classification of amplifiers.**

The function of a transistor at cut-off condition: The transistor is operated at cut–off condition when the emitter and collector junctions are both reverse-biased.

Consider the circuit in Fig 1.

$$V_{CE} = V_{CC} - (I_C \times R_L) ..... (1)$$

Since, $I_B = 0$ and $I_c = 0$ $V_{CE} = V_{CC}$

The transistor is said to be cutoff for the simple reason that it does not conduct any current as in Fig 1a.This corresponds to a switch in an open state. Therefore, a transistor at cut off is said to be at open state.

a) TRANSISTOR AT CUT OFF CONDITION   b) TRANSISTOR AT SATURATED CONDITION
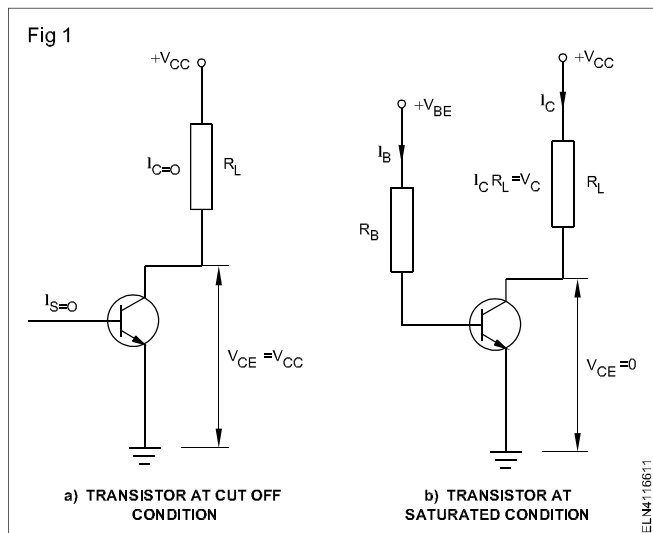
The function of a transistor at saturated condition : The transistor is operated at saturated condition when both the emitter and the collector junctions are forward biased.

In Fig 1b, if the value of R_B and R_L are such that V_{CE} tends to zero, then the transistor is said to be saturated. Putting $V_{CE} = 0$ in the equation (1) we get

$$V_{CE} = 0 = V_{cc} - I_c R_L \text{ or } I_c = V_{cc} - R_L$$

It should be noted that a transistor, when saturated, acts as closed switch of negligible resistance.

It is obvious that under saturation conditions,

• the whole of V_{cc} drops across R_L

• the collector current has maximum possible value called $I_{C(SAT)}$

The operation of transistor as switch: The switching action for Q_1 in Fig 2 illustrates how the output current can be controlled at the input. Note the following important operating characteristics.

• The transistor is normally off, without any output current unless forward voltage is applied in the base-emitter circuit.

• The forward voltage controlling the base current determines the amount of output current.

In Fig 2 the control circuit of the input determines the base current. For the power circuit, the output is the collector current. An NPN transistor is used for Q_1. This type requires positive V_{BE} forward voltage. The emitter is common to both (a) the control circuit at the input and (b) the power output circuit.
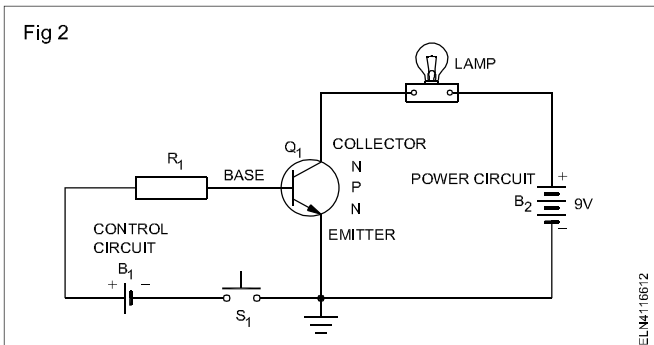
The base emitter junction of Q_1, in Fig 2 can be forward biased by the battery B_1. Switch S_1 must be closed to apply the forward voltage. Reverse voltage for the collector of Q_1 is supplied by B_2.The reverse polarity means that the N collector is more positive than the base. With switch S_1 open, no current flows in the base-emitter (or control) circuit.

The reason is that the forward voltage is not applied. Therefore, the resistance from the emitter to the collector of the transistor is very high. No current flows in the power circuit, and the lamp does not light.

Next, assume that switch S_1 is closed. This causes a small current to flow in the control circuit. R_1 is a current limiting resistor for the base circuit. Therefore, the resistance from the emitter to the collector of the transistor drops.

Consequently, a large current flows in the power circuit, causing the lamp to light.

Finally, the opening of the switch S_1 in the control circuit cause the lamp in the power circuit to go out. This is because the resistance from the emitter(E) to the collector (C) of Q_1 has again increased to near infinity.

In summary, a small current in the control circuit causes a large current to flow in the power circuit. With no current in the control circuit, the transistor acts like an open switch. With some current in the control circuit, the transistor acts like a closed switch.

Operation of transistor switching circuit : The schematic circuit in Fig 3 shows the measured voltages and collector current I_c in the 'transistor off' circuit. Note that only a tiny leakage current of 1micro amp flows from the emitter to the collector. The resistance from E to C is calculated as

$$R = \frac{V}{I} = \frac{9\,V}{0.000001\,A} = 9\,megohm$$

Fig 3
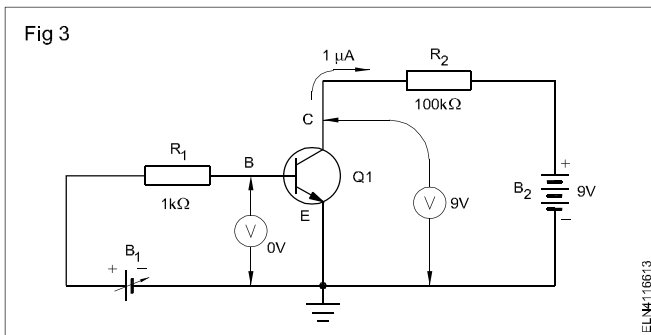
The transistor has a resistance of 9 Megohm, which is like the open or off condition of a switch.

The schematic in Fig 4, shows the measured voltages and currents in the 'transistor on' circuit. First, the voltage from the emitter to the base has been increased by adjusting B_1. The forward-biased voltage of 0,86V at the emitter-base junction of the transistor causes 1.8 mA to flow in the control circuit. This current in turn causes the resistance of the transistor from E to C to drop. The effect is that a large current of 85mA flows from the collector of the transistor. The resistance from E to C in Fig 4 is calculated as

$$R = \frac{V}{I} = \frac{0.4\,V}{0.085A} = 4.7\,ohm$$

Fig 4
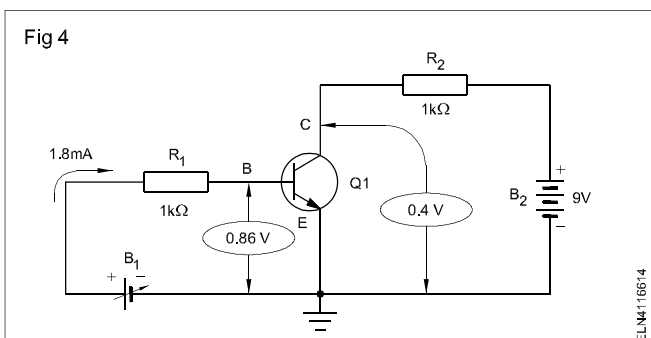
The resistance of the transistor from E to C has dropped from its previous high value of 9 megohm to a low value of 4.7 ohm. As a result, the transistor is acting like a closed switch.

The transistor in Fig 3 is said to be at cut off position. It has reached its maximum resistance from E to C and has cut off the current. The very tiny current still flowing is due to minority current carriers in the transistor, which is the leakage current.

The transistor in Fig 4 is said to be at saturation. It has reached its minimum resistance from E to C, which produces the maximum collector current. When used as a switch, the transistor is driven to cut off or to saturation by the base current caused by the emitter-base voltage.

Transistor switching times : Now let us pay attention to the behaviour of the transistor as it makes a transition from one state to the other. Consider the transistor circuit in Fig 5a, driven by the pulse wave-form in Fig 5b. This wave-form makes transitions between the voltage levels V_2 and V_1. At V_2 the transistor is at cut off, and at V_1 is applied between the base and the emitter through a resistor R_1 which may be included explicitly in the circuit or may represent the output impedance of the source in the wave-form Fig 5b.

Fig 5

a) SWITCHING CIRCUIT

b) INPUT WAVEFORM

c) RELATIONSHIP BETWEEN I_C INPUT WAVE FORM AND t
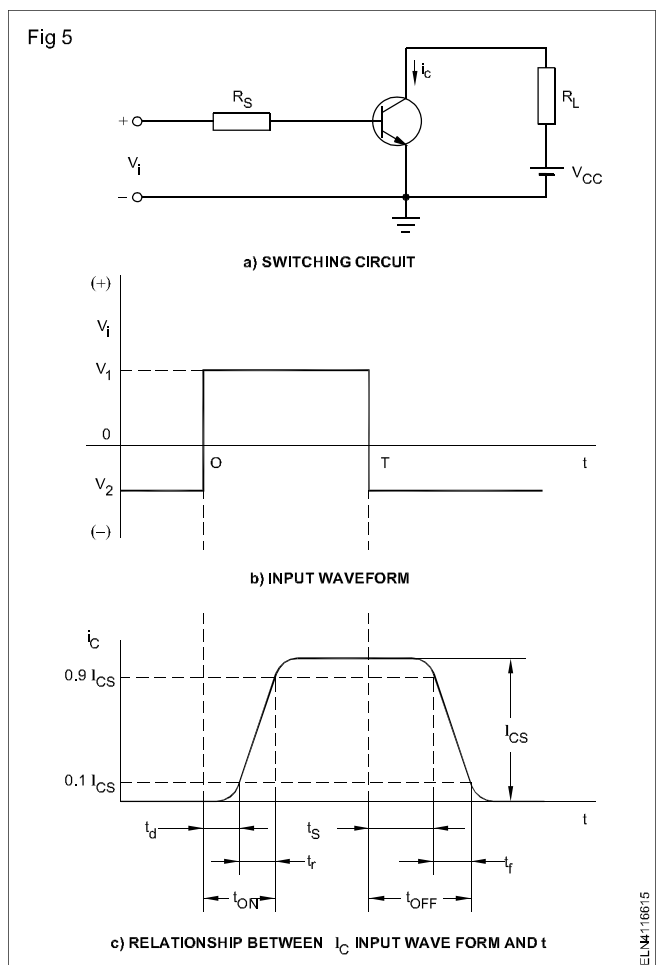
The response of the collector current I_c to the input waveform, together with its time relationship to that waveform, is in Fig 5c. The current does not immediately respond to the input signal. Instead, there is a delay, and the time that elapses during this delay, together with the time required for the current to rise to 10 percent of its maximum (saturation) value $I_{CS} = V_{cc}/R_L$, is called the delay time t_d. The current waveform has a nonzero rise time tr which is the time required for the current to rise from 10 to 90 percent of I_{CS}. The total turn-on time t_{ON} is the sum of the delay and rise time,

$$t_{ON} = t_d + t_r$$

When the input signal returns to its initial state at t = T (Fig 5b), the current again fails to respond immediately. The interval which elapses between the transition of the input waveform and the time when i_c has dropped to 90 percent of ICS is called the storage time t_s. The storage interval is followed by the fall time tt, which is the time required for i_c to fall from 90 to 10 percent of I_{CS}. The turn off time to t_{OFF} is defined as the sum of the storage and fall times,

$$t_{OFF} = t_s + t_F$$

The application of transistor switch: The transistor switch is used

• as an electronic ON and OFF switch

• in the stable, mono-stable and bi-stable or filp-flop multi-vibrator circuits

• in the counter and pulse generator circuit

• in the clipping circuits

• as a sweep starting switch in the cathode ray oscilloscope equipment

• as a relay, but unlike the mechanical relay, the transistor has no moving mechanical parts.

Classification of the Switching Transistor: Transistor switches are used very often as they are small and are of light weight, and they consume low power. The important specifications of a switching transistor are the numerical values of delay time, rise time, storage time and fall time. For the TEXAS INSTRUMENTS n-p-n silicon transistor 2N3830, under specified conditions can be as low as t_d = 10 nsec, t_r = 50 nsec, t_s = 40 nsec and t_f = 30 nsec.

Series voltage regulator

Voltage regulated power supply using zener diode is the simplest form of voltage regulator. But, zener voltage regulators have two main disadvantages:

1 When the load current requirement is higher, say of the order of a few amperes, the zener regulator requires a very high wattage zener diode capable of handling high current.

2 In a zener regulator, the load resistor sees an output impedance of approximately the zener impedance, R_z which ranges from a few ohms to a few tens of ohms (typically 5Ω to 25Ω). This is a considerably high output impedance because the output impedance of a ideal power supply should be zero ohms.

These two disadvantages of zener regulators are overcome in a simple series regulator shown in Fig 6.

The simple series regulator is in Fig 6a, redrawn in Fig 6b is nothing but a zener regulator followed by an emitter follower. A circuit like this can hold the load voltage almost constant, thus working as a voltage regulator.
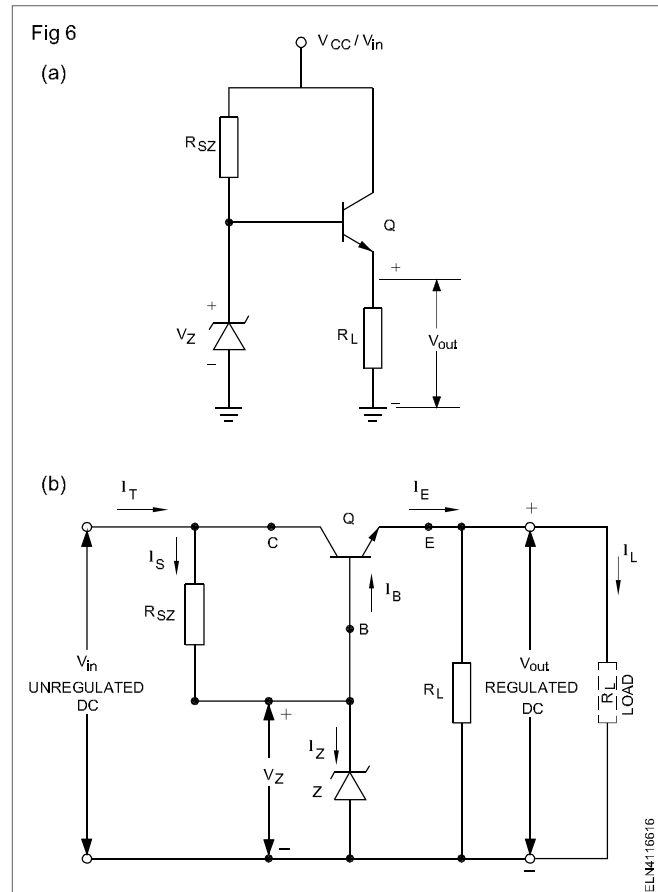
The advantages of this circuit are listed below;

1 Less load on the zener diode

Current through R_z is the sum of current just required to keep the zener fired and the small base current I_B.

$$I_B = \frac{\text{emitter curent}}{\beta_{dc} \text{ of transistor}} = \frac{I_E}{\beta_{dc}} = \frac{I_L}{\beta_{dc}}$$

Since the base current is very much smaller than the emitter current or the load current, a very small wattage zener diode itself is sufficient.

For instance for a load of say 1 amp, if the β_{dc} of the transistor is 100, then the zener diode need to handle only,

$$I_Z = I_{Z(min)} + \frac{I_L}{\beta_{dc}} = I_{Z(min)} + \frac{1\,Amp}{100}$$

Since $I_{Z(min)}$ will generally be in the range of 5 to 10mA, I_Z = 10mA + 10mA = 20mA.

2 Lower output impedance

If the zener resistance, R_Z is say 7Ω, then, in a zener regulator discussed in unit 9, the output impedance of the power supply will be approximately equal to R_Z = 7Ω.

Fig 7 shows the output equivalent circuit of the series regulator at Fig 6. As in Fig 7, the output impedance of the power supply will be,

Fig 7

$r'_e + \dfrac{R_Z}{\beta}$

$V_Z - V_{BE}$ R_L

r'_e = AC RESISTANCE OF TRANSISTOR

R_Z = INTERNAL RESISTANCE OF ZENER

β = CURRENT GAIN OF TRANSISTOR
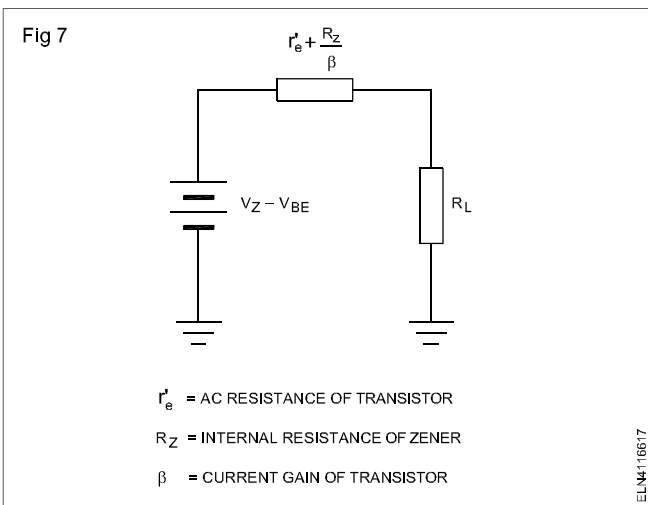
$$Z_{out} = r'e + \frac{R_Z}{\beta}$$

Since I_E is very large (load current), r'_e will be comparatively small, hence the term r'_e can be neglected. Therefore, in Fig 6 the output impedance will be,

$$Z_{out} \cong \frac{R_Z}{\beta} = \frac{7}{100} = 0.07\Omega$$

This low output impedance of 0.07Ω is close to the ideal output impedance of zero required for a power supply.

Working of a simple series regulator

In Fig 6b, the current through R_{SZ} should be atleast equal to zener breakdown current, plus, base current for the transistor Q.

The voltage across the zener, V_Z drives the base of the emitter follower. Therefore, the DC output voltage is bootstrapped to within one V_{BE} drop of the zener voltage. The regulated dc output voltage will be,

$$V_{out} = V_Z - V_{BE} \qquad \qquad ....[1]$$

The collector - emitter voltage across the transistor will be the difference in the voltage between the input and output.

$$V_{CE} = V_{in} - V_{out}$$

If the input voltage V_{in} increases, the output voltage V_{out} remains constant due to the bootstrapped zener voltage. Therefore, the drop across the collector-emitter, V_{CE} of the transistor increases compensating the rise in the input voltage V_i.

For example, in the series regulator shown in Fig 6, if V_{in} is 15 V and V_{out} is 12 volts, then, V_{CE} will be,

$$V_{CE} = V_{in} - V_{out} = 15\text{-}12 = 3\ V.$$

If V_{in} increases to say 20 V, then V_{CE} increases to 20-12=8 V, thus keeping the output voltage unaltered at 12 volts. Since the collector and emitter of the transistor in Fig 6 is in series with the input and output terminals, this type of regulators are known as series voltage regulators.

Because the transistor is in series, all the load current must pass through the transistor. Hence the transistor is referred to as the pass transistor.

Because of the fact, that all the load current must flow through the pass transistor and that the value of V_{CE} increases when V_{in} increases, the wattage rating of the pass transistor should be high enough to handle the dissipation.

For instance, while supplying a load current of 300 mA, with V_{in} at 20 V and V_{out} at 12V, V_{CE} will be 8 V. Therefore, the dissipation at the transistor will be,

$$P_D = V_{CE}\ x\ I_L = 8\ x\ 300\ mA = 2400\ mw = 2.4\ watts$$

To accommodate this, the wattage rating of the chosen pass transistor should be greater than 2.4 watts.

TIP: Allow at least 20% higher rating. For the example above, choose a transistor of rating 2.4 + 0.48 watts= 3 watts.

Because there will be quite a high dissipation depending on load current requirement, medium to high power transistors are used as pass transistors.

Temperature effect on output voltage

When temperature increases, V_{BE} decreases. Therefore, V_{out} decreases by the change of current in V_{BE}.

Data sheets of transistors usually give information about how much V_{BE} changes with temperature.

For all practical purposes, an approximate of 2 mV decreases in V_{BE} for each degree rise in temperature. For instance when the temperature of the transistor rises from 25°C (room temperature) to 75°C (due to power dissipation

at the transistor), V_{BE} decreases approximately 100 mV. Hence, the output will increases by 100 mV. This is relatively small, and hence, can be neglected.

Temperature also has an effect on the voltage across the zener. Any increase or decrease in the voltage across the zener is reflected at the output. Hence, while choosing the zener, it is equally important to know the temperature coefficient of the zener, specially when the power supply is connected to higher loads of the order of a few amperes.

Classifications of amplifiers : An amplifier is an electronic circuit which is used to amplify or increase the level of weak input signals into very high output signals. Transistors are used as amplifiers in most circuits. In addition, resistors, capacitors and a biasing battery are required to form complete amplifier circuits.

Almost all electronic systems work with amplifiers. We are able to hear the news or other programmes on our radio, simply because the amplifier in the radio amplifies the weak signals received by its antenna.

Classification of amplifiers: Linear amplifiers are classified according to their mode of operation, i.e. the way they operate according to a predetermined set of values. Various amplifier descriptions are based on the following factors.

1   Based on the transistor configuration

   a   common emitter (CE) amplifier

   b   common collector (CC) amplifier

   c   common Base (CB) amplifier

2   Based on the output

   a   voltage amplifier

   b   current amplifier

   c   power amplifier

3   Based on the input

   a   small signal amplifier

   b   large signal amplifier

4   Based on the coupling

   a   RC coupled amplifier

   b   transformer coupled amplifier

   c   impedance coupled amplifier

   d   direct coupled amplifier

5   Based on the frequency response

   a   audio frequency (AF) amplifier

   b   intermediate frequency (IF) amplifier

   c   radio frequency (RF) amplifier

   d   VHF and UHF amplifiers

6   Based on the feedback

   a   current series feedback amplifier

   b   current parallel feedback amplifier

   c   voltage series feedback amplifier

   d   voltage parallel feedback amplifier

7   Based on the biasing conditions

   a   Class A power amplifier

   b   Class B power amplifier

   c   Class AB power amplifier

   d   Class C power amplifier

Of the above mentioned, serial numbers one and two are explained at this state. Some of the amplifiers dealt in this book for detailed study the students can refer to any standard books for the remaining portions depending on their special interest.

Common-emitter amplifier: This type of circuit is by far the most frequently used. It has the greatest power gain, substantial current and voltage gains, and is specially advantageous in multistage application when a high gain is a primary requirement. A common-emitter amplifier stage with biasing from a single D.C supply battery is in Figure 8.

Fig 8

RESISTORS

R_1=22kΩ

R_2=5kΩ

R_L=3.3kΩ

R_e=0.5kΩ

CAPACITORS

C_1=10 µF

C_2=10 µF

C_3=200 µF
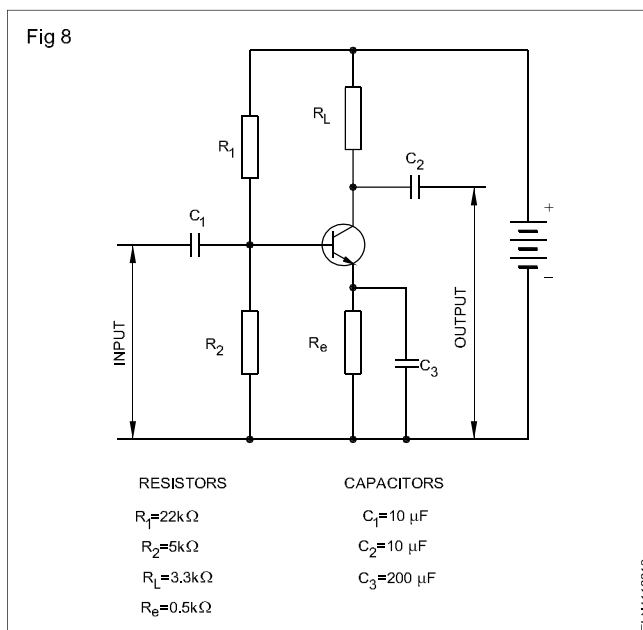
The A.C. signal is applied between the base and the emitter and the output is taken from the collector. For the transistor to operate, the emitter base junction must be forward-biased, the resistors R_1 and R_2 setting the base voltage so that the emitter is forward-biased. The collector current flows through the load resistors R_L and R_e and the voltage developed by R_L at the collector is the output.

The voltage gain of a transistor is largely determined by the value of this particular resistor since the voltage developed across it due to change in the collector current is far greater than that developed across the base resistor from the input signal.

Resistor R_e is included to minimise the effect of temperature changes in the collector current. To prevent R_e from reducing the signal gain by current feedback, a capacitor C_3 may be included in parallel with R_e.

The capacitors C_1 and C_2 are provided to prevent (block) the flow of direct current so that the D.C. bias conditions are in no ways affected by the signal circuit. In this way, the D.C. conditions at one stage are prevented from affecting the following stage, so that only D.C. signals are passed from one stage to the next one.

Common-collector amplifier : In this configuration, the collector is the common point for the input and output circuits, the input signal being applied between the base and collector and taken off between the emitter and collector, Fig 9. The notable feature is the large input impedance virtually equal to that of the parallel circuit of R_1 and R_2. The output resistance is, however, low and, hence it follows that the voltage gain is low, but a high current amplification can be obtained.

Fig 9
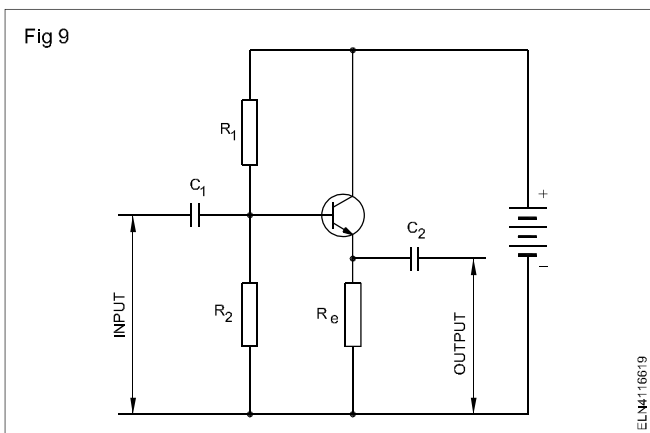
The functions of the capacitors C_1 and C_2 are the same as for the common-emitter stage, as the potential networks R_1 and R_2 which provide forward bias for the emitter-base junction. The main advantage of the common-collector circuit is the readiness with which it may be directly coupled to any point in a circuit regardless of voltage.

The circuit is often called the emitter-follower because the emitter voltage tends to follow the input voltage, the difference between the two being only the AC voltage across the base-emitter junction of the transistor which is quite small. Hence the output gain is less than 1.The current gain 50 to 500 is, however, high, being approximately equal to that of the common-emitter circuit. The output resistance is very low (less than 100 ohms) since the emitter-to-collector resistance is low and there is not resistance in the collector circuit.

The external resistance of the collector circuit, that is, the impedance presented by the transistor to the load is, however, very high (300 KΩ) and hence the emitter follower, circuit, transforms a very high input impedance into a low output impedance; it is in fact an impedance transformer. Hence its main application is as a buffer, i.e. an impedance matching device in which it can be connected between a high impedance source and a low impedance load without excessive loss of power due to mismatching or not suitable.

Common-base amplifier: In this circuit the base is the common terminal between the emitter terminal and the collector terminal. The emitter current I_e is the input current and the collector current I_c is the output current. (Fig 10) Since $I_e = I_b + I_c$ and since in this circuit Ie is greater than I_c, by the value of I_b, the current gain I_c/I_e will always be slightly less than one. Therefore, there can be no current gain in a common-base circuit. However, because of the low impedance of the forward-biased emitter-base junction and the high impedance of the reverse-biased collector-base junction a sizable voltage gain is obtained.

Fig 10
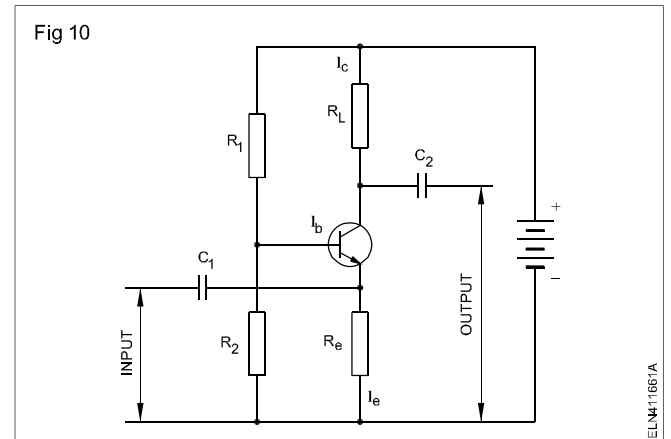
For instance, if we assume that input resistance of 200Ω, a load resistance of 50K and a current gain of 0.98, the voltage gain is 0.98 x 50k/200 = 245

The common-base circuit is not suitable for multi-stage amplification because its current and power gain are low when compared with the common-emitter. Also its low input impedance shunts the load resistance of any previous stage, thereby reducing the output voltage from that stage causing a corresponding fall in overall gain.

However, its ability to operate at high frequencies makes it useful in v.h.f. amplifiers. At such frequencies this circuit is more stable than the common-emitter amplifiers because of the very small capacitance linking input and output circuits (the emitter-collector capacitance).

Voltage amplifier: An amplifier is a circuit that incorporates one or more transistors and is designed to increase an alternating signal applied to the input terminals. It is called a voltage amplifier. If the size or magnitude of the output voltage is considerably greater than the input voltage, it is called the voltage gain of the amplifier.

The main function of a voltage amplifier is to produce a given gain with the minimum of distortion, i.e. the output voltages should have the same wave-form as the input wave-form, but should of course be much higher in magnitude. Examples for the voltage amplifier are the common base and the common emitter amplifiers.

Current amplifier: The function of the current amplifier is when the current injected in the base, load can influence to much greater current to flow in the emitter-collector circuit.

The remarkable result is that, if the base current is increased by a certain proportion, the base current in the collector current gives rise to a corresponding, but much larger changes in the collector current. We have achieved current amplification. The ratio of the output current to the input current is called the current gain of the amplifier.

An example for the current amplifier is the common-emitter, common-collector amplifier. The current gain of common-emitter amplifier is 50 to 300 and that of the common-collector amplifier is 50 to 500.

Power amplifier : Power amplifiers are used to drive the output mechanism, e.g. a loudspeaker, a pair of earphones, a moving coil meter or some other type of indicating device. The main function of a power amplifier is to deliver a good deal of undistorted power into the output device or load circuit. Examples for the power amplifiers are class A, class B, class AB and class C.

Fig 11 shows the complementary symmetry Class B push-pull power amplifier circuit. In a complementary pair of power amplifiers, one of them is an NPN type and the other a PNP type. With no input signal, neither transistor conducts and the output is zero. When the input signal is positive going, the NPN transistor T_1 conducts and the PNP transistor T_2 is cut off. When the signal is negative going, T_1 is tuned of while T_2 conductors. The maximum efficiency of this circuit is about 78%.

Fig 11
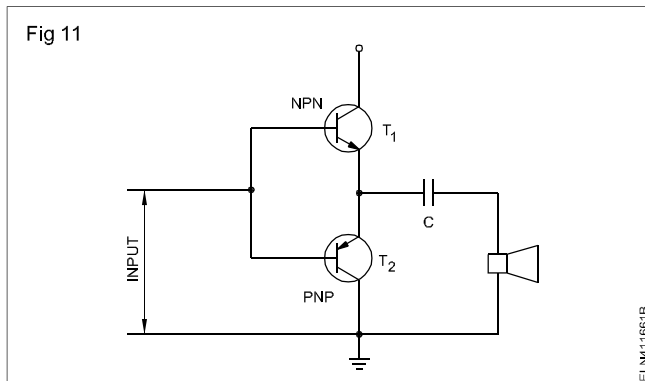
Function generator and cathode ray oscilloscope (CRO)

Objectives: At the end of this lesson you shall be able to
• **explain the use and control of function and AF (audio frequency) generator**
• **explain the function of CRO with block diagram**
• **state the functions of various controls in CRO**
• **state the use of CRO in electronic circuits.**

Introduction: A function generator is an equipment capable of providing sine, square and triangular wave outputs at different frequencies and amplitude. It has a maximum of 20 volts peak to peak single amplitude. A function generator finds applications in frequency modulations, tone control, Audio electronic, other laboratory and research work.

Panel controls and features of function generator

The front panel controls of function generator. (Fig 1)

Fig 1
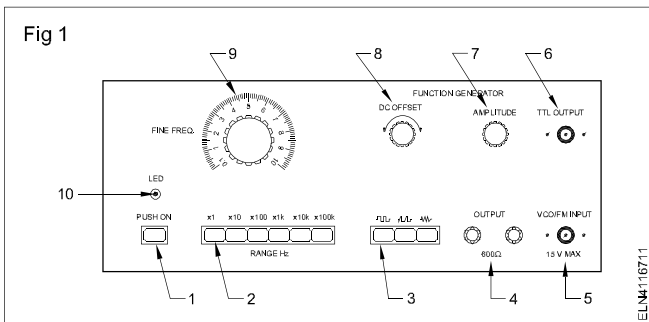
1 Power ON-OFF switch: To turn on the function generator this button should be depressed. To turn off the same button should be pressed to release.

2 Range selectors: The range selection is of decade frequency type. The output frequency is given by the product of range selected and frequency dial indication. For example if the 10 K range button in depressed and frequency dial is at 2, then the output frequency is 20 KHz.

3 Function selectors: These selectors select the desired output waveform. (square, sine or Triangle)

4 Output jack: The wave forms selected by the function switches are available at this jack.

5 VCO input jack: An external voltage (not exceeding ± 20V peak) input will vary the output frequency. The change in frequency is directly proportional to the input voltages.

6 TTL JACK: A TTL (Transistor, Transistor logic) square wave is available at this jack. This output is independent of the Amplitude.

7 Amplitude control: This controls the amplitudes of the output signal.

8 Offset control: This controls the DC offset of the output.

9 Fine frequency dial: The output frequency of the wave forms is given by the product of the setting of this dial and the range selected.

Operating information: The function generator is powered by 240V. AC mains. When the power ON switch is depressed the LED will glow.

The desired frequency is set by depressing the frequency range switch an positioning the fine frequency dial.

The desired wave from is selected by depressing the appropriate function button from sine, square or triangle.

The amplitude of the selected output signal is adjusted by Amplitude control knob. A variation of the display amplitude from 0-20 V peak is possible. The TTL output is not affected by the amplitude control.

Audio Frequency (AF) Generator (Fig 2): Audio frequency generators produce sine wave signals from 20 Hz to 20 kHZ. Certain type of AF generators produce sine wave upto 100 kHZ. In addition to sine wave there may be provision to produce square waves too.

Fig 2

AUDIO FREQUENCY GENERATOR
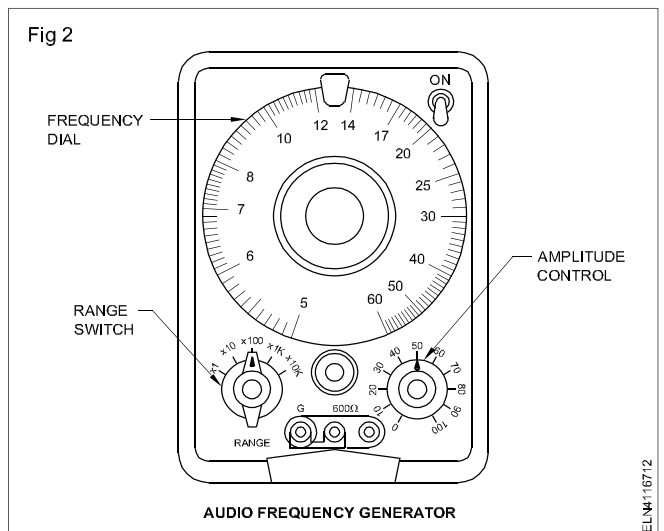
These generators contain a variable amplitude control which changes the signal amplitude from 10 mv to 20V. With the help of this generator the audio amplifier stages in radio, TV recorders and audio amplifier could be tested.

While the frequency range switch selects the desired frequency range switch selects the desired frequency range, the frequency dial is used to select the frequency within the desired range.

Cathode ray oscilloscope (CRO)

Introduction: The oscilloscope is an electronic measuring device which provides a visual presentation of any wave form applied to the input terminals. Cathode ray tube (CRT) like a television tube provides the visual display of the signal applied as a wave form on the front screen. An electron beam is deflected as it sweeps across the tube face, leaving a display of the input signal.

An oscilloscope usually consists of:

– Attenuator

– amplifiers

– saw-tooth generator

– gate amplifiers or Z-amplifier

– Trigger

– CRT (cathode ray tube)

– power supply

The block diagram of a simple cathode ray oscilloscope is shown in Fig 3.

Attenuator : The input signal should be attenuated to a suitable magnitude before it is applied to the amplifier. The attenuators are employed at the input of both vertical and horizontal amplifiers.
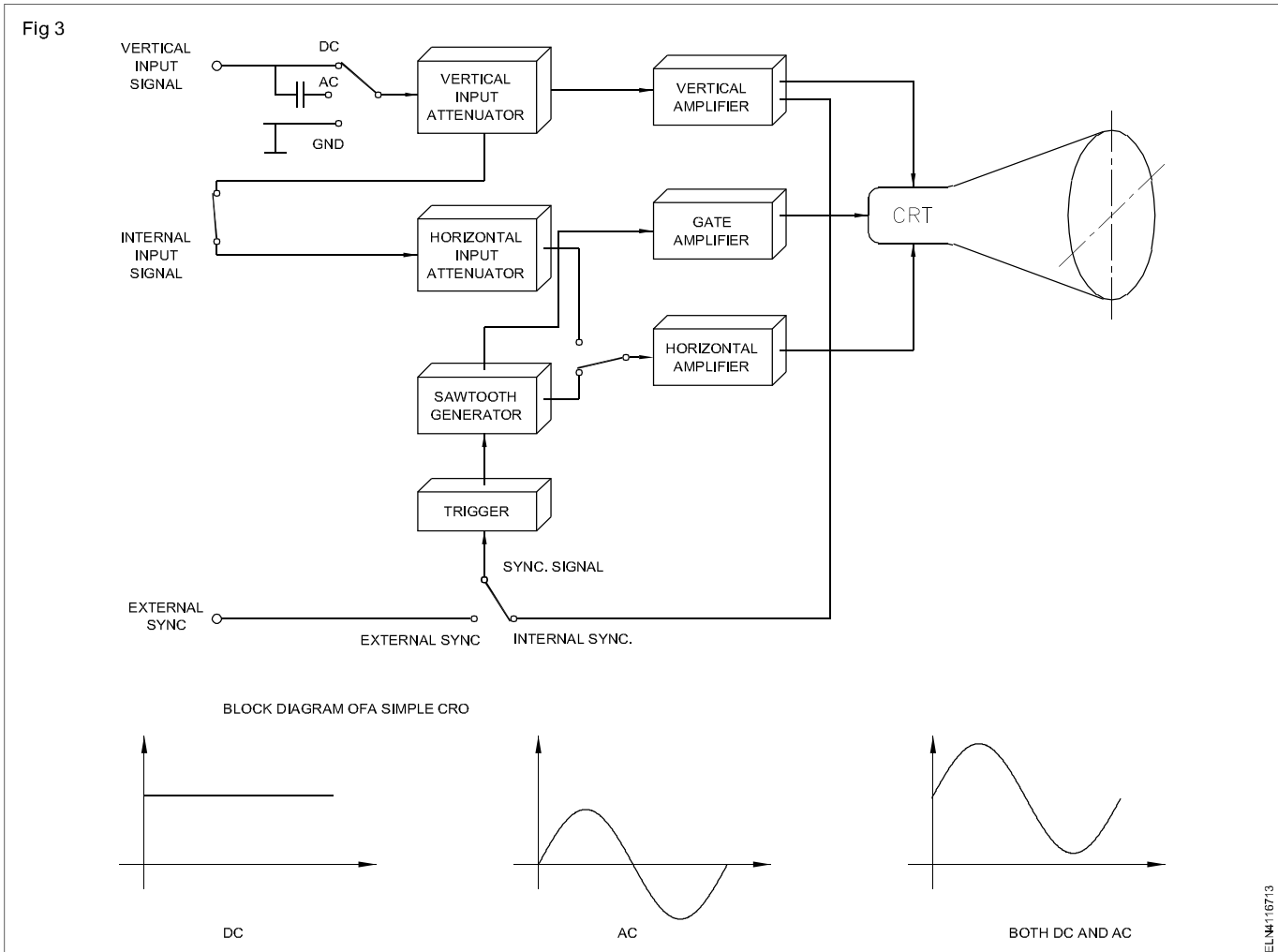
Amplifier : The amplifiers of an oscilloscope consist of a vertical amplifier and a horizontal amplifier. The vertical amplifiers amplify the vertical input signal before it is applied to the Y-plates. The horizontal amplifier amplifies the signal, before it is connected to the X-plates.

Saw-tooth generator: The measuring signal of any shape is connected to the Y-input(plates) and then it appears on the screen. The signal on X-plates should be such that the image on the screen is similar to that on the Y-plates. Hence a saw-tooth signal is required to be connected to the X-plates which makes the image on the screen like the signal connected at the vertical plate. The

saw-tooth signal is called the time base signal, and is produced by the saw-tooth generator. The shape of the saw-tooth signal is shown in Fig 4. The time-base signal consists of trace, retrace and hold off period.
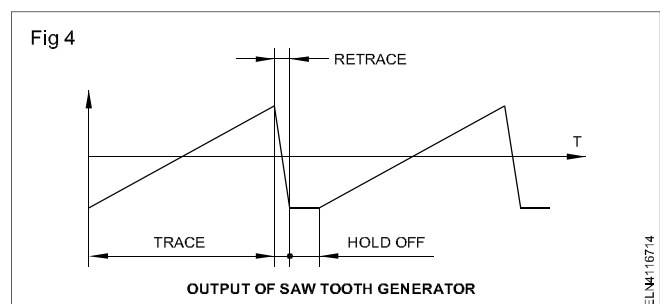
Gate amplifier or Z-amplifier: It is desirable that the image seen on the screen of the CRT must be continuous, that is, the electron beam is desired to appear only in the trace period of the time-base signal. The retrace period of the electron beam must not be visible on the screen. Therefore, the gate amplifier is required to control the electron beam in order that it appears only in the trace period.

The signal from the gate amplifier is a square wave and is related to the time-base signal. This is illustrated in Fig 5.

OUTPUT OF GATE AMPLIFIER
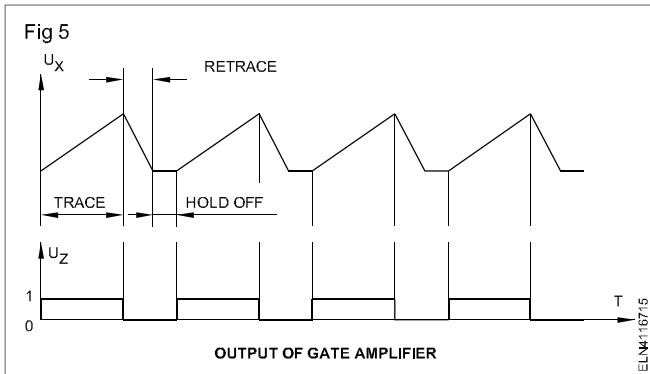
Trigger (Gate amplifier output) : As mentioned earlier, the measuring signal-wave form is connected to Y-input, which appears on the screen. In order to make the wave-form stationary on the screen, it is required that the starting point of the time base signal has to be fixed related to the signal connected to the Y-input. This is known s 'synchronization'. The functional stage which performs synchronization is the trigger.

The trigger will produce a pulse or impulse for triggering the time-base. Every time the time-base is triggered, one saw-tooth wave-form is produced.

There are three forms of triggering in an oscilloscope.

Internal triggering : The signal which is supplied to the trigger is the internal signal of the CRO produced by using the signal from the vertical input signal. The sequence of signal processing is shown in Fig 6.
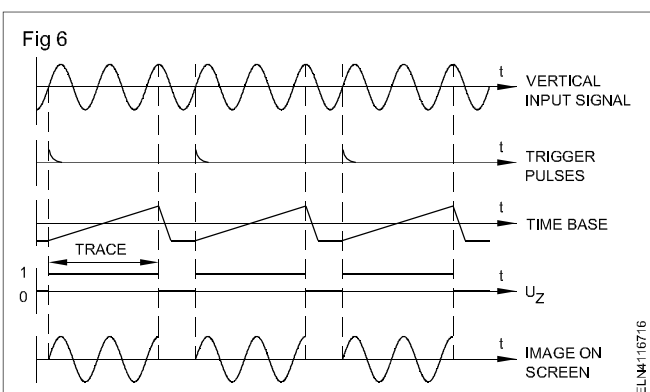
External triggering : The signal which is supplied to the trigger is the external signal, produced by using the signal from the external, sync.

Line triggering : The signal which is supplied to the trigger is the signal from the power supply of CRO. (Not shown in the block diagram)

Switches are provided to select the form of triggers as required. In a CRO, suitable timing can be selected that causes the image on the screen to be stationary.

CRO (The Cathode ray tube): The constructional features are explained later in this text.

Power supply: Low voltage and high voltage DC supplies which are required for the oscilloscope function are produced by rectifier filters and switch mode power supply circuits.

Controls and their functions in a CRO: The operating controls on the front panel of a general purpose oscilloscope is shown in Fig 7. The names of the controls and their functions are listed below.

CATHODE RAY OSCILLOSCOPE
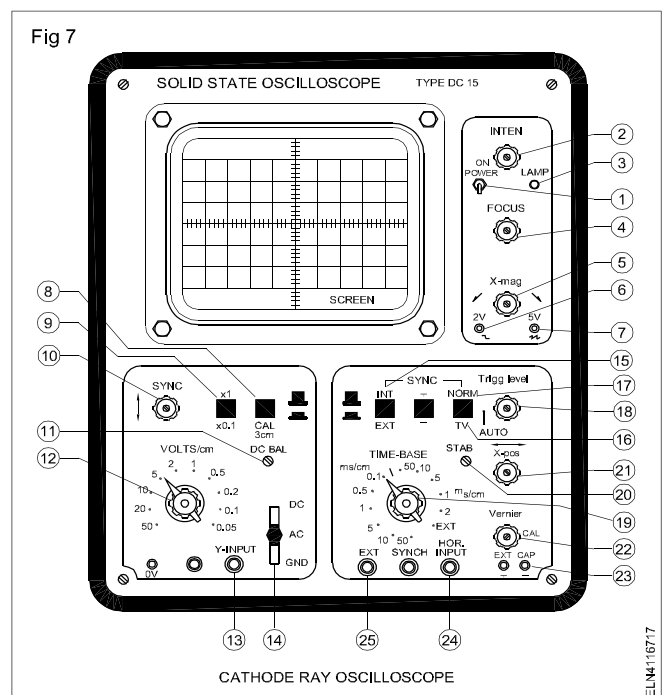
General

Power-on (1): It is toggle switch meant for switching on power. In the ON position, power is supplied to the instrument and the neon lamp (3) glows.

Intensity (2): It controls the trace intensity from zero to maximum.

It controls the sharpness of the trace. A slight readjustment of this control may be necessary after changing the intensity of the trace.

X-Magnification (5): It expands length of the time-based from 1 to 5 times continuously, and makes the maximum time-base to 40ns/cm.

Square wave (6): This provides a square wave of 2 V (p-p) amplitude to enable the user of the scope to check the Y-calibration of the scope.

Saw-tooth wave (7): This provides a saw-tooth, wave-form output coincident to the sweep-speed switch with an output of 5V (p-p). The load resistance should not be less than 10 k ohms.

Vertical section

Y (10) : This control enables the movement of the display along the y-axis.

Y (13) : It connects the input signal to the vertical amplifier through the AC-DC-GND coupling switch (14)

AC-DC-GND coupling switch (14): It selects coupling to the vertical amplifier, in DC mode, it directly couples the signal to the input; in AC mode, it couples the signal to the input through a 0.1 MF, 400-V capacitor. In GND position, the input to the attenuator (12) is grounded, whereas the Y-input is isolated.

Volts/cm (Attenuator) (12): It is a 10-position attenuator switch. It adjusts the sensitivity of the vertical amplifier from 50 m V/cm to 50 V/cm in 1,2,5,10 sequence. The attenuator accuracy is ±3%.

x1 or x 0.1 switch (9)

When switched in x 0.1 or position, it magnifies the basic sensitivity to 5 m V/cm from 50 m V/ cm

CAL switch (8): When pressed, a DC signal of 15 m V or 150 m V is applied to a vertical amplifier depending upon the position of x1-x0.1 switch (9) position.

DC bal (11): It is a preset control on the panel. It is adjusted for no movement of the trace when either x1 - x0.1 switch (9) is pressed, or the position of AC-DC-GND coupling switch (14) is changed.

X-Position (21): This control enables the movement of display along the X-axis.

Trigger level (18): It selects the mode of triggering. In AUTO position, the time-base line is displayed in the absence of the input signal. When the input signal is present, the display is automatically triggered. The span of the control enables the trigger point to be manually selected.

Time-base (19): This sector switch selects sweep speeds from 50 ms/cm to 0.2Ms/cm in 11 steps. The position marked EXT is used when an external signal to be applied to the horizontal input (24)

Vernier (22): This control is a fine adjustment associated with the time-based sweep-selector switch (19). It extends the range of sweep by a factor of 5. It should be turned fully clockwise to the CAL position for calibrated sweep speeds.

Sync. selector (15, 16, 17): The INT/EXT switch (15) selects internal or external trigger signal. The +ve or -ve

switch (16) selects whether the wave-form is to be triggered on +ve or -ve step. NORM/TV switch (17) permits normal or TV (line frequency) frame.

Stab (20): It is a preset control on the panel. It should be adjusted so that you just get the base line in the AUTO position of the trigger level control (18). In any other position of the trigger level control, you should not get the base line.

Ext. Cap (23): This pair of connectors enables the time-base range to be extended beyond 50 ms/cm by connecting a capacitor at these connectors.

Hor. input (24): In connects the external signal to the horizontal amplifier.

Ext. sync. (25): It connects the external signal to the trigger circuit for synchronization.

Application of CRO

AC voltage measurement: The screen of the cathode ray oscilloscope usually has a plastic gratitude overlay, marked in centimeter divisions. The vertical amplitude of any wave form indicates peak-to-peak voltage.

To measure unknown AC voltages the main supply AC should be isolated through a isolation transformer and the attenuator is set to 50 V/ div. The AC-DC switch is set to AC position (out). Voltage to be measured is connected to the input and common terminal. Set the time base switch to display several cycles of the wave form. Adjust the V/div switch to get a wave form at a convenient height such that the positive and negative peaks appears with-in the screen.

Measure the vertical amplitude (no. of divisions peak-to-peak) of the voltage on the screen. Now multiply the amplitude by the volts/div setting to find the peak-to-peak voltage value.

Example : Assume a vertical deflection of 6.4 divisions as in Fig 8 and a volt/div setting of 5 volts.

Fig 8
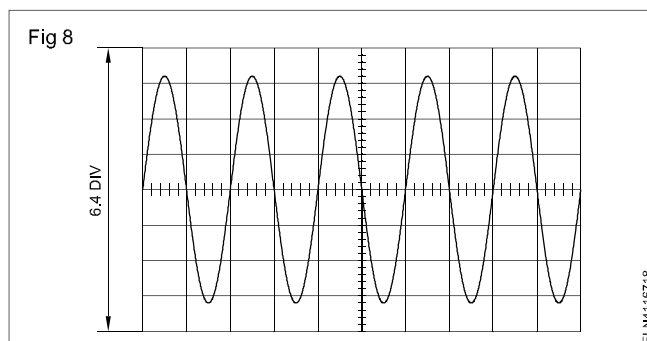
Peak-to-peak voltage	= 6.4 x 5 = 32 V
therefore peak voltage	= 16 V
therefore RMS voltage	= 16 x 0.707 = 11.31 V

or RMS voltage $= \dfrac{\text{Peak to peak voltage}}{2.83} = \dfrac{V_{PP}}{2 \times \sqrt{2}}$

$$= \dfrac{32}{2 \times \sqrt{2}} = 11.31v$$

DC voltage measurement : The input selector switch is set to DC position. Adjust the Y shift position to get the trace at the centre of the screen. This line represents zero DC volts. Connect the +ve of the DC voltage to be measured to input terminal and the -ve to the common terminal. Now the horizontal line will move up. (Down for reverse polarity) the volts/div switch is set as required.

Now measure the vertical distance in divisions form the zero reference line.

The DC voltage can be found by multiplying the vertical distance (division) with VOLT/DIV setting.

An example is worked out with reference to Fig 9

Fig 9

DC VOLTAGE MEASUREMENT

2.6 Div

ZERO
REFERENCE
LINE
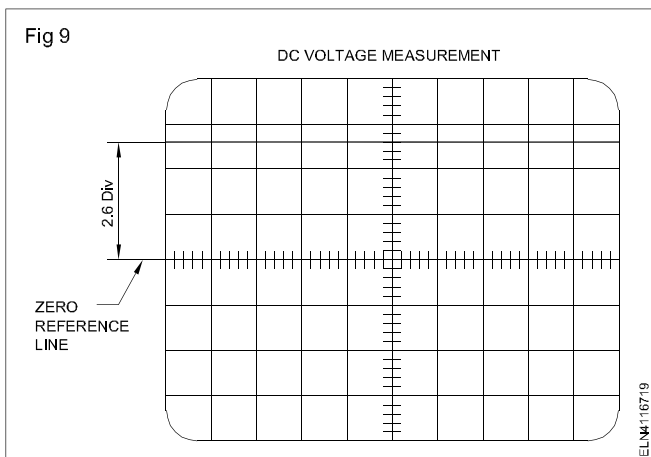
Assume a vertical deflection of 2.6 division and a Volts/Div setting of 20 V.

DC voltage = 2.6 x 20 = 52V.

Measurement of time and frequency : The wave-form to be measured is connected to the V input. The volts/Div switch is set to display a suitable vertical amplitude of the wave-form. The Time/Div switch is set to display

approximately two cycles of the wave-form to be measured. Adjust the Y-SHIFT control to move the trace so that the measurement points are on the horizontal centre line. The X-SHIFT control is adjusted to move the start of the measurement points to a convenient reference line.

The distance (divisions) between the points of one cycle is measured as in Fig 10.

Fig 10

PERIOD AND FREQENCY MEASUREMENT

5 DIV
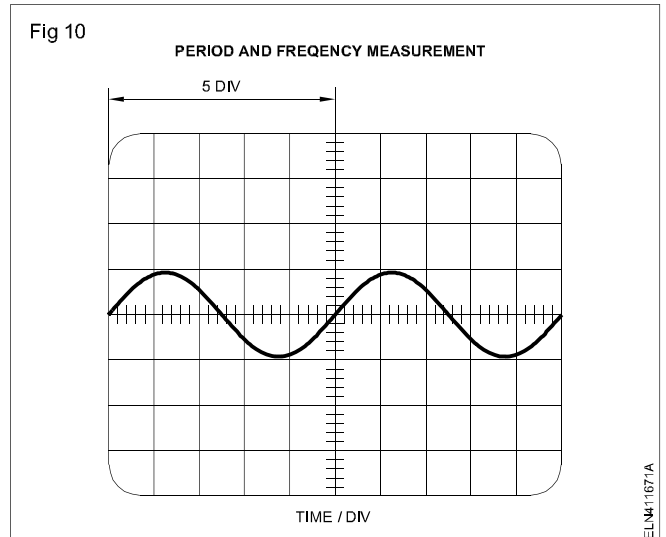
TIME / DIV

The product of the divisions of one cycle and the setting of time/div switch gives the period of one cycle.

The frequency can be determined by the formula

$$\text{Frequency} = \dfrac{1}{\text{Time period}}$$

where frequency is in hertz and time in seconds.

Example

Time   =   Div x time base setting

=   5 x 0.2 ms

=   1 ms

therefore frequency $= \dfrac{1}{T} = \dfrac{1}{1 \times 10^{-3}} = 1000 \, \text{Hz}$

Frequency   = 1 kHz.

Printed circuit boards (PCB)

Objectives : At the end of this lesson you shall be able to
• **state the types of etchants used for etching and preparation of etchant solution**
• **state the reasons for agitating the etchant solution while etching**
• **list the important points while drilling holes on PCBs**
• **list the advantages of marking component positions on PCBs.**

Introduction

Printed circuit board in which the connecting wires are replaced by a thin conducting path called copper or silver foil which is moulded in one side of the insulated board. The insulating board is generally made up of phonetic, paper or fibre glass or epoxy.

The moulded conducting path generally known as tracks size depend on the power of the circuit. The width of tracks are varied few millimeters to less than one millimeter depend on the circuit.

The thin tracks less than one millimeter made up with silver tracks where IC circuits and micro controller circuits are to be made. Several process moulded to make PCB and it is explained below.

Etching

Once the required portions on the copper foil side of the laminate is painted/masked and dried, the next step is to remove the copper present in the unmasked portions of the laminate. This process is known as etching.

Only after etching the unwanted areas of the copper foil, the metal side of the laminate gets the actual shape of the circuit connection required.

Etching is done using any one of the following chemicals;

– Alkaline ammonia

– Sulpuric-hydrogen peroxide

– Ferric chloride

– Cupric chloride

The most popular amongst beginners and economical way of etching, is the manual etching process. This is done generally using a solution of ferric chloride. Ferric chloride is available in liquid, powder and crystal forms.

While preparing the etching solution, concentrated ferric chloride solution/powder is mixed with lukewarm water(27°F) and stirred well using a glass rod. This forms a diluted acid ($FeCl_3$) solution.

The ratio of ferric chloride and water decides the rate of etching. The typical ratio is, 100mg of concentrated ferric chloride powder/liquid for one litre of water. This $FeCl_3$ is

prepared in a plastic tray of suitable size such that the painted laminate to be etched can be fully immersed as shown in Fig 1.

Fig 1
PAINTED PATTERN FACING UPSIDE
Fecl₃ SOLUTION
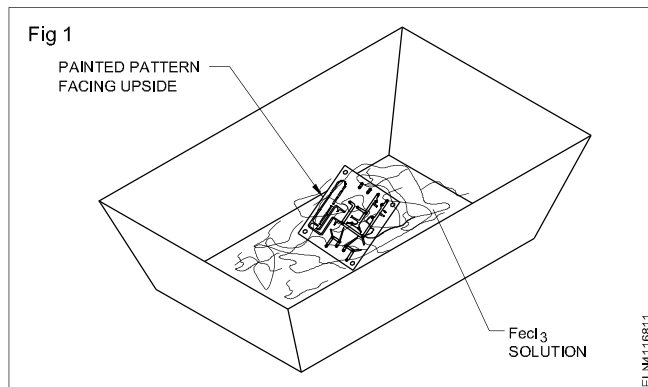
Since ferric chloride is an acid solution, although diluted, it is harmful to the skin. Hence, rubber gloves are to be used while working with this solution.

The painted laminate to be etched is slid into the $FeCl_3$ solution of required quantity, with the painted surface of the laminate facing the top as in Fig 1, such that, as the process of etching progresses, the extent of etching is visible.

To ensure speedy and uniform etching, the etchant solution is agitated lightly by shaking and tilting the tray as shown in Fig 2. Too much of agitation of the solution should be avoided, as this may peel off the ends of the painted tracks and remove those portions which were not intended to be etched.

Fig 2
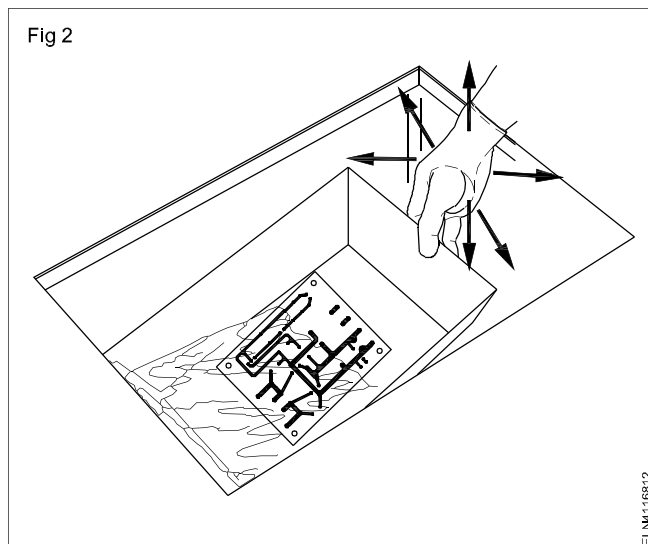
As the etching progresses, the copper in the unwanted portion is gradually removed. When the etching is complete, all the copper in the unwanted portion disappears and the etched portion will have the colour of the insulator of the laminate board.

Once the unwanted portions of copper are completely etched, the board is taken out of the solution and is cleaned using fresh water to remove the remaining $FeCl_3$ solution. This stops any further etching process.

After cleaning the board using water and drying, the etch-resistant ink/paint on the lay out pattern is removed using solvents, such as, thinner or petrol. The cleaned board will then have bright copper stripes and pads, only in the required portions representing the circuit as in Fig 3.

Fig 3
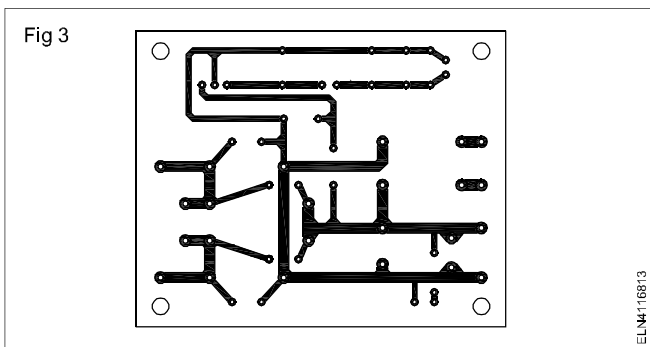
Drilling holes on PCBs

The next step after etching and removing the mask/paint is to drill holes of required diameter at the pad centers for inserting the components, input/output and V_{cc} &

ground(Gnd) connections. Extra care is to be taken while drilling holes because carelessness while drilling may peel off the pad area of the copper. Some hints for drilling on PCB's are given below;

– If the point where drilling is to be made is not clear, punch the point again such that the drill bit sits at the punched point before starting the drilling.

– Use a high speed drill gun/machine.

– Use drill bits of the required size. If an exact size drill bit is not available, use a drill bit one size smaller but never one size larger.

– Fix the PCB firmly on a vice using a wooden block so that the PCB does not become loose while drilling and peel of the pad area copper.

– Ensure that all the points required are drilled because, once the components are mounted, drilling holes on the PCB may damage the mounted components due to vibration.

After drilling holes, clean the PCB such that it is free from burr and dust. Apply varnish on the layout pattern, to protect the copper pattern from corrosion.

Preparing and marking component lay out

A typical component side of a PCB with the components marked on it is in Fig 4.

COMPONENT SIDE LAYOUT
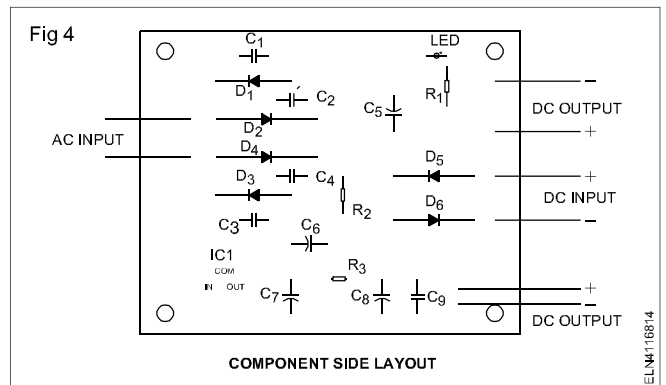
Marking the position of the components on the component side of the PCB has two main advantages,

– Increases the speed of mounting the components as the need of searching for the correct place for mounting the component is eliminated.

– Polarities of the components' terminals can be marked on the board itself such that the possibility of polarity errors committed while assembling the board is eliminated.

The standard procedure of component marking is to mark either the symbol of the component along with its code number or just the code number across the pads as shown in Fig 4.

A separate component list sheet, containing the component code number along with its value as shown below, is prepared for reference while collecting the components and assembling the PCB.

Component	Code	Specification
Resistors	R1 R2,R3	1K Ohms,1W, 5% 680 Ohms,1/4W,10%
Capacitors	C1 C2 to C7	1000uF, 50V, axial 0.01uF, 100V, ceramic disc
Diodes	D1,D2, D3,D4	1N4007

For circuits using less number of components, instead of a separate component list the component values are marked directly on the printed circuit board as in Fig 5.

To prepare manually the component side layout of the PCB, the reverse of the pad positions of the PCB's solder side lay out is traced on to a graph sheet, and the component positions and polarities indicated using standard symbols. The components are numbered and a component list is prepared.

Fig 5
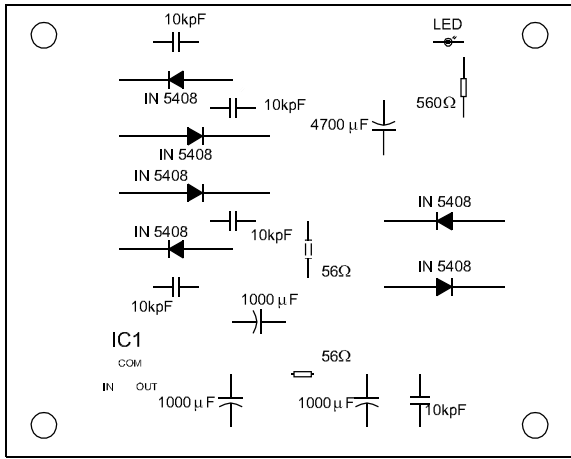
COMPONENT SIDE LAYOUT

ELN4116815

The component side layout is then traced on to the insulator side (component side) PC board using a carbon sheet and pencil. The traced portions on the board are redrawn/touched using a permanent marker pen or using paint and a thin brush.

Power electronic devices - UJT and FET

Objectives: At the end of this lesson you shall be able to
• **state the construction and working characteristics of SCR and its testing**
• **state the use of UJT for triggering gate circuits**
• **explain the function of DIAC and TRIC**
• **state the FET principle working, biasing, applications**
• **state the JFET principle, biasing, application as an amplifiers.**

Introduction

Thyristors are four layer device which can be switched 'ON' or 'OFF' electronically to control relatively large amounts of current for motors and other electrical equipment. The Silicon Controlled Rectifier (SCR) and the Triac are examples of Thyristor. Almost all electronic controls used in modern industries consist of electronic circuits with Thyristors.

Construction of SCR: The cross-sectional view of a typical SCR and the symbol are shown in Fig 1. Basically, the SCR consists of a four-layer pellet of P and N type semiconductor materials. Silicon is used as the intrinsic semiconductor to which the proper impurities are added.

Fig 1

a) CONSTRUCTION

b) SYMBOL

SILICON CONTROLLED RECTIFIER
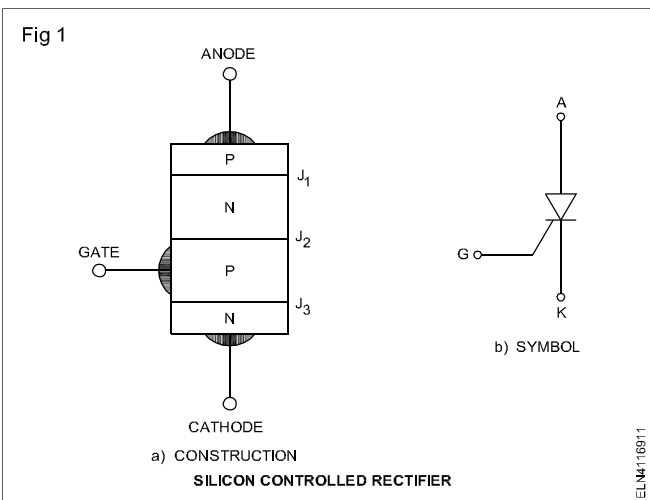
Working of SCR: The SCR is a four-layer device with three terminals, namely, the anode, the cathode, and the gate. When the anode is made positive with respect to the cathode (Fig 1), junction J_2 is reverse-biased and only the leakage current will flow through the device.

The SCR is then said to be in the forward blocking state or off-state. When the anode-to-cathode voltage is increased, the reverse-biased junction J_2 will break down due to the large voltage gradient across the depletion layers. This is the avalanche breakdown. Since the other junctions J_1 and J_3 are forward-biased, there will be free carrier movement across all the three junctions, resulting in a large anode-to-cathode forward current I_F. The voltage drop V_F across the device will be the ohmic drop in the four layers, and the device is then said to be in the conduction state or on-state.

In the ON-state, the current is limited by the external impedance. If the anode-to cathode voltage is now reduced, since the original depletion layer and the reverse-biased junction J_2 no longer exist due to the free movement of the carriers, the device will continue to stay ON. When the forward current falls below the level of the holding current I_h, the depletion region will begin to develop around J_2 due to the reduced number of carriers, and the device will go to the blocking state. Similarly, when the SCR is switched on, the resulting forward current has to be more than the latching current I_L.

This is necessary for maintaining the required amount of carrier flow across the junctions; otherwise, the device will return to the blocking state as soon as the anode-to-cathode voltage is reduced. The holding current is usually lower than, but very close to the latching current; its magnitude is in the order of a few milliampere(mA). When the cathode is made positive with respect to the anode, junctions J_1 and J_3 are reverse-biased, and a small reverse leakage current will flow through the SCR. This is the reverse blocking state of the device.

When the SCR is reversed biased the device will behave in the same manner as two diodes connected in series with the reverse voltage applied across them. The inner two regions of the SCR will be lightly doped as compared to the outer layers.

Hence, the thickness of the J_2 depletion layer during the forward-bias condition will be greater than the total thickness of the two depletion layers at J_1 and J_3 when the device is reverse-biased. Therefore, the forward break-over voltage V_{BO} will be generally higher than the reverse break-over voltage V_{BR}.

SCR has two stable and reversible operating states. The change over from off-state to on-state, called turn-on, is achieved by increasing the forward voltage beyond V_{BO}. There reverse transition, termed turn-off, is made by reducing the forward current below I_h. A more convenient and useful method of turning on the device employs the gate drive.

55

Characteristics of SCR

SCR voltage current characteristic: Fig 2 shows the voltage current characteristic of an SCR whose gate is not connected(open). When the anode-cathode circuit is reverse biased a very small current in micro ampere called reverse blocking current flows through the SCR. When the reverse break over voltage reaches a value equivalent to peak reverse voltage V_{BR}, the SCR conducts due to reverse avalanche breakdown and the current increases sharply into ampere.

In most of the cases the SCR gets damaged in this mode. The behaviour of the SCR at reverse bias mode is shown by VI characteristic of Fig 2.

When the SCR is forward biased, there is small forward leakage current (as in Fig 2) called forward blocking current which remains small, until the forward breakdown voltage V_{BO} is reached. This is the forward avalanche region.

Fig 2
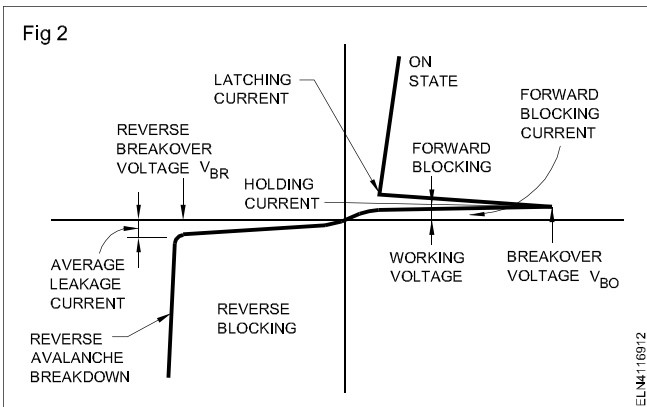
At that point current increases suddenly to higher conduction level. At this point the anode to cathode resistance of the SCR becomes very small and the SCR acts like a closed switch. The voltage across the SCR drops to about 1.4V. Hence we can say that in forward bias mode when the applied voltage is less than B_{FO} the SCR behaves as open switch and when the applied voltage exceeds B_{FO} the SCR behaves as closed switch. The current through SCR is limited by the external load resistance.

Holding and latching currents: The holding current is the +I value necessary in the anode circuit to keep the SCR in conduction while it is ON. The latching current is +I value needed to switch the SCR anode circuit ON from the OFF condition. This I (current) is typically about three times more than the holding current. When the SCR is switched into conduction, the gate voltage must be on long enough for the anode current to reach the value for latching.

Triggering of SCR: SCR can be switched into conduction either by increasing the forward voltage beyond V_{BO} or by applying a positive gate signal when the device is forward-biased. Of these two methods, the latter, called the gate-

control method, is used as it is more efficient and easy to implement for power control.

Gate-current control: Injecting gate current into the SCR lower the break over voltage, as shown in Fig 3. Here I_{GO} is for zero gate current. This situation is the same as that shown in Fig 2, but the other examples in Fig 3 are for increasing gate current. Note that, as gate current is increased, the break over voltage is reduced.

Fig 3

EFFECT OF GATE CURRENT IN LOWERING THE BREAKOVER VOLTAGE OF AN SCR
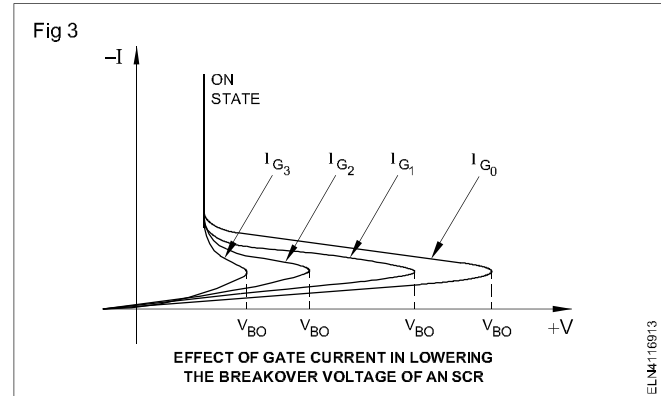
When there is enough gate current, the break over voltage becomes lower than the operating voltage or the forward blocking voltage of the SCR. That is how the SCR is used. The injection of gate current lower the break over voltage to a value below that of the applied voltage, thereby turning the SCR on.

Note that the 'ON' state is the same for all different values of gate current in Fig 3. The gate current triggers the SCR 'on'; but when the SCR conducts the amount of forward current is determined by the anode circuit impedance.

Applications: The following are the major applications of SCR

– Power control

– Over voltage protection

– Time delay circuit

– Soft start circuit

– Logic and digital circuits

– Pulse circuits references

– Phase control in AC power control

– full-wave control circuit

– Speed control of motors

– Regulated DC power supplies

– DC motor control

Testing of SCR by multimeter

SCR can be tested in the multimeter in the following sequence.

Set the multimeter to a low range. Adjust to zero and infinity with the adjustment knob. Connect the SCR as shown in Fig 4. The meter will not indicate any reading. Even the test prods are interchanged because of the junctions. The multimeter shows infinite resistance. Connect the SCR as in Fig 4. When the gate is touched momentarily with the anode prods, the meter reads low resistance between 30 and 40 ohm. When the gate is removed, the meter still continues to read the same value of 30 and 40 ohm.

Fig 4

1. ANODE CONNECTS TO POSITIVE OF OHMMETER

Ohms

2. GATE MOMENTARILY CONNECTED TO ANODE

3. OHMMETER READING DROPS TO LOW RESISTANCE
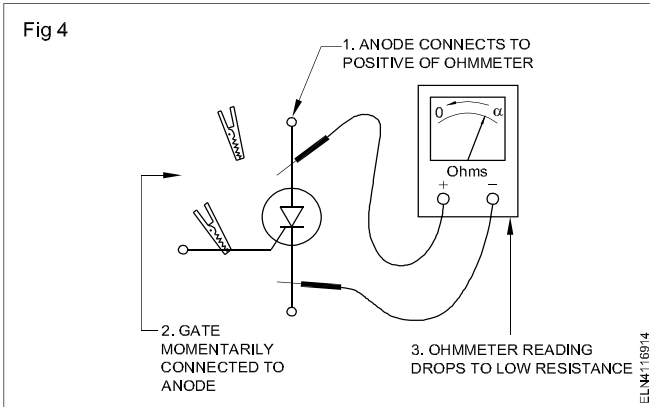
This means that the SCR is in good working condition. If the meter does not show any reading, the SCR is faulty. When the gate is given a small forward bias, the gate switching the SCR and the internal resistance of the junction is low, so the current can flow easily from the cathode to the anode. Once the SCR is conducted, even if the gate's forward bias is removed, the SCR anode-to-cathode current will flow through the meter, and the multimeter will continue to read a low resistance, ie 30 to 40ohm.

The DIAC and TRIAC

Like UJTs, DIAC is a semi-conductor device used extensively as a trigger device for triacs and thyristors gate circuit. In its most elementary form, DIAC is a three layer device as in Fig 5 without gate terminal.

Fig 5

ANODE 1

SILICON PELLET

OR

ANODE 2

ANODE 1

ANODE 2

a) BASIC CONSTRUCTION OF DIAC   b) COMMON SYMBOLS USED FOR DIAC
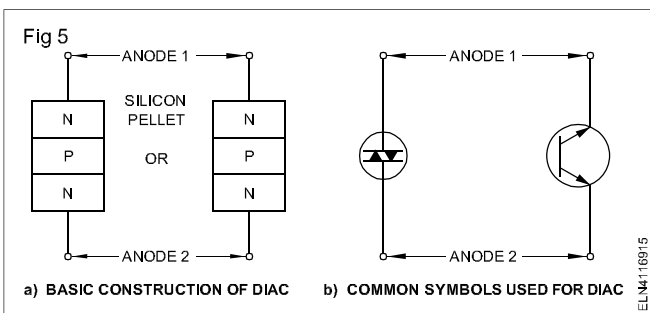
As can be seen from Fig 5, DIAC is a three layer, two terminal semi-conductor device capable of conducting current in both directions.

DIACs resembles an NPN or PNP bipolar transistor with no base connection. Unlike bipolar transistor, the diac possess uniform construction. This means, N-type and P-type doping is essentially the same at both junctions. As in Fig 5, diac may be constructed as either an NPN or PNP structure.

Fig 6a shows the experimental setup for testing the diac. The isolation transformer is used to isolate the circuit from the supply mains. The variable transformer is used to apply the variable voltage to diac under test. The characteristic curve of a typical diac is shown in Fig 6b.

Fig 6

(a) ISOLATION TRANSFORMER   VARIABLE AC TRANSFORMER

240V 50Hz

DIAC V_{DIAC}

R_1 2K

(b)

$+I_A$ ANODE 1

V

$-I_A$ ANODE 2

BREAKOVER VOLTAGE TYPICALLY 20 TO 40V

BREAKOVER CURRENT TYPICALLY 50 TO 200 µA

RATED REVERSE CURRENT I_F TYPICALLY 180mA AT 1.0V

3RD QUADRANT

$+I_A$

1ST QUADRANT

RATED FORWARD CURRENT I_F TYPICALLY 180mA AT 1.0V

BREAKOVER CURRENT TYPICALLY 15 TO 200 µA

BREAKOVER VOLTAGE TYPICALLY 20 TO 40V

$-I_A$

CHARACTERISTIC OF DIAC

As shown in the experimental setup at Fig 6a, when a small voltage of either polarity is applied across a DIAC, the current flow is very small as can be seen from its characteristics in the first and the third quadrants. If the applied voltage is steadily increased, the current will remain at a low value until the applied voltage reaches a value known as the breakover voltage of the DIAC as in Fig 6b.

Once this point is reached the diac current increases rapidly and the diac voltage falls to a low value. At this point, the diac exhibits negative resistance characteristics (current conduction increases while the voltage across the device decreases). The diac will continue to conduct current as long as the current is greater than the holding current of the device.

A diac acts in a similar manner to two zener diodes that are connected in reverse parallel and it therefore it is able to rectify AC voltage during both half cycles. The symbol used for DIAC is in Fig 5b.

Application of DIAC: DIAC can be used to trigger triac or SCR at specified voltage levels.

DIAC testing: DIACs are similar to two diodes connected back to back and break down in either direction once the applied voltage reaches the breakdown voltage of the

diode. While testing a diac using a ohmmeter, it should show high resistance (infinite resistance) when checked in either direction. The quick test only confirms that the DIAC is not shorted; however this quick test is worth carrying out before using the Diac in a circuit.

TRIAC

TRIAC is a three terminal gated semi-conductor device for controlling AC in either direction. The term TRIAC stands for TRIODE AC semi-conductor. TRIAC is very similar to that of two SCR connected in reverse parallel. A Triac is able to conduct a large current in both directions, being trigged ON in one direction or the other by a gate pulse of the appropriate polarity.

UJT and its applications of triggering circuits

UJTs are employed in a wide variety of circuits involving electronic switching and voltage or current sensing applications. These include

– triggers for thyristors

– as oscillators

– as pulse and sawtooth generators

– timing circuits

– regulated power supplies

– bistable circuits and so on.

Let us analyse the waveform generated across the capacitor and R_1 with respect to the relaxation oscillator or free running oscillator as in Fig 7.

Fig 7

UJT AS RELAXATION OSCILLATOR
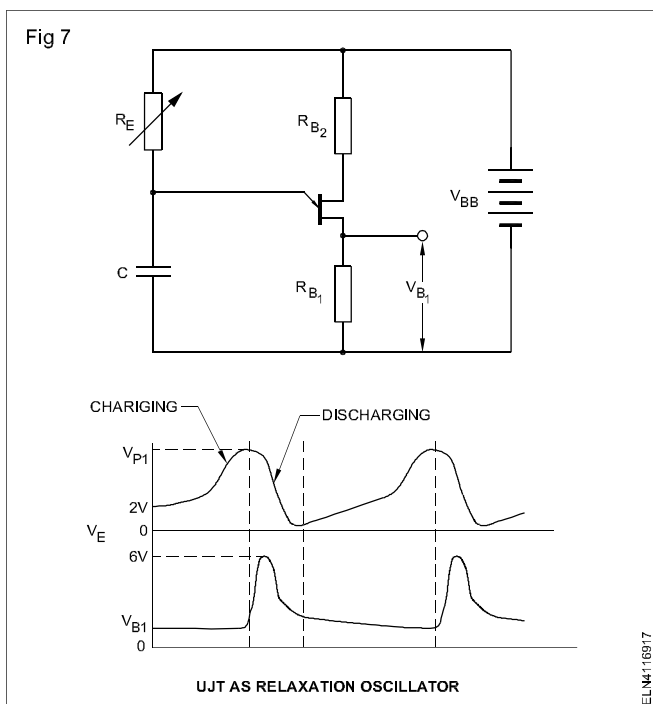
The negative - resistance portion of the UJT characteristic is used in the circuit shown in Fig 7 to develop a relaxation oscillator.

The wave form developed across the capacitor is shown in Fig 7 as V_E, whereas the waveform produced across the resistor R_{B1} is shown as a pulse V_{B1}.

The frequency of oscillation

$$f = \frac{1}{R_E C}$$

Where R_E is the value of variable resistor in ohms and C is the value of the capacitor in farad.

By varying the value of R_E, the frequency of the oscillator can be varied. Although such an oscillator using a DC supply voltage could be used to trigger a SCR, there would be trouble in synchronizing the pulses with the cycles of alternating current. Fig 8 shows a stable triggering circuit for an SCR in which the firing angle can be varied from 0° to 180°.

Fig 8

UJT RELAXATION OSCILLATOR USED FOR TRIGGERING THE SCR
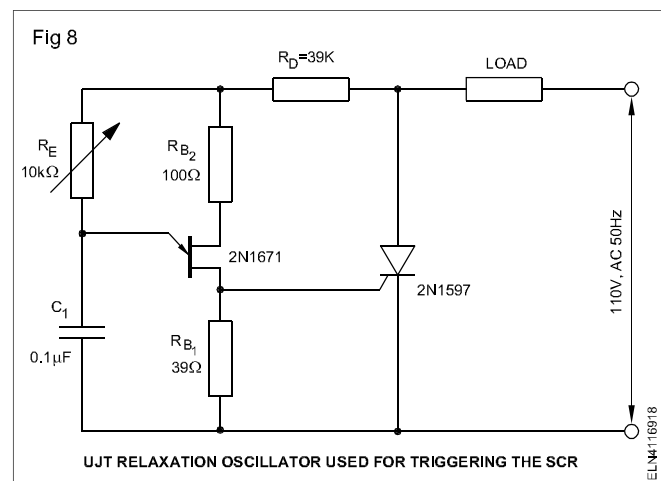
The low output impedance of the UJT (39 ohms) is ideal for driving the SCR, which has a relatively low input impedance from gate to cathode.

Resistor R_D is used as a dropping resistor to restrict the peak voltage across the UJT to within its specifications.

By varying the variable resistor R_E the oscillator frequency can be varied thereby the frequency of trigger pulses which are used to trigger the SCR. Time used for delay in switching the SCR could be measured through a stop watch from the time of switching on.

Basic construction of a Triac, its symbol and a typical Triac is shown in Fig 9a, 9b and 9c. As can be noticed in Fig 9, the electrodes of a Triac are labelled as,

– Main terminal-1 (MT_1)

– Main terminal-2 (MT_2) and

– Gate (G)

The terminals are so labelled because, this device operated in both directions and hence the terms anode and cathode does not apply.

Fig 9

(a)

MAIN TERMINAL 2 (MT$_2$) BONDED CONTACT AND HEAT SINK

N P

SILICON PELLET N

P

N N

GATE (G)

MAIN TERMINAL 1 (MT$_1$)

(b)

(c)

MT2

GATE

MT1

CONSTRUCTION AND SYMBOL OF TRIAC

ELN4116919
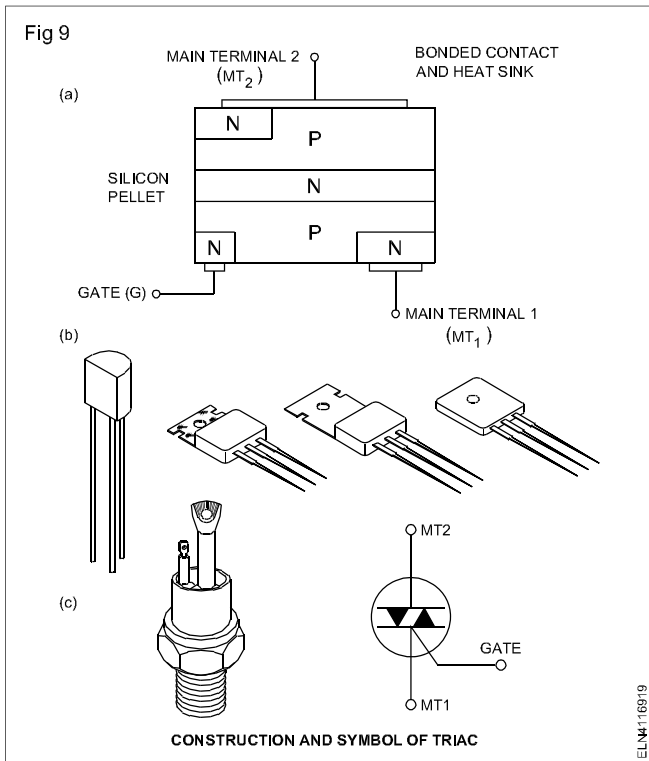
TRIAC triggering : Triac can be triggered/turned-ON by,

1 applying a gate current,

2 applying a voltage exceeding the avalanche breakdown voltage V$_{BO}$

3 allowing the MT$_1$ - MT$_2$ applied voltage to increase at a rate in excess of the maximum dv/dt figure.

Methods 2 and 3 above are not employed in normal Triac operation but they may be considered as limiting factors in circuit design. Hence, in all further discussion it is restricted to triggering the Triac via the gate. Since Triac is a bidirectional device, it can be triggered into conduction by a negative or a positive gate signal. Triacs potentials are considered with respect to main terminal - 1 (MT$_1$). This gives the following possible operating situations or modes;

– MT$_2$ +ve with respect to MT$_1$ - Gate signal +ve (1st quadrant +)

– MT$_2$ +ve with respect to MT$_1$ - Gate signal –ve (1st quadrant –)

– MT$_2$ –ve with respect of MT$_1$ - Gate signal +ve +(3rd quadrant +)

– MT$_2$ –ve with respect to MT$_1$ - Gate signal –ve (3rd quadrant –)

Unfortunately, Triac is not equally sensitive in all the above said modes. It is least sensitive in 3rd quadrant mode (MT$_2$ negative with respect of MT$_1$ and triggered by a +ve gate signal) so this mode is very rarely used in practice. When a Triac is ON the current flowing between MT$_1$ and MT$_2$ is known as principal current. The TRIAC will remain ON as long as the current flowing through it is larger than the holding current as in the static characteristics of a Triac in Fig 10.

Fig 10

FORWARD CURRENT

2nd QUADRANT

+MT$_2$ G –MT$_1$ +

+MT$_2$ G –MT$_1$ –

1st QUADRANT

LATCHING CURRENT
HOLDING CURRENT

I$_G$ = 4mA
I$_G$ = 0mA

REVERSE VOLTAGE

V$_{80}$

V$_{80}$

FORWARD VOLTAGE

HOLDING CURRENT
LATCHING CURRENT

I$_G$ = 4mA

I$_G$ = 0mA

3rd QUADRANT

4th QUADRANT

–MT$_2$ G +MT$_1$ –

–MT$_2$ G +MT$_1$ +

REVERSE CURRENT

CHARACTERISTIC OF TRIAC

ELN411691A
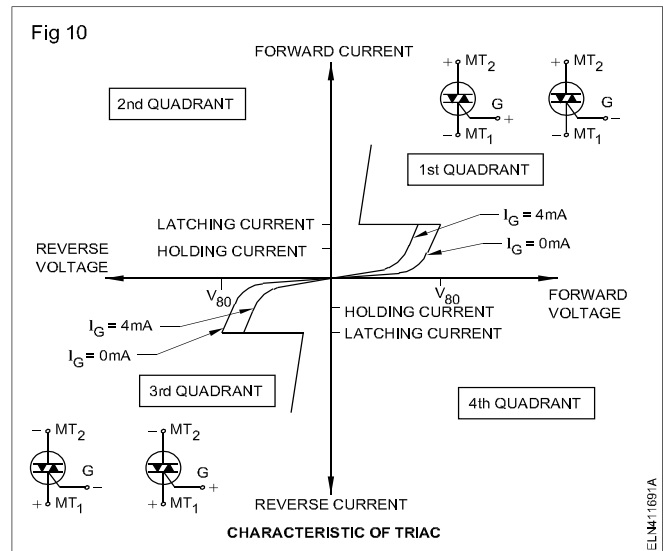
From the Triac static characteristics. When MT$_2$ is positive with respect to MT$_1$, the (Fig 6) Triac operates in the first quadrant of its static characteristics, if it is not triggered, the small forward current increases slowly with increase in voltage until the breakdown voltage V$_{BO}$ is reached and then the current increases rapidly. The device can be, and usually is, turned 'ON' at a smaller forward current by injecting a suitable gate current and the characteristics shows the effect of increasing the gate current from zero to 4mA.

The gate current must be maintained until the main current is atleast equal to the latching current. When terminal MT$_1$ is positive with respect to MT$_2$ the Triac operates in the third quadrant and the current flows in the opposite direction.

Full wave control using a TRIAC: Fig 11a shows a Triac used for controlling the current flowing in an AC circuit. Fig 11b shows the wave forms with different settings of POT V$_{R1}$.

Fig 11

R$_1$

VR$_1$

R$_G$ G

C

LOAD V$_L$

MT$_1$

MT$_2$

a) SIMPLE TRIAC CONTROL CIRCUIT

SUPPLY VOLTAGE

LOW SETTING OF V$_{R1}$

V$_L$
I$_L$
on off on off on

MID SETTING OF V$_{R1}$

MAX SETTING OF V$_{R1}$

b) TRIAC CONTROL WAVEFORMS

ELN411691B
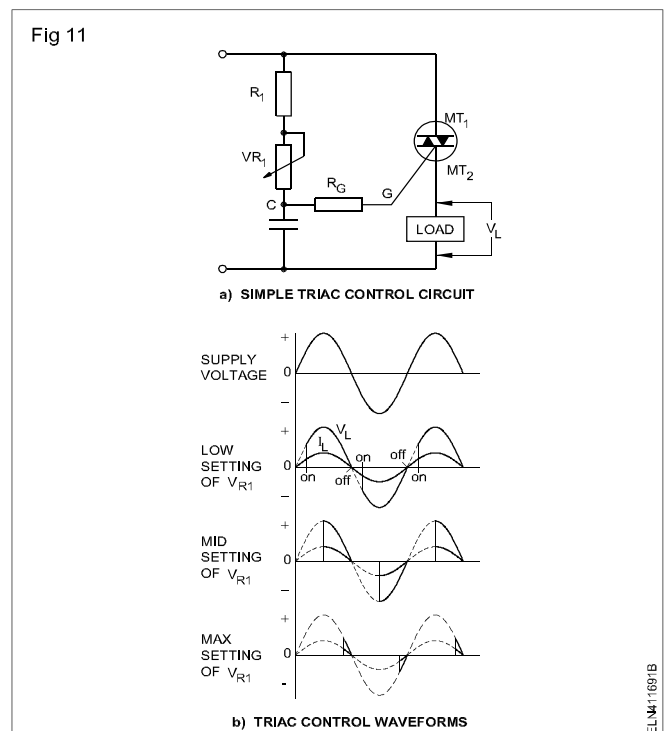
Note: In Triac the terms forward and reverse do not arise since it is bidirectional.

Quick testing TRIAC: A quick test can be carried out on triac using an ohmmeter. If the readings taken are comparable to the one shown in table below, the Triac can be considered as satisfactory and can be used in circuit;

Meter polarities +	Resistance
MT_2	$MT_1 > 1M$
MT_1	$MT_2 > 1M$
MT_2	$G > 1M$
G	$MT_2 > 1M$
MT_1	$G > 300\Omega$
G	$MT_1 > 300\Omega$

Field-effect transistor (FET)

The main difference between a Bi-polar transistor and a field effect transistor is that,

Bi-polar transistor is a current controlled device

In simple terms, this means that the main current in a bi-polar transistor (collector current) is controlled by the base current.

Filed effect transistor is a voltage controlled device

This means that the voltage at the gate(similar to base of a bi-polar transistor) controls the main current.

In addition to the above, in a bi-polar trasistor (NPN or PNP), the main current always flows through N-doped and P-doped semiconductor materials. Whereas, in a Field effect transistor the main current flows either only through the N-doped semiconductor or only through the P-doped semiconductor as in Fig 12.

Fig 12
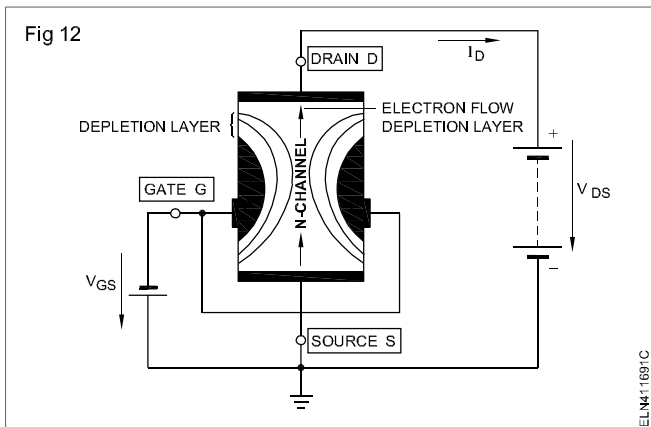
If the main current flow is only through the N-doped material, then such a FET is referred as a N-channel or N-type FET. The current through the N-doped material in the N-type FET is only by electrons.

If the main current flow is only through the P-doped material, then such a FET is referred as a P-channel or P-type FET. The current through the P-doped material in the P-type FET is only by Holes.

Unlike in bipolar transistors in which the main current is both by electrons and holes, in contrast in FETs depending on the type(P or N type) the main current is either by electrons or by holes and never both. For this reason FETs are also known as Unipolar transistors or Unipolar device.

There are a wide variety of FETs. In this lesson one of the fundamental types called as Junction Field Effect Trasistor (JFET) is discussed.

Junction Field effect Transistor(JFET)

It is a three terminal device and looks similar to a bi-polar transistor. The standard circuit symbols of N-channel and P-channel type FETs are shown in Fig 13.

Fig 13
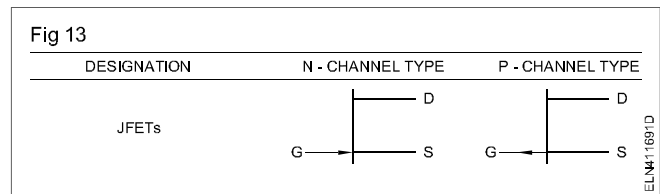
The internal diagram of a N-channel FET is shown in Fig 14.

Fig 14
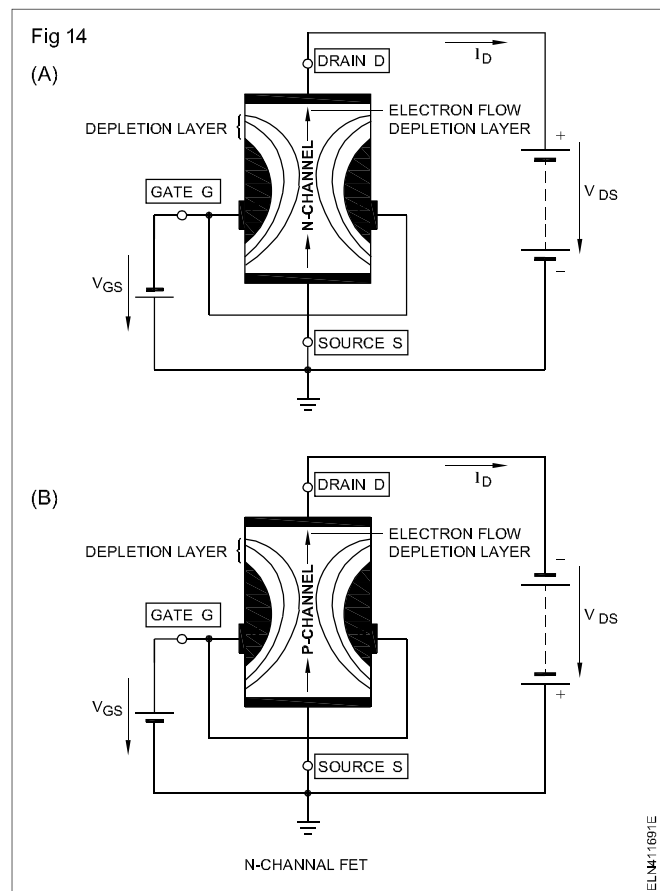
FET notation listed below are essential and worth memorizing,

1 **Source terminal:** It is the terminal through which majority carriers enter the bar(N or P bar depending upon the type of FET).

2 **Drain terminal:** It is the terminal through which majority carriers come out of the bar.

3 **Gate terminal:** These are two internally connected heavily doped regions which form two P-N junctions.

4 **Channel:** It is the space between the two gates through which majority carriers pass from source to drain when FET is working(on).

Working of FET

Similar to Biploar transistors, the working point of adjustment and stabilization are also required for FETs.

Biasing a JFET

– Gates are always reverse biased. Therefore the gate current I_G is practically zero.

– The source terminal is always connected to that end of the supply which provides the necessary charge carriers. For instance, in an N-channel JFET source terminal S is connected to the negative of the DC power supply. And, the posive of the DC power supply is connected to the drain terminal of the JFET.

Whereas in a P channel JFET, Source is connected to the positive end of the power supply and the drain is connected to the negative end of the power supply for the drain to get the holes from the P-channel where the holes are the charge carriers.

Let us now consider an N channel JFET, the drain is made positive with respect to source by voltage V_{DS} as shown in Fig 15a. When gate to source voltage V_{GS} is zero, there is no control voltage and maximum electron current flows from source(S) - through the channel - to the drain(D). This electron current from source to drain is referred to as Drain current, I_D.

When gate is reverse biased with a negative voltage(V_{GS} negative) as shown in Fig 15b, the static field established at the gate causes depletion region to occur in the channel as shown in Fig 15b.

This depletion region decreases the width of the channel causing the drain current to decrease.

If V_{GS} is made more and more negative, the channel width decreases further resulting in further decrease in drain current. When the negative gate voltage is sufficiently high, the two depletion layers meet and block the channel
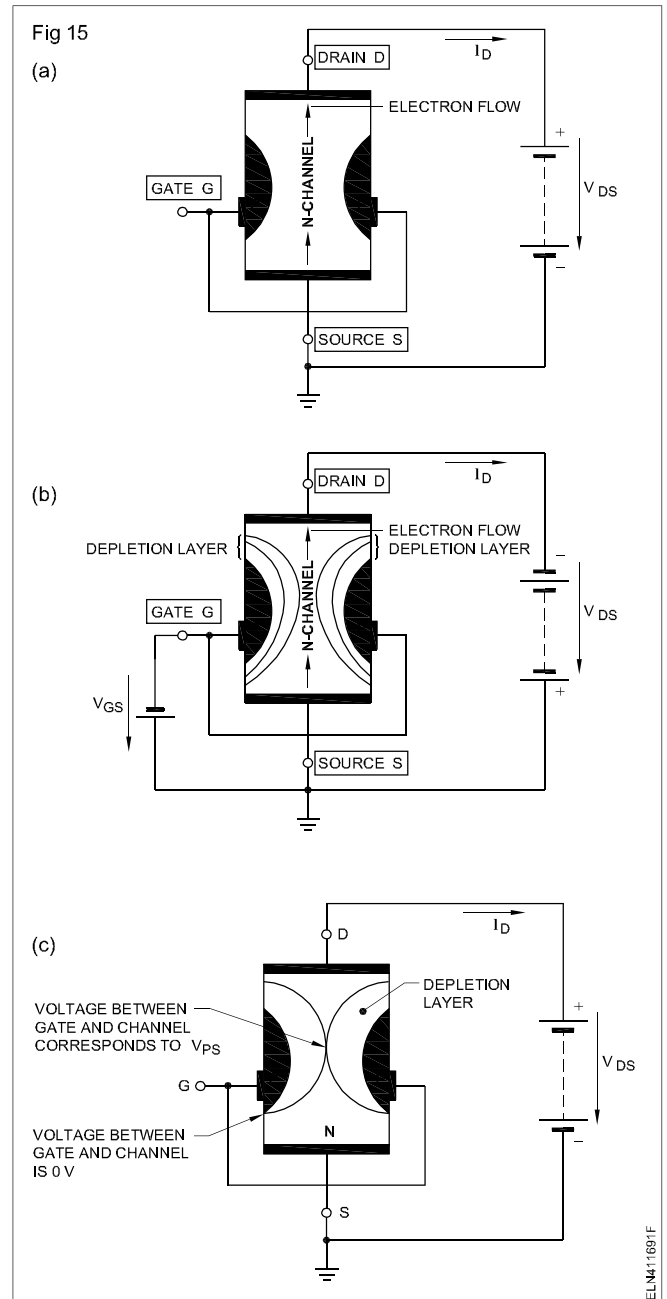
Fig 15

cutting off the flow of drain current as in Fig 15c. This voltage at which this effect occurs is referred to as the Pinch off voltage, V_P.

Thus, by varying the reverse bias voltage between gate and source($-V_{GS}$), the drain current can be varied between maximum current (with $-V_{GS}=0$) and zero current(with $-V_{GS}$=pinch off voltage). So, JFET can be referred as a voltage controlled devices.

P channel JFET operates in the same way as explined above except that bias voltages are reversed and the majority carrier of channel are holes.

Important specifications of typial JFETs

	BF245B	BFW10
Polarity of the device (N-type/P-type)	Nj	Nj
Maximum drain-source voltage, V_{DS}	30 V	30 V
Maximum gate-source voltage, V_{GS}	30 V	30 V
Maximum drain current, I_D	25 mA	20 mA
Maximum forward gate current, I_G	10 mA	10 mA
Pinch-off Voltage (at I_D=0), V_P		8 V
Maximum power dissipation, P_{max}	300 mW	300mW
Package type	TO92	TO72
Pin Diagram (Refer 6605 data manual)	fig W141e	fig W158b

The term Nj in the specification indicates that it is a N-type junction FET.

As discussed earlier FETs also need a proper biasing arrangement for it to work. Like transistors, FETs can also be connected in different configuration. Fig 16 gives a summary and comparision of basic FET configurations.

Advantages of FET

1   Since they are voltage controlled amplifier this makes their input impedence very high

2   They have a low noise output. This makes them useful as preamplifiers where the noise must be very low because of high gain in the following stages.

3   They have better linearity

4   they have low interelectrode capacity.

Typical applications of JFET

One very important characteristic of JFET is its very high input impedence of the order of 10^9 ohms. This characteristic of FET, has made it very popular at the input stage of a majority of electroinc circuits.

As discrete components FETS are mainly used in,

•   DC voltage amplifiers

•   AC voltage amplifiers(input stage amplifers in HF and LF ranges)

•   Constant current sources

•   Integtated circuits of both analog and especially in Digital technology.

1   FET AC voltage amplifier

In the circuit at Fig 17, the amplification is determined by the design. it can be varied within certain limits of the drain resistance and the source resistance are made variable. Potentiometer can be connected in series for this purpose.

CIRCUIT DIAGRAM OF THE CALCULATED A.C VOLTAGE AMPLIFIER
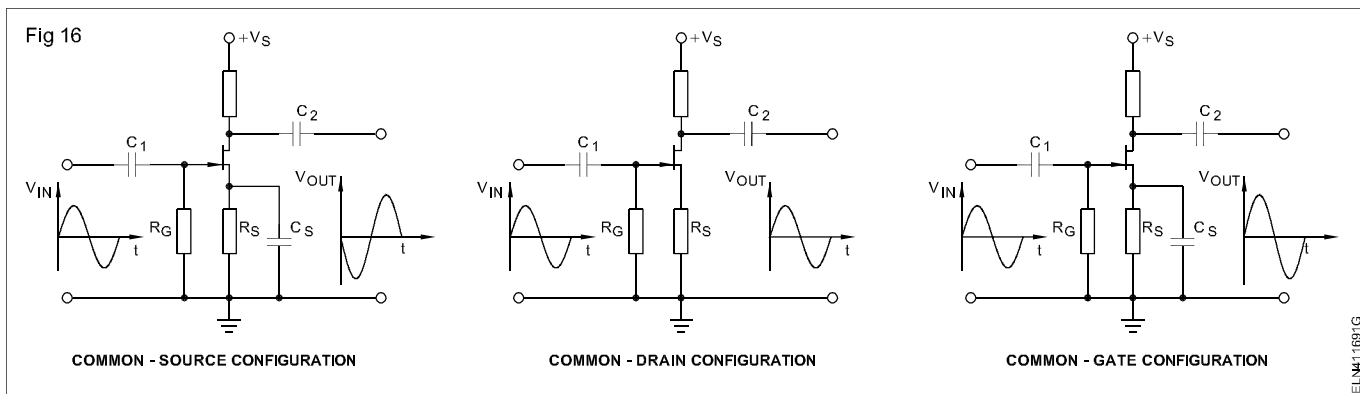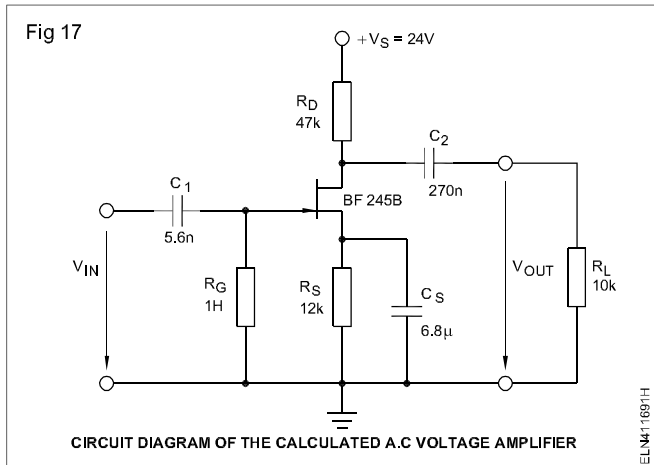
Power supplies-troubleshooting

Objectives: At the end of this lesson you shall be able to
• **list the initial activities involved in troubleshooting**
• **list the three general steps involved in troubleshooting**
• **list and explain the two popular methods of troubleshooting**
• **list the possible defects in a power supply**
• **state the meaning and use of Problem Trees (PT) and service flow diagram (SFD).**

Introduction

Troubleshooting in any equipment or in a circuit involves the following activities:

– To identify the exact nature of the problem.

– To identify the section causing the problem.

– To isolate and arrive at the exact cause(s).

– To confirm the causes by necessary tests.

– To replace the problem-causing parts.

– To re-test and confirm the satisfactory working.

The following are the general steps involved in troubleshooting.

i Physical and sensory tests

– Look for the most common physical faults, such as broken wires, cracked circuit boards, dry solders and burnt out components.

– Smell for hot or burning components.

– Feel with the fingers for unduly hot components.

ii Symptom diagnosis

Learn the operation of the system to be repaired with the help of its block diagram and its input and output specifications.

Observe the symptoms produced by the defective system, and determine which section or function would produce the symptoms.

iii Testing and replacing defective components

When the probable defective section has been diagnosed, check the probable components in that section of the circuit that are most likely to go defective in the order given below:

Components should be checked in the order given below because that is the order in which they fall in most cases.

– **Active high power components:** For example, components such as transistors, ICs, and diodes. High power devices are physically large in size and are used for handling the high power, generally in output circuits.

– **Active low power components:** These are the same as in (a) but are physically small and can handle smaller amounts of power.

– **High voltage/power passive components:** Such components are resistors, capacitors, transformers, coils, etc. which handle large amounts of voltage/power. They are found in power supplies and output circuits.

– **Low power passive components:** These are the same as in (c) but are physically smaller and handle comparatively less power and are low in value (ohm, microfarad, microhenry, etc.)

> **Note: This procedure may not turn out to be true always. Hence, do not attempt to replace common sense and meter measurements with the procedure.**

While troubleshooting any electronic system, two main methods are generally adopted. They are:

Step-by-step method of troubleshooting: This approach is preferred by the beginners. In this approach, the problem causing part or section is identified by testing the parts or sections from the beginning to the end as shown in Fig 1.

TROUBLE SHOOTING SEQUENCE - STEP - BY-STEP APPROACH
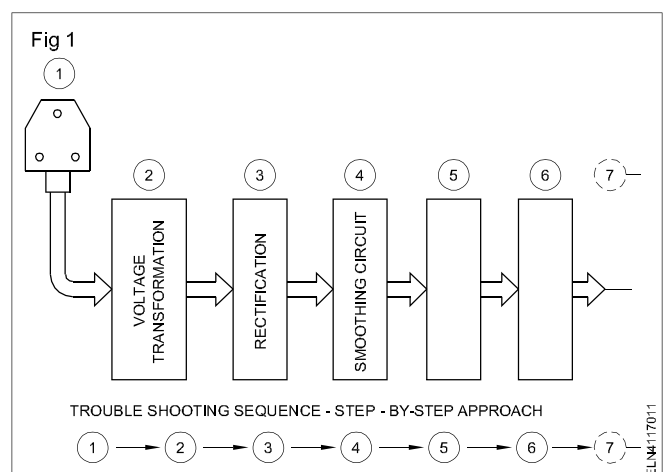
Although this approach may take more time, this is the most suited approach for the beginners.

Shortcut or logical approach method of troubleshooting: This method is used by the experienced servicing people. In this method, the problem causing part or section is identified from the nature of the problem symptom. Divide and conquer procedure is adopted to arrive at the exact cause. This method takes less time comparatively.

Troubleshooting power supplies: All electronic systems can be broken down into blocks, generally based on their function. Fig 1 shows the various blocks of a simple power supply. Each block has a particular function to perform.

Before carrying out the troubleshooting of power supplies, the first thing to be done is to isolate the load connected to the power supply. This is because the connected load itself may be the cause of the problem as shown in the problem tree (PT) in Fig 2.
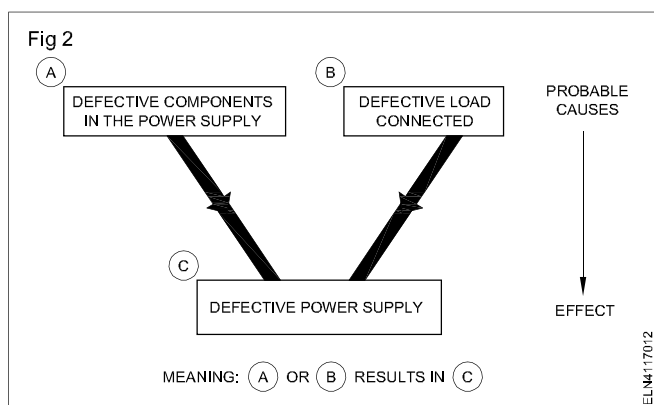
Once it is confirmed that the power supply has the same defect even with the load disconnected, you can follow either the step-by-step approach or the logical approach to troubleshoot the power supply.

Step-by-step approach to troubleshoot power supply: In the step-by-step approach of troubleshooting, the various blocks of the power supply is in Fig 1 and the components of the blocks are checked one by one, starting with block 1 and in steps as given below.

Step 1: Confirm the presence and satisfactory level of the mains supply from which the power supply is powered.

Step 2: Switch the power ON and test and note down the exact nature of the problem. Although the nature of the problem has been already told, it is essential to confirm the exact nature of the problem. This is because, in a real life situation, the customer may not be a technical person to inform the exact nature of the problem.

Step 3: Carry out physical and sensory tests.

Step 4: Trace the circuit to identify any wrong polarity connections.

Step 5: Remove the power cord of the power supply from the mains and test the power cord.

Step 6: Test the transformer.

Step 7: Test the diode(s) of the rectifier section.

Step 8: Test the capacitor(s) of the filter section.

Step 9: Test the bleeder resistor, surge resistor and other resistors, if any.

Step 10: Test the output indicator lamps/LEDs.

After completing all the above steps, from the defective components identified, analyze the root cause for the problem and confirm that the cause will not reoccur if the identified components are replaced.

Step 11: Replace the identified defective component(s).

Step 12: Switch the power ON and test the power supply, first without load, and then connecting it to the load.

Logical approach to troubleshoot power supply: In this approach steps 1 to 4 of the step-by-step approach are the same. The next step is to refer to the Logical Service Flow Diagram (SFD) for the identified problem and proceed with the troubleshooting as directed in the SFD.

SFDs are very good tools in troubleshooting as they take into account, the divide and conquer technique, thus reducing the overall time taken to troubleshoot the defect in the power supply.

The possible types of defects that can occur in a simple power supply consisting of a bridge rectifier and capacitance input filter are listed below alongwith their SFD numbers.

Possible defects in a power supply using bridge rectifier and filter capacitor

i   No output voltage

This defect in the power supply may be due to one or more component of the circuit. Problem Tree-1 (PT-1) given at the end of this lesson for the causes of the problem.

This PT shows the cause-effect relationship of the defective components with the problem. The cause is given at the top and the effect at the bottom for the only reason that it is a normal tendency to read a page from the top to the bottom.

PT-1 shows two problem trees. The first in Chart 1, indicated as Level-1 is a simple tree which gives the level-1 causes of the problem. Level-2 is an extension of the same problem tree, which gives one more level of the causes for the causes given in the simple tree at level-1.

> **Hints to Instructor: Instructor to discuss PT-1 and ensure that trainees clearly understand the need and meaning of PTs.**

Chart 2 at the end of this lesson, shows the sequence to be adopted while servicing a defective power supply. The Service Flow Sequence - 1(SFS-1) at Chart 2 is self-explanatory. However the following tips make it easy to go through the SFS.

- The flow is from top to bottom.

- Rectangular blocks indicate work to be done or action to be taken.

- Follow the path of the arrow.

- Diamond blocks indicate a decision to be taken after conducting a test or making a measurement. If the answer to the question in the diamond block is YES, follow the path of YES and continue. If the answer is NO, follow the path of NO and continue.

- Rounded rectangular ;block indicates the end of the job.

ii Low output voltage/increased ripple in output

Here, note that two defects are combined. The reason being, that these two defects generally occur simultaneously. If the output voltage is low, the cause(s) for this also results in increased ripple and vice versa. Of course with one exception that, if the mains level itself is low or if the secondary voltage of the transformer itself is low due to shorted windings, a low output voltage is not associated with increased ripple. The cause for this defect are given in problem tree PT-2 in Chart 3. Chart 4 shows, the service flow diagram (SFS-2) for servicing the defect.

> **NOTE: The SFSs and PTs for a fullwave rectifier with a capacitance filter is almost similar to that of a bridge rectifier. However, it is suggested that the trainees shall make SFSs and PTs for a fullwave rectifier power supply on their own for practice and better understanding of the method.**

NATURE OF DEFECT   :   **No Output voltage**

TYPE OF SYSTEM   :   **Bridge rectifier with capacitor filter**

LEVEL 1

**Possibility
order**

Open wire connections
or
Dry solder points

.... ①

No voltage across Transformer
Primary or Secondary winding .... ②

Filter capacitor
shorted .... ③

Rectifier diodes
open .... ④

No output
Voltage

LEVEL 2

Bad soldering   Mishandling

Open wire connections
or
Dry solder points

No Mains supply   Defective transformer

No voltage across
transformer Primary or
Secondary winding

Ageing   Low capacitor
voltage rating

Filter capacitor
shorted

Shorted load   Low I_F/PIV rating

Rectifier Diodes
open

Service flow sequence (SFS-2)

NATURE OF DEFECT   :   **Defective power supply with NO OUTPUT VOLTAGE**

```
                          ┌─────────────────┐
                          │  Start servicing │
                          └─────────────────┘
                                   │
                                   ▼
                   ┌──────────────────────────────┐
                   │ Carry out physical defect     │
                   │ checkings and rectify defects │
                   │ found. (Step 1 of Task 1)     │
                   └──────────────────────────────┘
                                   │
                                   ▼
                   ┌──────────────────────────────┐
                   │ Carry out component polarity, │
                   │ trace, check and rectify      │
                   │ defects. (Step 2 of Task 1)   │
                   └──────────────────────────────┘
```

Tr. Sec voltage present ? — NO / YES

Tr. Pri. voltage present ? — NO / YES

Power cord may be defective. Power-off, Test, repair/replace power cord.

Transformer may be defective. Power-off, Test, repair/replace transformer

DC output of PSU present ? — NO / YES

Power-OFF PSU

Filter capacitor OK ? — NO / YES

Replace capacitor

Test diodes. Replace defective diodes

Power ON

Power ON

Equipment serviced Report to Instructor

Problem Tree - PT2

NATURE OF DEFECT : **Low Output DC/Increased ripple**

TYPE OF SYSTEM : **Bridge rectifier with capacitor filter**

LEVEL 1

| Filter capacitor open or leaky | ·· | ① |

| One or pair of Diode(s) open | ························· | ② |

| Tr. Sec. voltage low | ············ | ③ |

Low output voltage/ increased ripple in output

LEVEL 2

| Ageing | | Low capacitor voltage rating |

Filter capacitor open or leaky

| Shorted load | | Low I_F/PIV rating |

One or pair of Diode(s) open

| Mains voltage low | | Some windings of sec. shorted |

Transformer secondary voltage low
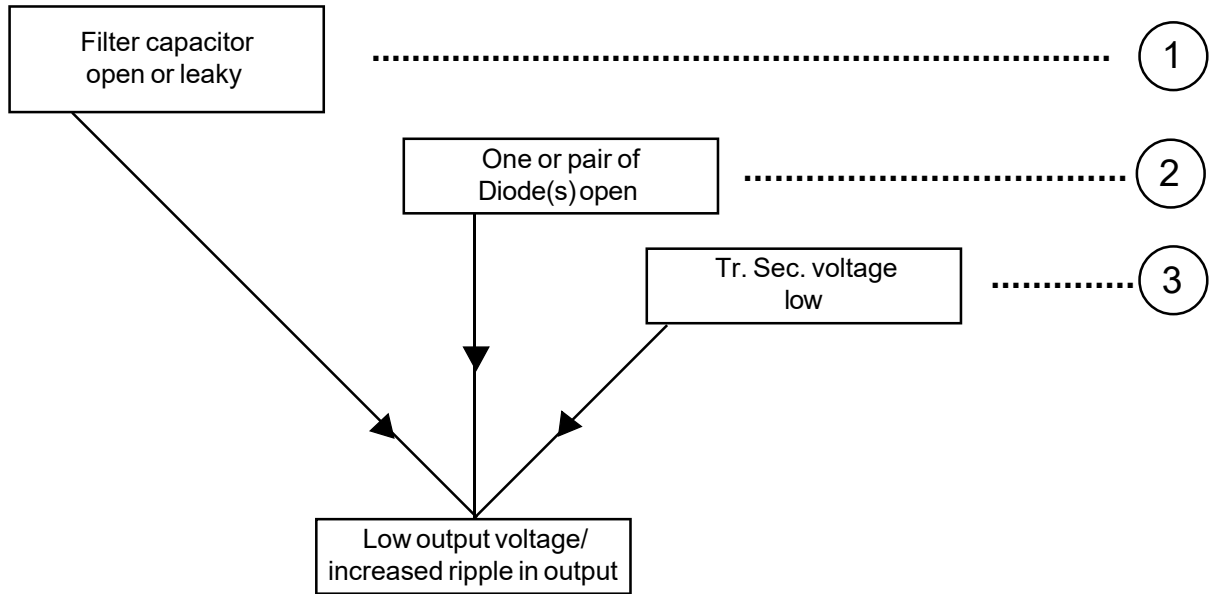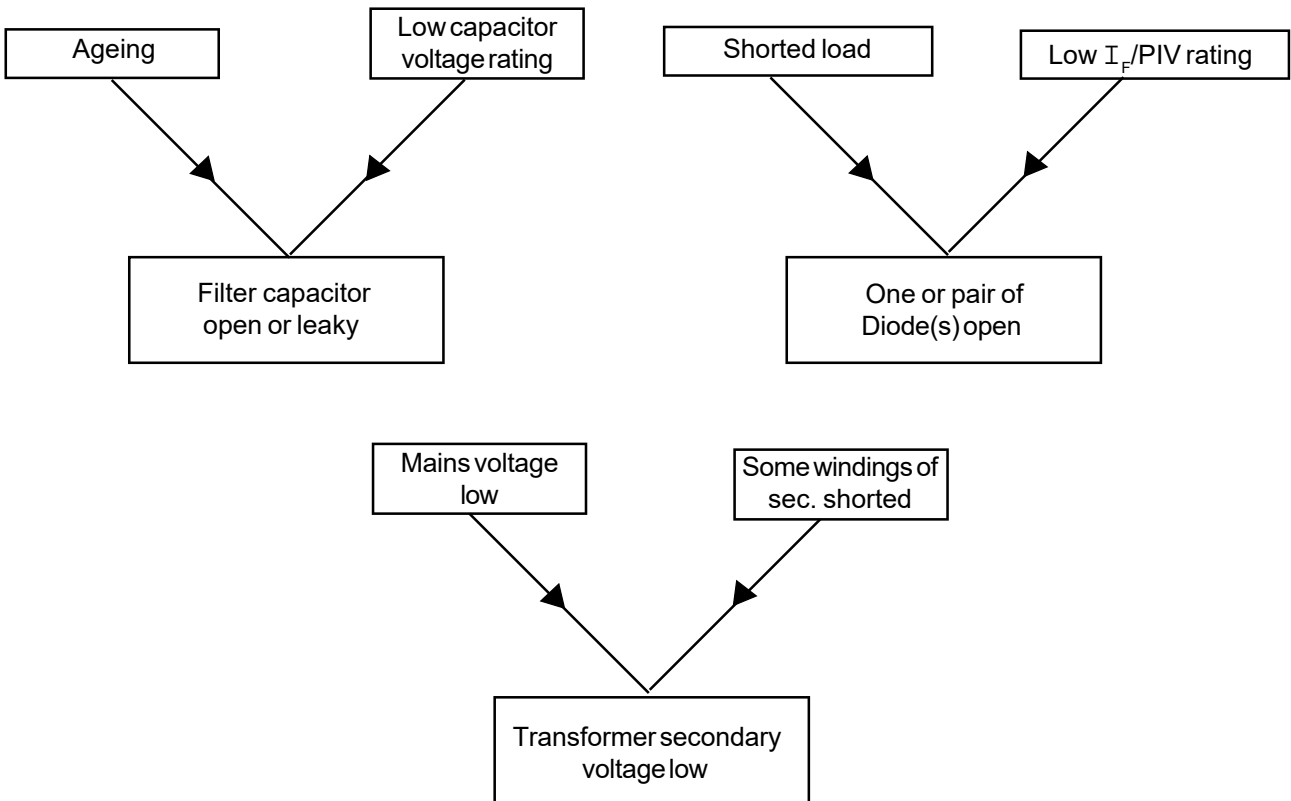
Power control circuit using SCR,DIAC,TRIAC & IGBT

Objectives : At the end of this lesson you shall be able to
• **explain the construction and working of SCR,DIAC,TRIAC & IGBT**
• **explain power control circuits using SCR**
• **explain power control circuit using DIAC & TRIAC**
• **explain the construction and using of IGBT.**

Introduction to power electronics devices

Industrial electronics is concerned primarily with electronics applied to industries such as industrial equipments, controls and processes. An important application of electronics in industries is in controlling of machinery.

In communication electronics, domestic & entertainment electronics, generally, the electronic devices operate with currents in the order of Microamper to Milliamper. For industrial applications, most frequently, devices are required to handle currents in the range of ampere to several thousands of ampere. This, therefore calls for high power electronic devices. One such high power electronic device frequently used in industrial electronic application is the SCR,TRIAC,IGBT and DIAC for associate triggering circuits.

This devices can be used to run, dc motors from an ac power source, control power tool speed,also to control motor speeds of small appliances like, mixers and food blenders, illumination control, temperature control and so on.

Silicon Controlled Rectifier (SCR)

Before Silicon controlled rectifiers were invented(1956), a glass tube device called Thyratron was used for high power applications. Silicon Controlled Rectifier (SCR) is the first device of the thyristor family. The term thyristor is coined from the expression Thyratron-transistor.SCR is a semiconductor device. SCR does the function of controlled rectification. Unlike a rectifier diode, SCR has an additional terminal called the gate which controls the rectification(gated silicon rectifier).

The basic principle application of SCRs is to control the amount of power delivered to a load(motor, lamp, etc.,).A rectifier diode will have one PN junction. SCRs on the other hand will have two PN junctions (P-N-P-N layers). Fig 1 shows the electrical symbol, basic construction and a typical SCR packages.

Basic operation of SCR

When a gate direct current is applied to the gate terminal, forward current conduction commences in the SCR(latched into conduction). When the gate current is removed, the forward current through the SCR **does not cut-off**. This

means, once the SCR is latched into conduction, the gate loses control over the conduction. The current through the SCR can be turned off only by reducing the current through it(load current) below a critical value called the **Holding current**.
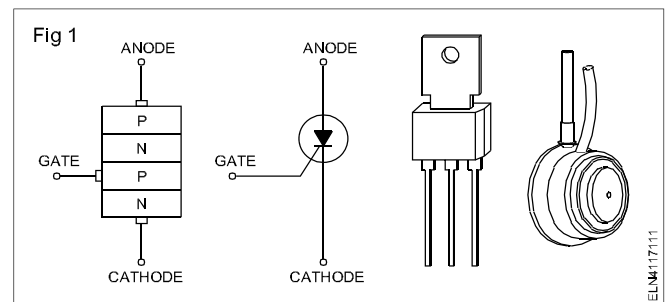
Fig 2 shows how an SCR can be gated into conduction or turned off.

In Fig 2a, with switched S1 open the SCR is in OFF state and no current is flowing through the load.

In Fig 2b, when S_1 is closed, a small gate current(around 1/1000 or less compared to load current) turns-ON (fires) the SCR. A heavy load current starts flowing through the SCR and load R_L.

In Fig 2c, when S_1 is opened, gate current becomes zero. This will have no effect on the current through the SCR and the heavy load current continues to flow through the SCR in the DC gate supply.

In Fig 2d, if a shorting wire is placed across the anode and the cathode terminals, the current though the SCR gets by-passed and all the current starts flowing through the shorted wire instead through the SCR. This means the current through the SCR is reduced below the rated holding current(minimum current required through SCR to keep it latched). This turns-OFF the SCR. Even when the shorting wire is removed the SCR remains to be in OFF state.

Fig 2e shows an alternative method of turning-OFF the SCR. In this instead of shorting the anode and cathode terminals of the SCR, the load current is cut-off by opening the Switch S_2. This reduced current through the SCR below the holding current and thus turns- OFF the SCR. Once the SCR is turned_OFF, the SCR does not turn-ON even if the switch S_2 is closed. To make the SCR fire again, with the switch S_2 closed, the gate current should be made to flow by closing the switch S_1.

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Fig 2
(a)

(b)

(c)

(d)

(e)
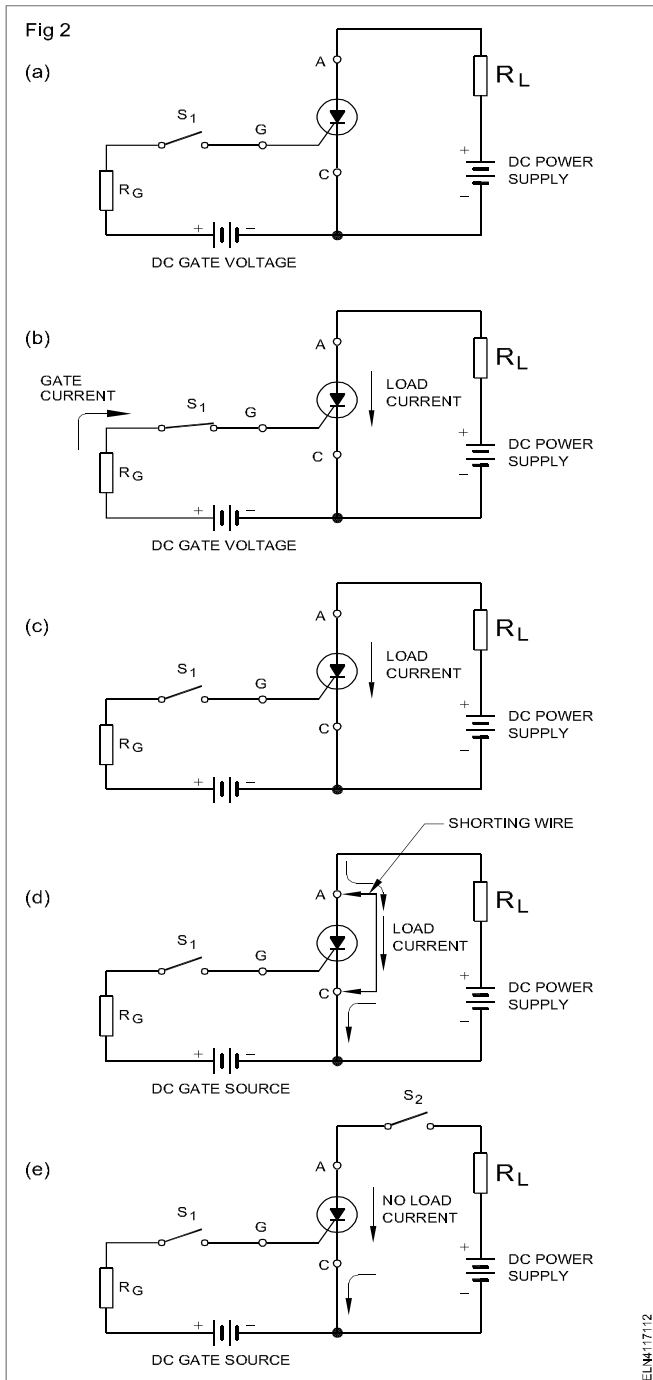
Since the SCR does not conduct in the reverse direction, the anode of the SCR should always be positive with respect to cathode for conduction.

Important features of SCR,

• A very small gate current will control the switching OFF a large load current.

SCR operation with AC supply

Operation of SCR with AC circuit is similar to SCR operation . Fig 3 illustrates working of SCR in AC control circuits.

The SCR gate circuit consists of resistor R_1, potentiometer R_2 and silicon diode D_1. Resistors R_1 and R_2 act as a variable voltage divider. By adjusting the value of R_2 the

gate current I_G can be suitably modified. Diode D_1 prevents negative voltage being applied to the gate when the ac supply is in the negative half cycle.

[X] During the +ve half cycle of the AC power source, as the positive half cycle voltage increases, the gate current I_G increases. When I_G reaches the trigger level, SCR fires and allows current I_L to flow through the load.

From this point onwards the SCR impedance is low and current I_L continues to flow throughout the +ve half cycle even though the gate current reduces below the trigger value(recall: once SCR is fired it continues to conduct even if the gate trigger is decreased or removed).

[Y] At the end of the +ve half cycle of AC power source, the +ve voltage drops to zero and SCR ceases to conduct(recall: one method of turning off SCR is to reduce the current through the SCR to below the holding current. This can be done by either opening the load circuit or reducing the supply to zero). Thus the SCR remains in off state throughout the negative half cycle.

Cycle [X] and [Y] repeats and current through the load flows in pulses as in Fig 3d.

Fig 3b,3c shows the voltage wave forms of source and gate voltage.
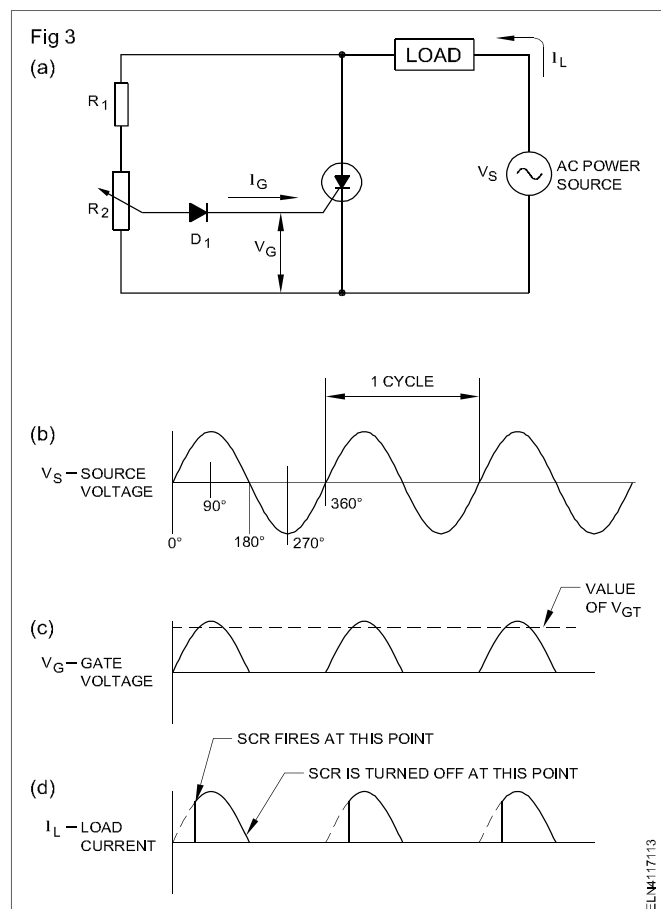
Fig 3

If the value of R_2 is varied, the point at which SCR triggers also varies changing the firing point shown in Fig 3d. In the circuit shown in Fig 3a, the firing of SCR can be adjusted anywhere between almost 180 degrees(maximum) to 90 degrees(minimum).

This simple AC control circuit shown in Fig 3a using SCR can be used to control the current through the load during the +ve half cycle of AC. During the -ve half cycle the SCR remains turned off. Thus, SCR can be used as an excellent switching device in AC control circuits.

> The circuit in Fig 3 is useful only in limited applications such as temperature control of soldering iron etc.,

Power control using SCR

- DC Motor speed control
- AC Motor speed control
- Regulated DC power supplies
- Power control
- Circuit breakers
- Time delay circuits
- Soft start circuits
- Pulse, logic and digital circuits and so on.

Speed control of DC motors: In this Related Theory information only brief outline of power circuits is discussed. Due variation of motor load currents, inductance effect in winding, the practical circuit should be modified to suit the requirement. DC motors consists of field winding and armature winding. The speed of DC motors can be varied by two methods,

1 controlling the field current

2 controlling the armature voltage

The first method is used for controlling the motor speed above the rated speed of the motor. The second method is used for controlling the motor speed below the rated speed of the motor.

Speed control of DC shunt motor by controlling the armature voltage: This is the most popular method of controlling the speed of DC shunt motors. Fig 4a illustrates the speed control of a DC shunt motor with separate field excitation. The DC supply to the field winding is given from a full wave bridge rectifier. The DC supply to the armature is given using a 'symmetrical half controlled bridge rectifier'. By controlling the SCRs 1 and 2, the DC voltage to the armature can be varied by varying the motor speed. The principle of operation of the circuit at Fig 4a can be understood by examining the current and voltage wave forms shown in Fig 4b. SCR-1 and 2 are fired in half cycles.

During the positive ;half cycle, SCR_1 and D_3 will conduct. The SCR firing angle is set to desired angle as in Fig 4b. Hence the reduced applied armature voltage is shown shaded (Fig 4b). This applied voltage to the armature can be varied by changing the firing angle using a suitable phase control circuit thus controlling the motor speed. A similar operation will take place during the negative half cycle as in Fig 4b when SCR_2 and D_1 conduct.

Fig 4
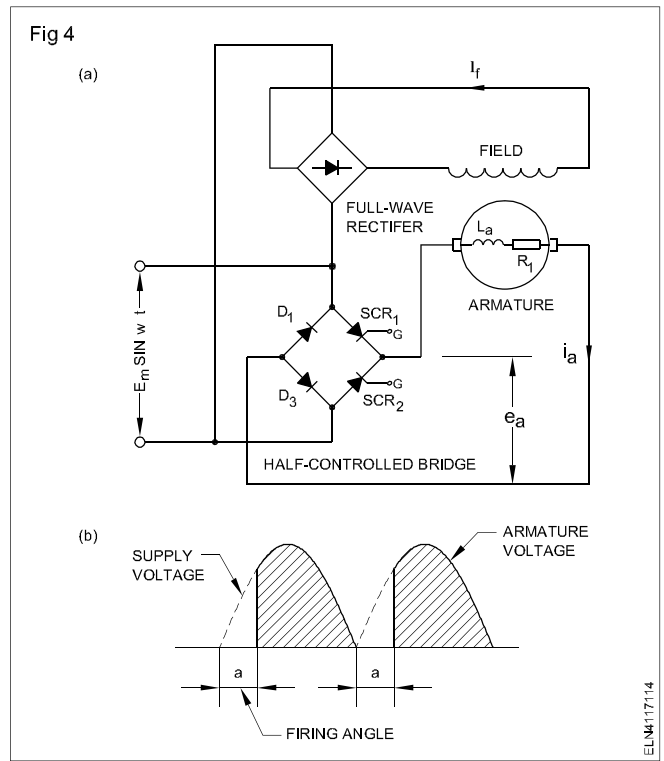
Fig 5

> There are few more details to be known specially while designing and setting the firing angles. For details refer reference books of SCR.

Fig 5a shows another simple circuit for speed control of DC motors. The speed control is based on controlled full wave rectified supply to the armature through an SCR. This control circuit is applicable only to shunt or separately excited motors. The voltage and current wave forms are given in Fig 5b. Please note that DC series motor cannot be controlled by this circuit. For reasons refer reference books on motor control circuits.
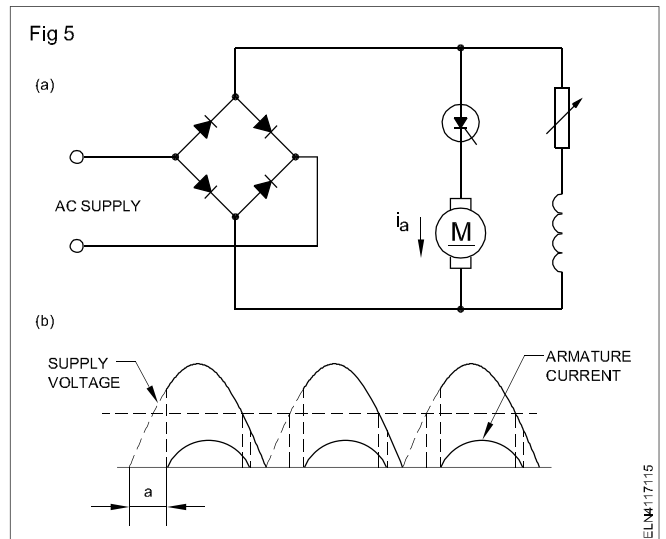
Fig 6 shows a speed controller by armature control method for a separately excited 415volts DC motor.

Other DC motor's speed control circuits are discussed in further lessons after learning a few more components that go along with SCR in motor speed control.

Fig 6
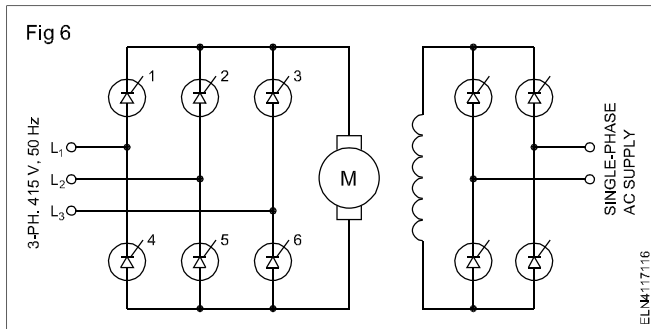
Speed control of AC motors: Phase control can be very conveniently used for speed control of AC motors also. This is achieved by applying a variable voltage to the motor whose speed is to be controlled. As the speed of the synchronous motors does not change when the input voltage is varied, this method is useful only for commutator or induction motors.

For AC motors, full wave phase control circuits are required. Fig 7 shows a schematic arrangement for speed control of single phase and three phase induction motors. When the firing angle of SCR are varied the RMS input voltage to the motor can be changed thus changing the speed of the motor.

Fig 7

a) SINGLE - PHASE MOTOR

b) THREE - PHASE MOTOR
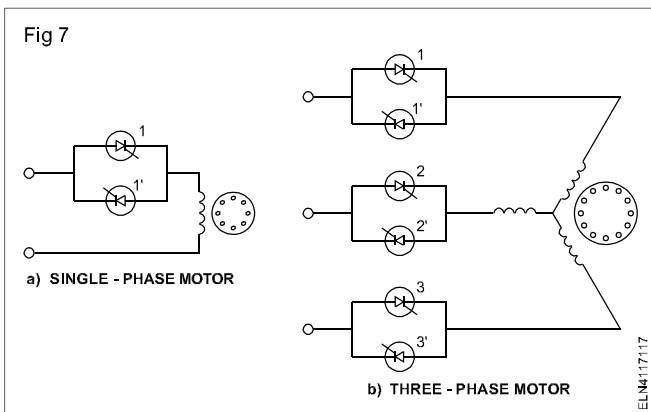
Power circuit using TRIAC and DIAC

TRIAC or SCR for speed control of AC motors: Compared to SCR, Triac is most popular and works satisfactorily for lamp dimmer circuits and speed control of universal motors. Although both SCR and TRIAC can be used to phase control and vary the current through the lamp or motor, TRIAC being a full wave device, symmetrically controls the phase of both half cycles of the applied AC.

The resultant full wave current format then produces smooth lamp or motor operation that can be attained from the half wave rectification using SCRs. This is particularly noticeable during low/dim light requirement or low speed for motors.

The circuit at Fig 8 shows a TRIAC phase control circuit for controlling the brightness of the lamp or speed of universal motors.

The load shown in circuit at Fig 8 is a general load rather than a motor symbol because, this circuit can also be used for light dimmers and for the control of heaters.

Fig 8
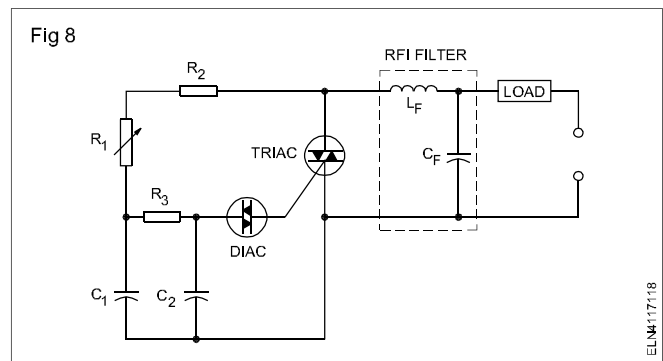
This circuit features a double time constant phase-shift network. This reduces hysteresis in firing of the triac, thereby making the manual adjustment of dimmer operation or control off speed more repeatable.

The DIAC used as trigger device, adds to the reliability of the circuit. The elemental low-pass filter comprising L_F and C_F attenuates much of the radio-frequency interference (RFI) that gets generated and tries to get into the power line. This high frequency RF1 energy is generated by the extremely rapid turn-on time of the TRIAC. Which should be eliminated to avoid radio interference due to higher frequency content of the rectified wave form Otherwise, the frequency may interfere with reception at nearby places or in the main line circuit elsewhere.

Lamp dimmers: Lamp dimmer is a circuit which controls as AC power supplied to an incandescent lamp thereby controlling the intensity of light emitted by the lamp from almost zero to full brilliance.

Conventional and soft-start dimming of incandescent lights: Advantage of semi-conductor based light dimmers over the auto transformer connected light dimmers

Old technology light dimmers used high wattage rheostats adjustable auto-transformers or saturable reactors, which were large, expensive generated considerable heat and power loss. Present day semi-conductor light dimmers have overcome these difficiencies and have therefore become very popular for many applications.

Modern semi-conductor dimmers are inexpensive, reliable, small generate little heat, and are easy to control remotely. These properties have not only permitted semi-conductor dimmers to supersede older types in theatres and auditoriums with excellent results, but have made dimmers practical for built-in home lighting, table and floor lamps, projection equipment and other uses.

Semi-conductor based light dimmers: Two light dimmers for incandescent light bulbs are discussed below. Both these dimmer circuits control light intensity by adjusting the angle of conduction of a triac connected in series with the bulb. The first dimmer uses a very simple circuit that is ideal for highly compact applications requiring minimum cost. The second dimmer features soft starting for low in rush current and consequent long lamp life. Soft start lamp dimmers are especially useful with expensive

lights with short lives, such as projection lamps and photo-graphic bulbs.

Simple light dimmer: The circuit shown in Fig 9 is a wide range light dimmer using very few parts. The circuit can be operated using any mains supply source (240V, 50Hz) by choosing appropriate value of circuit components. The circuit can control upto 1000watts of power to incandescent bulbs.

Fig 9
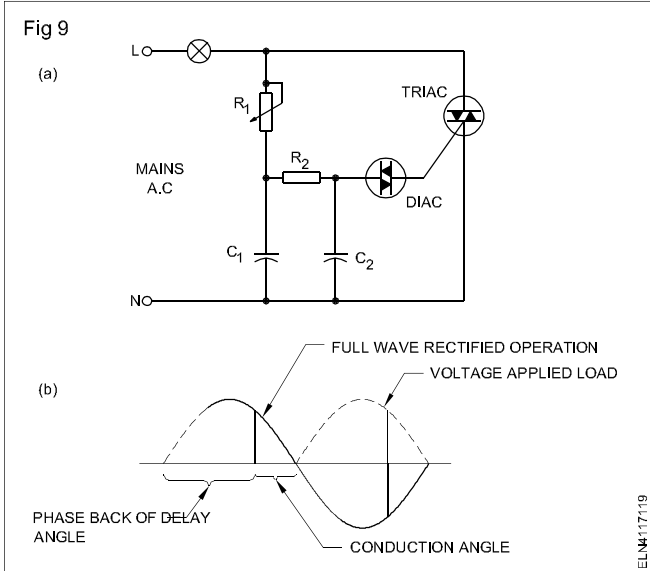
The power to the bulbs is varied by controlling the conduction angle of Triac. Many circuits can be used for phase control, but the single Triac circuit used is the simplest and is therefore chosen for this particular application.

The control circuit for this Triac must function as shown in Fig 9b. The control circuit must create a delay between the time voltage is applied to the circuit and the time it is applied to the load. The Triac is triggered after this delay and conducts current through the load for the remaining part of each alteration. This circuit can control the conduction angle from 0° to about 170° and provides better than 97% of full power control.

Light dimmer with soft-start option: The circuit at Fig 10 is a light dimmer with soft start option. Soft starting is desirable because of the very low resistance of a cold lamp filament compared to its hot resistance. At the time of initial switching ON, the low resistance of the lamp causes very high inrush currents which leads to short filament/lamp life. Lamp failures caused by high inrush currents is eliminated by the soft start feature, which applies current to the bulb slowly enough to eliminate high surges.

Operation of the circuit at Fig 10 begins when voltage is applied to the diode bridge consisting of D_1 through D_4. The bridge rectifies the input and applies a DC voltage to resistor R_1 and zener diode D_5. The zener provides a constant voltage of 20volts to unijunction transistor Q_1, except at the end of each alternation when the line voltage drops to zero. Initially the voltage across capacitor C_1 is zero and capacitor C_2 cannot charge to trigger Q_1. C_1 will

begin to charge, but because the voltage is low, C_2 will have adequate voltage to trigger Q_1 only near the end of the half cycle. Although the lamp resistance is low at this time, the voltage applied to the lamp is low and the inrush current is small. Then the voltage on C_1 rises, allowing C_2 to trigger Q_1 earlier in the cycle.

At the same time the lamp is being heated by slowly increasing applied voltage and by the time the peak voltage applied to the lamp has its maximum value, the bulb has been heated sufficiently so that the peak inrush current is kept to a reasonable value.

Resistor R_4 controls the charging rate of C_2 and provides the means to dim the lamp. Power to the load can be adjusted manually by varying the resistance of R_4. T1 is a pulse transformer. In addition to supplying the trigger to Triac, this transformer isolates the high current load circuit from the low power triggering circuit (gate isolation methods for Triac is discussed in further paragraphs).

Fig 10
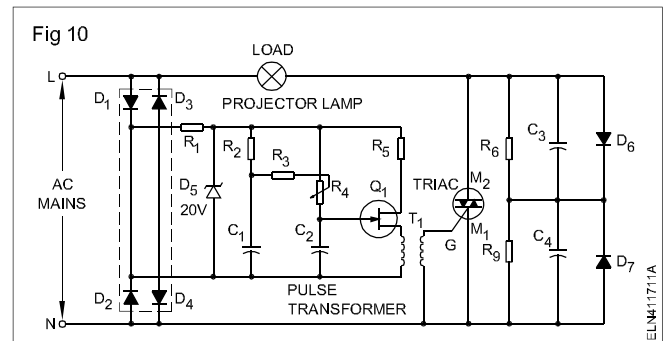
A simple lamp dimmer cum Universal motor speed controller: In the lamp dimmer cum universal speed controller circuit is in Fig 11, a Triac is used as control device. Phase control technique is used to control conduction angle of the triac which inturn control the power fed to the lamp.

Fig 11
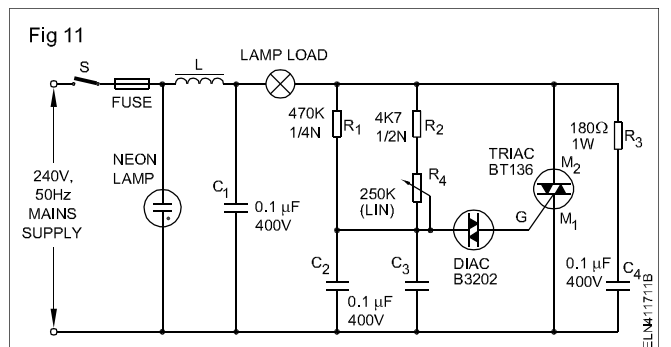
A lamp L is connected in series with AC mains supply to the Triac. The trigger pulses to Triac gate is given through Diac. The Diac is triggered at the same breakover voltage level (30V) during both positive and negative half cycles.

Potentiometer R_4 provides the facility for varying the intensity of light or speed of a universal motor.

Snubber circuit: One problem with the Triac control is the sudden application of reverse voltage across the triac immediately after it has stopped conduction. This is a serious problem when the load is a highly inductive as in

motors. This reapplied voltage denoted by dv/dt can trigger-on (unwanted or false triggering) the device losing the phase control.

To avoid this false triggering, an R and C series network is placed across the circuit R_4 and C_4 as shown in Fig 11. This RC network slows down the rate of rise of voltage applied across the Triac. This RC circuit connected across the Triac circuit is called snubber circuit.

The inductance L and capacitor C_1 forms a low pass filter to substantially reduce the radio frequency interference (RF) generated by the rapid turn-on and turn-off the triac.

Fan speed regulator: The lamp dimmer circuit at Fig 11 can be used equally well as a fan speed regulator. The only change to be made is to connect a fan in place of the lamp shown in the circuit at Fig 11. The speed can be varied from almost zero to full speed by just rotating POT R_3.

IGBT (Insulated Gate Bipolar Transistor)

The insulated Gate Bipolar Transistor (IGBT) is the latest device is power electronics. It is obtained by combining the properties of BJT and MOSFET. We know that BJT has lower on - state losses for high values of collector current. But the drive requirement of BJT is little complicated. The drive of MOSFET is very simple (i.e only voltage is to be applied between gate and source). But MOSFET has high on - state losses.

The gate circuit of MOSFET and collector emitter circuits of BJT are combined together to form a new device. This device is called IGBT. Thus IGBT has advantages of both the BJT and MOSFETs. Fig 12 shows the symbol of IGBT. Observer that the symbol clearly indicates combination of MOSFET and BJT.

Fig 12
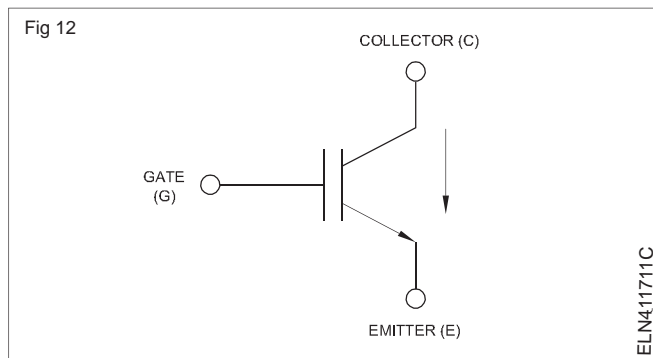
The IGBT has three terminals : Gate (G), collector (C) and emitter (E), Current flows from collector to emitter whenever a voltage between gate and emitter is applied. The IGBT is said to have turned 'ON'. When gate emitter voltage is removed, IGBT turns - off. Thus gate has full control over the conduction of IGBT. When the gate to emitter voltage is applied, very small (negligible) current flows. This is similar to the gate circuit of MOSFET. The on - state collector to emitter drop is very small like BJT.

Structure of IGBT

The structure of IGBT is similar to that of MOSFET. Fig 13 show the vertical cross section of IGBT . In this structure observe that there is additional P+ layer. This layer is collector (Drain) of IGBT.

Fig 13
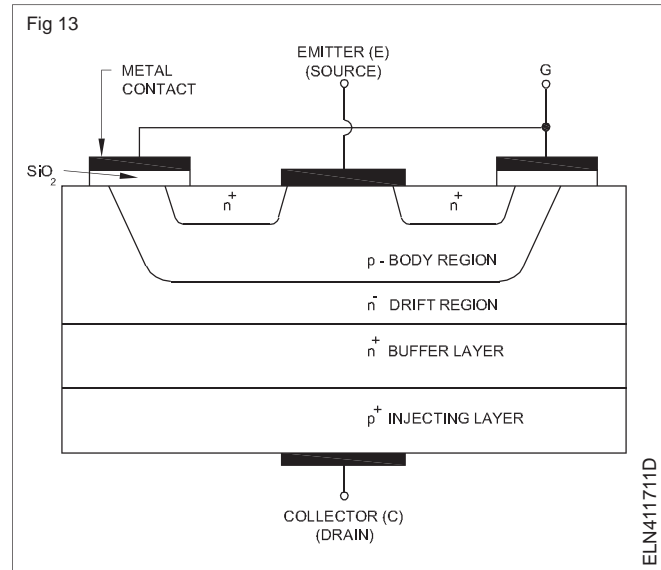
This P+ injection layer is heavily doped. It has the doping intensity of 10^{19} per cm^3. The doping of other layer is similar to that of MOSFET. n+ layers have 10^{19} per cm^3. P-type body region has doping level of 10^{16} per cm^3. The n-drift region is lightly doped (10^{14} per cm^3).

Punch through IGBT

The n+ buffer layer is not necessary for the operation of IGBT. The IGBTs which have n+ buffer layer are called punch through IGBTs. Such IGBTs have asymmetric voltage blocking capabilities. Punch through IGBTs have faster turn-off times. Hence they are used for inverter and chopper circuits.

Non - punch through IGBT

The IGBTs without n+ buffer layer are called non-punch through IGBTs. These IGBTs have symmetric voltage blocking capabilities. These IGBTs are used for rectifier type applications.

Operation of IGBT

When $V_{GS} > V_{GS}$(threshold), then the channel of electrons is formed beneath the gate as in Fig 14. These electrons attract holes from p+ layer. Hence, holes are injected from p+ layer into n- drift region. Thus hole / electron current starts flowing from collector to emitter. When holes enter p-type body region, they attract more electrons from n+ layer. This action is exactly similar to MOSFET.

Fig 15 shows the structure of IGBT showing how internal MOSFETs and transistors are formed. The MOSFET is formed with input gate, emitter as source and n- drift region as drain. The two transistors T_1 and T_2 are formed

as in Fig 15. The holes injected by the P+ injecting layer go to the n- drift region. This n- drift region is base of T_1 and collector of T_2. The holes in the n- drift region further go to the p - type body region, which is connected to the emitter. The electrons from n+ region (which is emitter) pass through the transistor T_2 and further in the n- drift region. Thus holes and electrons are injected in large amounts in n- drift region. This reduces the resistance of the n- drift region. This is called conductivity modulation of n- drift region. Note that such conductivity modulation does not exist in MOSFET. The connection of T_1 and T_2 is such that large amount of hole/electrons are injected in n- drift region.

Fig 14

Fig 15
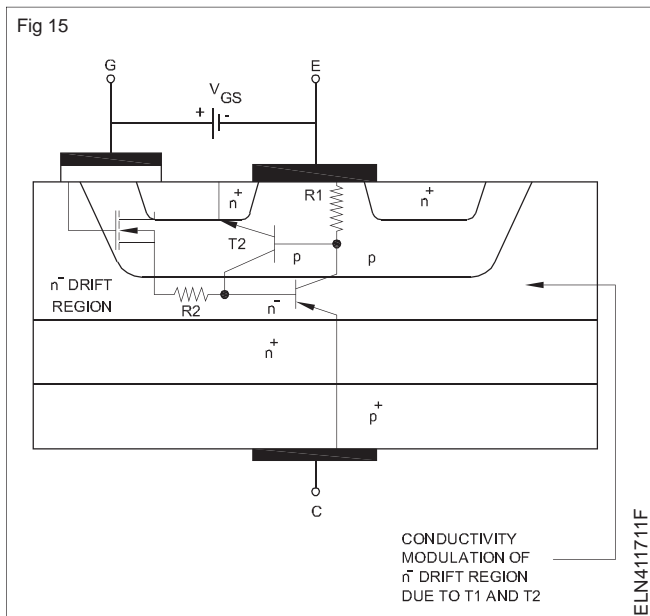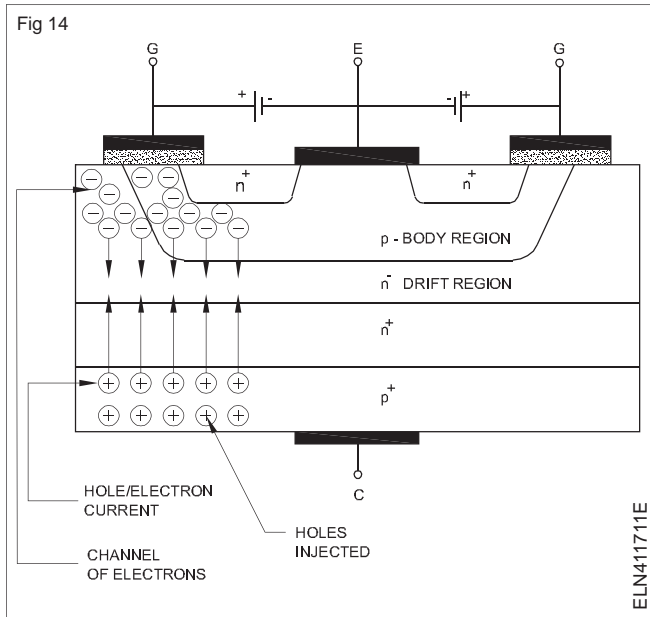
The action of T_1 and T_2 is like SCR which is regenerative. The gate serves as trigger for T_1 through internally formed MOSFET. Fig 16 shows the equivalent circuit. In this figure observe that when gate is applied ($V_{GS} > V_{GS}$(th)), the internal equivalent MOSFET turns ON. This gives base drive to T_1. Hence T_1 starts conducting. The collector of T_1

is base of T_2. Therefore T_2 also turns ON. The collector of T_2 is base of T_1. Thus the regenerative loop begins and large number of carriers are injected in n- drift region. This reduces the on- state loss of the IGBT just like BJT. This happens due to conductivity modulation of n- drift region.

Fig 16
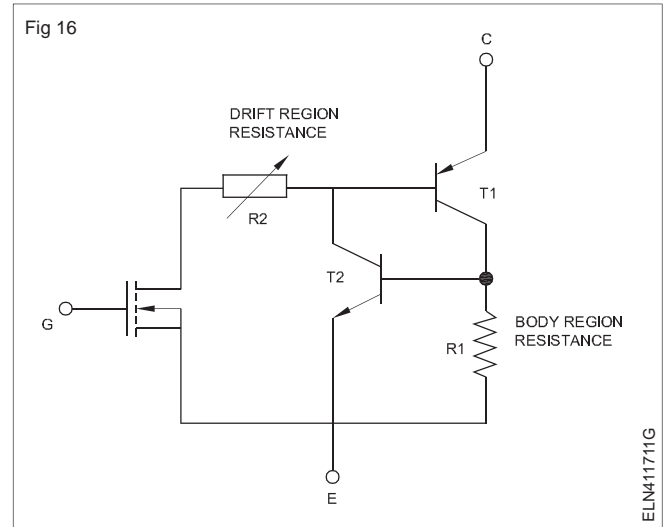
When the gate drive is removed, the IGBT should turn-OFF. When gate is removed, the induced channel will be vanished and internal equivalent MOSFET will turn-OFF. Hence T_1 will turn -OFF if T_2 turns-OFF T_2 will turn - OFF if the p- type body region resistance R_1 is very very small. Under such situation, its base and emitter will be virtually shorted. Hence T_2 turns - OFF. Therefore T_1 will also turn - OFF. Hence structure of IGBT is organizes such that body region resistance (R_1) is very very small.

If R_1 is very very small, than T_2 will never conduct and the equivalent circuit of IGBT will be as in Fig 17. IGBTs are thus different than MOSFETs because of conduction of current from collector to emitter. For MOSFETs, on state losses are high since resistance of drift region remains same. But in IGBTs, resistance of drift region reduces when gate drive is applied. This resistance reduces because of P+ injecting region. Hence, on state loss of IGBT is very small.

Fig 17
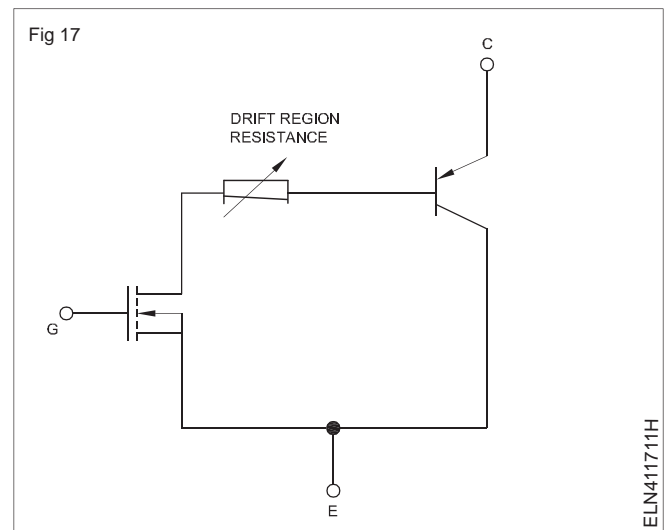
Merits, Demerits and Applications of IGBT

Merits of IGBT

1 Voltage controlled device. Hence drive circuit is very simple.

2 On - state losses are reduced.

3 Switching frequencies are higher than thyristors.

4 No commutation circuits are required.

5 Gate have full control over the operation of IGBT

6 IGBTs have approximately flat temperature coefficient.

Demerits of IGBT

1 IGBTs have static charge problems.

2 IGBTs are costlier than BJTs and MOSFETs.
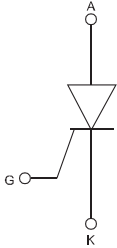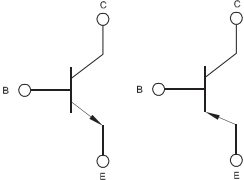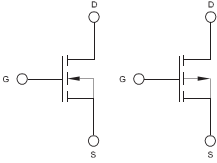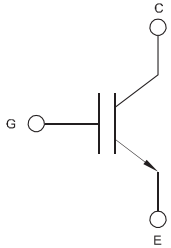
Applications of IGBTs

1 AC motor drives, i.e. inverters.

2 DC to DC power supplies, i.e choppers

3 UPS systems.

4 Harmonic compensators.

Comparison of Power Devices

The power devices can be compared on the basis of switching frequency, gate drive circuit, power handling capacity etc. Table 1 shows the comparison of SCR, BJT, MOSFET and IGBT.

Table 1

S.No.	Parameter	SCR	BJT	MOSFET	IGBT
1	Symbol				
2	Triggered i.e latching or linear	Triggered or latching device	Linear trigger	Linear trigger	Linear trigger
3	Type of carriers in device	Majority carrier device	Bipolar device	Majority carrier device	Majority carrier device
4	Control of gate or base	Gate has no control once turned on	Base has full control	Gate has full control	Gate has full control
5	On-state drop	< 2 Volts	< 2 Volts	< 4-6 Volts	< 3.3 Volts
6	Switching frequency	500 Hz	10 kHz	up to 100 kHz	20 kHz
7	Gate drive	Current	Current	Voltage	Voltage
8	Snubber	Unpolarized	Polarized	Not essential	Not essential
9	Temperature coefficient	Negative	Negative	Positive	Approximately flat, but positive at high current
10	Voltage and current ratings	10 kV/4kA	2 kV/4kA	1 kV/50 A	1.5 kV/400 A
11	Voltage blocking capability	Symmetric and	Asymmetric	Asymmetric	Asymmetric
12	Application	AC to DC converters, AC voltage controllers, electronic circuit breakers	DC to AC converters, induction motor drives, UPS, SMPS, Choppers	DC choppers, low powers, UPS, SMPS, brushless DC motor drives	DC to AC converters, AC motor drivers, UPS choppers, SMPS etc,.

Integrated circuit voltage regulators

Objectives: At the end of this lesson you shall be able to
• **explain integrated circuit**
• **state the classification of integrated circuit**
• **state the types of IC voltage regulators**
• **design voltage regulator for a required output voltage**
• **modify fixed voltage regulator to variable output regulator, circuit.**

IC introduction

Integrated circuit

Electronic circuits invariably consist of a number of discrete components connected to each other in a specific way. For instance, the series regulator circuit discussed in earlier lessons, consists of transistors, zener diodes, resistors and so on, connected in a defined way for it to function as a regulator. If all these components instead of building on a board, if they are built on a single wafer of a semiconductor crystal, then, the physical size of the circuit becomes very small. although small, this will do the same job as that of the circuit wired using discrete components. Such miniaturised electronic circuits produced within and upon a single crystal, usually silicon, are known as Integrated circuits or ICs. Integrated circuits (ICs) can consists of thousands of active components like transistor, diodes and passive components like resistors and capacitors in some specific order such that they function in a defined way, say as voltage regulators or amplifiers or oscillators and so on.

Classification of Integrated circuits: Integrated circuits may be classified in several ways. However the most popular classifications is as follows:

1 Based on its type of circuitry

   i Analog ICs - Example: amplifier ICs, voltage regulator ICs etc.

   ii Digital ICs - Example: Digital gates, flip-flops, address etc.

2 Based on the number of transistors built into IC

   i Small scale integration (SSI) - consists of 1 to 10 transistors.

   ii Medium scale integration (MSI) - consists of 10 to 100 transistors.

   iii Large scale integration (LSI) - 100 to 1000 transistors.

   iv Very large scale integration (VLSI) - 1000 and above.

3 Based on the type of transistors used

   i Bipolar - carries both electron and hole current.

   ii Metal oxide semiconductor (MOS) - electron or hole current.

   iii Complementary metal oxide semiconductor (CMOS) - electron or hole current.

> **Note: The terms MOS and CMOS are another type of transistor and the trainees are requested to refer any standard electronic book for further reference.**

ICs are available in different packages and shapes. The usual packages are:

– dual in the packages DIP

– single in line package SIP and

– metal can packages.

ICs handling power more than IW are provided with heat sinks.

Advantages of integrated circuits over discrete circuit (Refer Table 1)

Table 1

Integrated circuits	Discrete circuits
Advantages	
1 All in a single chip	All are separate discrete components
2 Requires less space due to smaller size	Requires more space
3 Cheaper due to mass manufacture	Costlier due to individual components
4 More reliable due to specific construction	Less reliable
5 Easy for servicing and repairs	Difficult for servicing and repairs
Disadvantages	
1 ICs are manufactured for specific applications having specific circuits	Discrete devices can be used for any circuit
2 If any part of IC is defective, the entire IC is to be replaced	Only particular defective component requires replacement

When the advantages are considered, the disadvantages of IC are negligible. They are widely used for different applications such as voltage regulators, audio amplifiers, TV circuits, computers, industrial amplifiers etc. ICs are available in different pin configurations in different outlines suitable for different circuits.

Integrated circuit (IC) voltage regulators: The series voltage regulators discussed in earlier lessons are available in the form of integrated circuits (ICs). They are known as voltage regulator ICs.

There are two types of voltage regulator ICs. They are,

– Fixed output voltage regulator ICs

– Adjustable output voltage regulator ICs.

Fixed output voltage regulator ICs: The latest generation of fixed output voltage regulator ICs have only three pins as in Fig 1. They are designed to provide either positive or negative regulated DC output voltage.

Fig 1

3 PIN IC REGULATOR
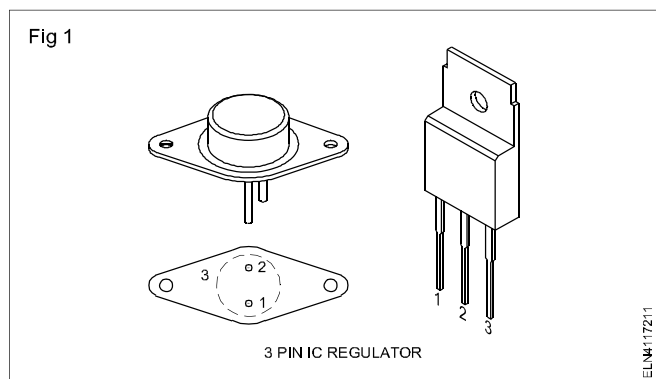
These ICs consist of all those components and even more in the small packages in Fig 1. These ICs, when used as voltage regulators, do not need extra components other than two small value capacitors as in Fig 2.

Fig 2
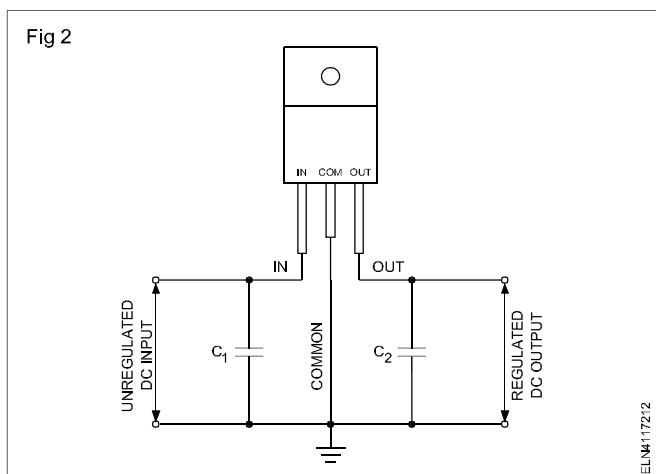
The reason behind using capacitor C_1 is when the voltage regulator IC is more than a few inches from the filter capacitors of the unregulated power supply, the lead inductance may produce oscillations within the IC. Capacitor C_1 prevents setting up of such oscillations. Typical value of bypass capacitor C_1 range from 0.220µF to 1µF. It is important to note that C_1 should be connected as close to the IC as possible.

The capacitor C_2 is used to improve the transient response of the regulated output voltage. C_2 bypasses these transients produced during the ON/OFF time. Typical values of C_2 range from 0.1µF to 10µF.

Fixed voltage three terminal regulators are available from different IC manufacturers for different output voltages (such as 5V, 9v, 12V, 24V) with maximum load current rating ranging from 100mA to more than three amps.

The most popular three terminal IC regulators are,

1 LMXXX-X series
   Example: LM320-5, LM320-24 etc.

2 78XX and 79XX series
   Example: 7805, 7812, 7912 etc.

A list of popular three terminal regulators is given in IC data book.

Specifications of three terminal IC regulators: For simplicity in understanding, let us consider the specification of a three terminal IC µA7812. The table 2 given below lists the specifications of µA7812.

Table 2

Parameter	Min.	Type.	Max.	Units
Output voltage	11.5	12	12.5	V
Output regulation		4	120	mV
Short-circuit output current			350	mA
Drop out voltage			2.0	V
Ripple rejection	55	71		dB
Peak output current		2.2		A

Output voltage: This specification indicates the regulated DC output voltage that can be obtained from the IC. As can be seen from the sample specification table given above, the manufacturer specifies minimum, typical and maximum output voltage. While using this IC take the typical value as this value corresponds to the output voltage at IC under normal input and load conditions.

Output regulation: This indicates the amount by which the output voltage may vary at rated maximum load condition. For example, in µA7812 IC, the output voltage may vary by 4mV from its rated 12V DC when the rated typical load current is 2.2A.

Short circuit output current: This indicates the shorted current I_{SC}, if the output gets shorted. In µA 7812 the output current is limited to 350mA when the output terminals are shorted.

These regulators also canbe used fold back current limiting.

Drop out voltage: For instance, in µA7812 in which the output voltage is +12V, the input unregulated DC voltage to the regulator must be higher than the output voltage. The specification drop out voltage indicates, the minimum positive different between the input and output voltages for the IC to operate as a regulator. For example, in, µA7812 the unregulated input voltage should be atleast 2 volts more than the regulated DC output of 12V. This means for µA7812 the input must be atleast 14V.

The difference between the voltage across the input and output of the IC should also not to be very high as this causes unwanted dissipation. As a thumb rule, the input voltage to the regulator shall be restricted to a maximum of twice the output voltage of the regulator. For example, for µA7812, the unregulated input voltage should be more than 14V, but less than 24V.

– Ripple rejection

This indicates the ratio of ripple rejection between the output to input, expressed in decibels,

– Peak output current

This indicates the highest output or load current that can be drawn. Above this rated maximum current the safety of the IC is not guaranteed.

Identification of output voltage and rated maximum load current from IC type number

– 78XX and 79XX series are 3 Terminal voltage regulators.

– All 78XX series are positive output voltage regulators

– All 79XX series are negative output voltage regulators

The term XX indicates the rated output regulated voltage.

Example

7805	
Indicates positive output regulator	Indicates output voltage is +5V
7912	
Indicates negative output regulator	Indicates output voltage is –12V
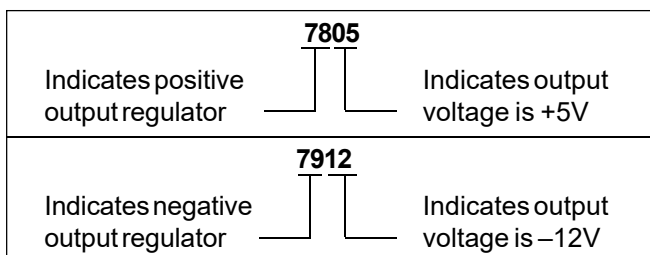
It is important to note that, different manufacturers of 78 XX/ 79XX series such as Fair Child (MA/Mpc), Motorola, Signetics (SS) adopt slightly different coding schemes to indicate the rated maximum current of the three pin regulated. ICs. One such scheme is given below.

78LXX   -   L indicates rated maximum load current as 100mA.

78MXX   -   M indicates rated a maximum load current as 500mA

78XX   -   Absence of an alphabet between 78 and XX indicates that the rated maximum load current is 1A.

78SXX   -   S indicates rated maximum load current is 2amp.

Example

µPC 78 M 15H

Indicates positive

Fair Child (Manufacturer's code)

Positive regulator

Indicates Regulated output voltage is 15V

Rated maximum load current is 500mA
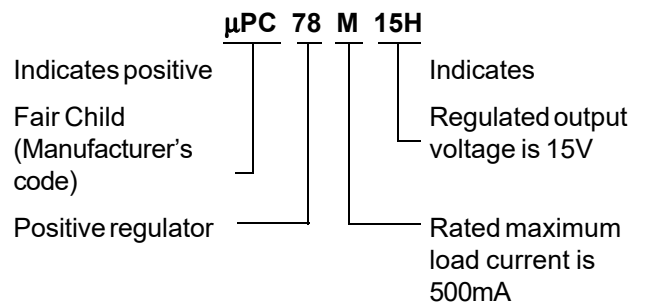
LM 3XX series of 3 terminal voltage regulators: In LM series of three terminal regulators, to find the specifications, it is suggested to refer to its data manual. However, the following tips will help in identifying whether the IC is a fixed positive or fixed negative regulator.

LM320-X and LM320-XX → Fixed –ve voltage regulators.

LM340-X or LM340-XX → Fixed +ve voltage regulators.

Examples

LM 320 - 5

RCA (Manufacturer)

Output voltage -5V

Fixed negative voltage regulator

LM 340 - 15

RCA

Output

Fixed positive voltage regulator
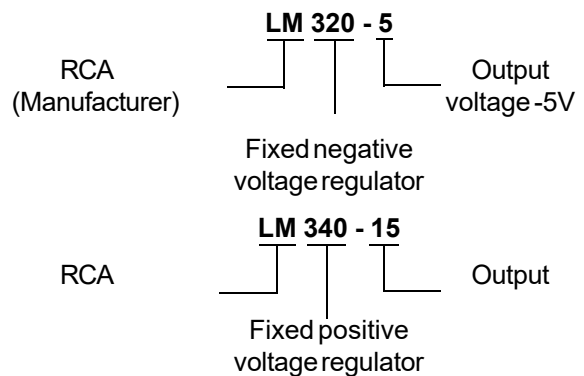
Practical 78XX and 79XX voltage regulator: Fig 3 shows the circuit connections of a 12V, 1A regulated power supply using 7812.

+12V FIXED OUTPUT VOLTAGE REGULATOR CIRCUIT
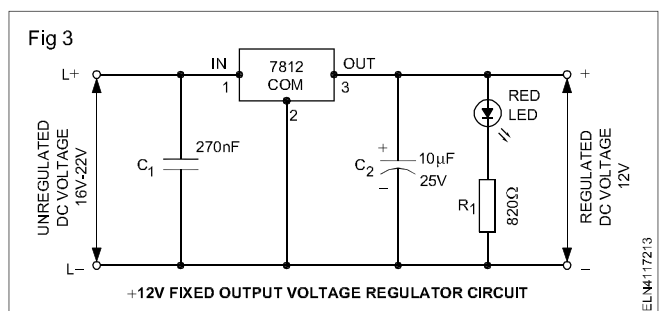
The output voltage of a 3-terminal regulator IC is with reference to the IC's common terminal (COM). When the COM terminal is grounded, the output voltage of the regulator will be the specified output voltage of the IC as in Fig 3. But the output voltage of the IC can be increased above the specified value by rising the voltage at the COM terminal as in Fig 4. Because of 6.1V zener, the output voltage of the IC can be increased above the specified value by raising the voltage at the COM terminals

as in Fig 4. Because of 6.1V zener, the output voltage will be 6.1V + 12V = 18.1V or approximately 18V as in Fig 4.

Fig 4
+18V FIXED OUTPUT VOLTAGE REGULATOR CIRCUIT
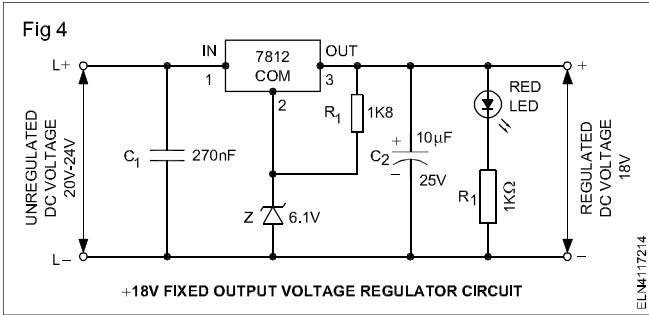
When the COM terminal of the IC is grounded as in Fig 2, the quiescent current flowing from the COM terminal to ground in 78 series is around 8µA. This current decreases as the load current increases. When a zener is connected at COM terminal as in Fig 4, to ensure that the zener is always in the reverse ON condition, resistor R_1 is used. If R_1 = 1.8K, I_z will be 7mA which is sufficient to keep the zener ON always.

Fig 5 shows a variable output voltage regulator. The variable reference voltage at COM terminal is obtained using a POT.

Fig 5
VARIABLE OUTPUT VOLTAGE REGULATOR CIRCUIT
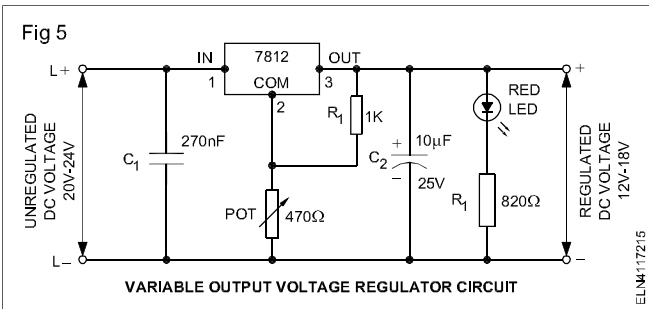
Four-terminal regulators: These are adjustable output voltage regulators and are also available as +ve and -ve regulators. These ICs have internal reference voltages and are protected internally for thermal overload, short circuit etc. Table 1 provides important specifications for most common ICs.

Fig 6 to 8 shows the common ICs used as voltage regulators with their terminal marking and Fig 9 to 11 shows the circuit configuration.

Fig 6

Fig 7

Fig 8

Fig 9
BASIC POSITIVE REGULATOR

$$V_{OUT} = V_{CONT} \left(\frac{R_1 + R_2}{2} \right)$$

Fig 10
POSITIVE 5 TO 30V ADJUSTABLE REGULATOR

Fig 11
−30V To −2.2V ADJUSTABLE REGULATOR
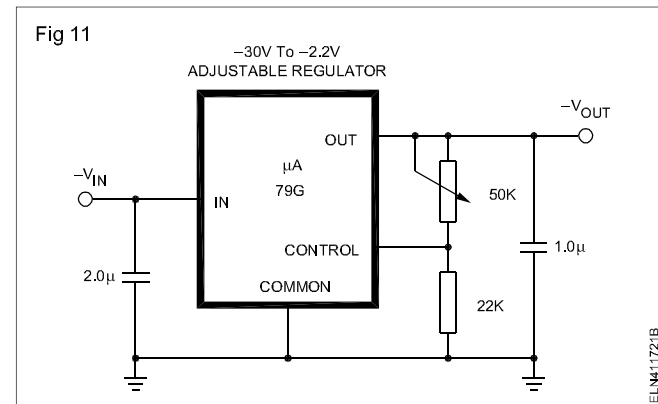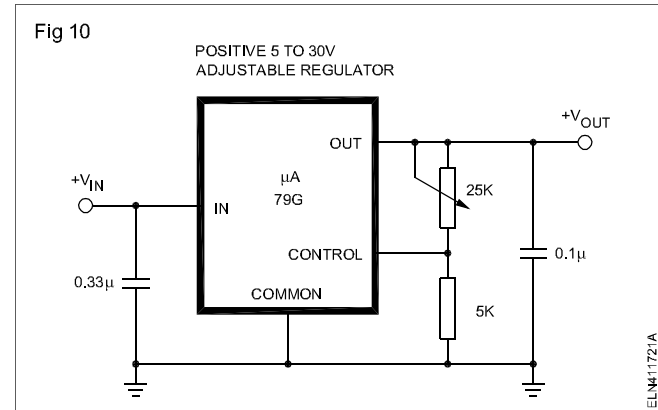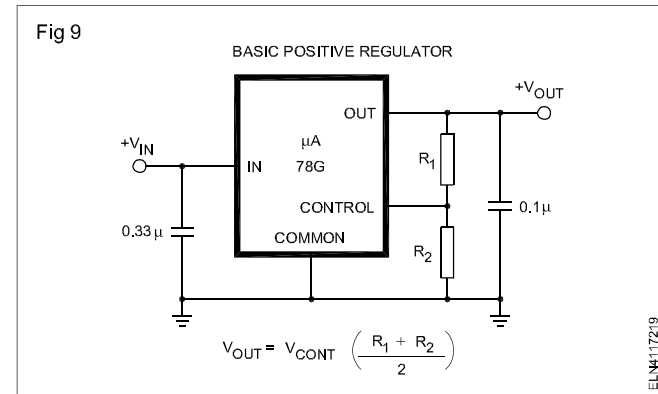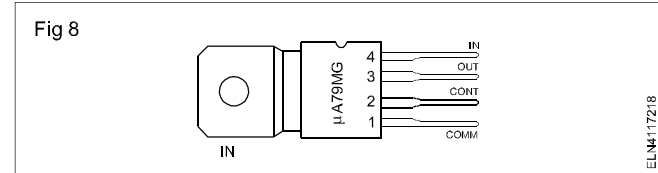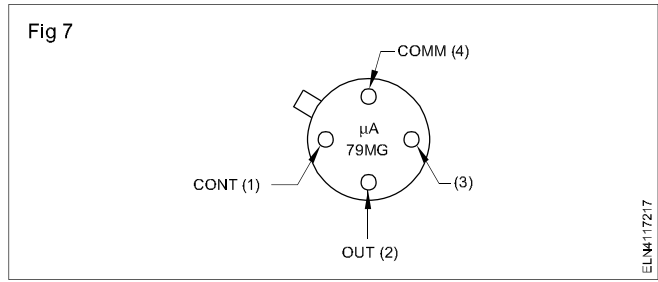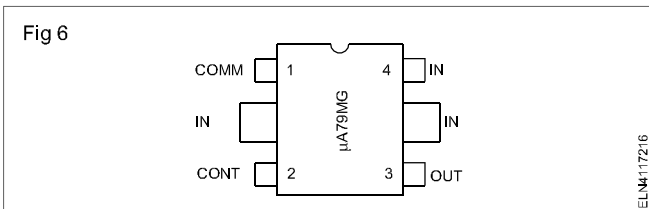
Table 3

Specifications of a 4-terminal voltage regulator

SI. No.	IC	MA 78G	MA78MG	MA79G	MA79MG
1	Input voltage range	7.5V to 40V	7.5V to 40V	–7V to –40V	–7V to –40V
2	Output voltage range	5V to 30V	5V to 30V	–2.23V to –30V	–2.23V to –30V
3	Line regulation	← better than 1% for all →			
4	Load regulation	← better than 1% for all →			
5	Drop out voltage	3V	3V	2.5V	2.5V
6	Peak output current	2.2A	800mA	2.2A	–800mA
7	Control pin current	5µA	5µA	2 µA	2µA
8	Short circuit current	750mA	300mA	250mA	100mA
9	Internal reference voltage	5V	5V	2.23V	2.23V
10	Ripple reflection {When the $[(V_{IN}) - (V_{OUT})] > 10$ V}	← better than 1000 →			

Binary numbers, logic gates and combinational circuits

Objectives : At the end this lesson you shall be able to
• **explain the digital electronics principle and positional notation and weightage**
• **explain decimal to binary conversion, binary odometer**
• **explain hexadecimal number system**
• **convert decimal to hexa, hexa to decimal and BCD system**
• **explain logic gates principle - NOT, OR and AND gates with truth table**
• **explain combinational gates - NAND, NOR with truth table and logic pulser.**

Introduction

When we hear the word 'number' immediately we recall the decimal digits 0,1,2....9 and their combinations. Digital circuits do not process decimal numbers. Instead, they work with binary numbers which use the digits '0' and '1' only. The binary number system and digital codes are fundamental to digital electronics. But people do not like working with binary numbers because they are very long when representing larger decimal quantities. Therefore digital codes like octal, hexadecimal and binary coded decimal are widely used to compress long strings of binary numbers.

Binary number systems consists of 1s and 0s. Hence this number system is well suited for adopting it to the digital electronics.

The decimal number system is the most commonly used number system in the world. It uses 10 different characters to show the values of numbers. Because this number system uses 10 different characters it is called base-10 system. The base of a number system tells you how many different characters are used. The mathematical term for the base of a number system is radix.

The 10 characters used in the decimal number systems are 0,1,2,3,4,5,6,7,8,9.

Positional notation and weightage

A decimal integer value can be expressed in units, tens, hundreds, thousands and so on. For example decimal number 1967 can be written as 1967 = 1000 + 900 + 60 + 7. In powers of 10, this becomes.

				$1 \times 10^3 = 1000$
10^3	10^2	10^1	10^0	$9 \times 10^2 = 900$
				$6 \times 10^1 = 60$
1	9	6	7	$7 \times 10^0 = 7$
				1967

i.e. $[1967]_{10} = 1(10^3) + 9(10^2) + 6(10^1) + 7(10^0)$

This decimal number system is an example of positional notation. Each digit position has a weightage. The positional weightage for each digit varies in the sequence 10^0, 10^1, 10^2, 10^3 etc starting from the least significant digit.

The sum of the digits multiplied by their weightage gives the total amount being represented as shown above.

In a similar way, binary number can be written in terms of weightage.

To get the decimal equivalent, then the positional weightage should be written as follows.

$$[1010]_2 = 1(2^3) + 0(2^2) + 1(2^1) + 0(2^0)$$

$$= 8 + 0 + 2 + 0$$

$$[1010]_2 = [10]_{10}$$

Any binary number can be converted into decimal number by the above said positional weightage method.

Decimal to Binary conversion

Divide the given decimal number by 2 as shown below and note down the remainder till you get the quotient - zero.

Example

```
         0
      ┌──────
   2  │  1      1  ──────→ MSB
   2  │  2      0
   2  │  4      0
   2  │  8      0
   2  │ 17      1
   2  │ 34      0  ──────→ LSB
```

The remainder generated by each division form the binary number. The first remainder becomes the LSB and the last remainder becomes the MSB of binary number.

Therefore, $[34]_{10} = [100010]_2$

Counting binary number

To understand how to count with binary numbers, let us see how an odometer (KM indicator of a car) counts with decimal numbers,

The odometer of a new car starts with the reading 0000.

After traveling 1KM , reading becomes 0001.

Successive KM produces 0002, 0003 and so on upto 0009

At the end of 10th KM , the units wheel turns back from 9 to 0, a tab on this wheel forces the tens wheel to advance by 1. That is why the number changed from 0009 to 0010. That is, the units wheel is reset to 0 and sent a carry to the tens wheel. Let us call this familiar action as reset and carry. The other wheels of odometer also reset and carry. For instance, after covering 999KM , the odometer shows 0999.

After the next KM , the unit wheel resets and carries, the tens wheel resets and carries, the hundreds wheel resets and carries and the thousands wheel advances by 1 to get the reading 01000.

Binary odometer

Visualize a binary odometer, a device whose wheels have only two digits 0 and 1. When each wheel turns, it displays 0 then 1 and then back to 0 and the cycle repeats. A four digit binary odometer starts with 0000.

After 1km, it indicates - 0001.

The next km forces the units wheel to reset and sends carry. So the number changes to 0010.

The third km results in 0011.

After 4km, the units wheel resets and sends carry, the second wheel resets and sends carry and the third wheel advances by 1. Hence it indicates 0100.

Table below shows all the binary numbers from 0000 to 1111 equivalent to decimal 0 to 15.

Decimal	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001

Decimal	Binary
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

Addition of binary numbers

Sum	Carry
0 + 0 = 0	0
1 + 0 = 1	0
0 + 1 = 1	0
1 + 1 = 0	1 (one plus one is equal to zero with carry one)

Ex: 1

$$1\ 0$$
$$+\ 1\ 1$$
$$\overline{1\ 0\ 1}$$

Ex: 2

$1 + 1 + 1 = 1$

$+\ 1$ (One plus one plus one is equal to one with carry one)

$$10$$
$$+\ 1$$
$$\overline{11}$$

Hexadecimal number system: In hexadecimal system there are 16 characters. They are 0,1,2,3,4,5,6,7,8,9, A,B,C,D,E,F where A=10, B=11, C=12, D=13, E=14, F=15 in decimal. In this system, the base is 16. This system is mainly used to develop programmes for computers.

For Example

$[23]_{16} = [35]_{10}$; $16^1 \times 2 + 16^0 \times 3 = 32 + 3 = 35$;

$[2C]_{16} = [44]_{10}$; $16^1 \times 2 + 16^0 \times 12 = 32 + 12 = 44$;

Decimal to hexadecimal conversions

The conversion of decimal to hexadecimal is similar to binary conversion. Only difference is that divide the decimal number successively by 16, and note down the remainder.

```
         0
16 |  1       1  ─────→ MSB
16 | 27      11 or B
16 | 432      0  ─────→ LSB
```

$[432]_{10} = [1B0]_{16}$

Hexadecimal to Decimal

This conversion can be done by putting it into the positional notation.

Ex: $223A_{16}$ = $2 \times 16^3 + 2 \times 16^2 + 3 \times 16^1 + A \times 16^0$

$\qquad$ = $2 \times 4096 + 2 \times 256 + 3 \times 16 + 10 \times 1$

$\qquad$ = $8192 + 512 + 48 + 10$

$\qquad$ = 8762_{10}

BCD (Binary Coded Decimal)

Binary Coded Decimal (BCD) is a way to express each of the decimal digits with a binary code, since there are only ten code groups in the BCD system, it is very easy to convert between decimal and BCD. Because decimal system is used for read and write, BCD code provides an excellent interface to binary systems. Examples of such interfaces are keypad inputs and digital readouts.

8421 code

The 8421 code is a type of binary coded decimal (BCD), binary coded decimal means that each decimal digit, 0 through 9 is represented by a binary code of four bits. The designation 8421 indicates the binary weights of the four bits (2^3, 2^2, 2^1, 2^0). The ease of conversion between 8421 code numbers and the familiar decimal numbers is the main advantage of this code. All you have to remember are the ten binary combinations that represents the ten decimal digits as shown in the Table.

Decimal digit	0	1	2	3	4
BCD	0000	0001	0010	0011	0100
Decimal digit	5	6	7	8	9
BCD	0101	0110	0111	1000	1001

The 8421 code is the pre-dominant BCD code, and when we refer to BCD, we always mean the 8421 code unless otherwise stated.

Inverters (NOT Gate)

An inverter is a gate with only one input signal and one output signal. The output state is always the opposite of the input state. Logic symbol is shown in Fig 1.

Fig 1
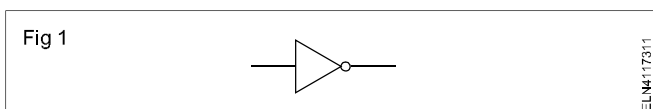
Transistor inverter

The Fig 2 shows the transistor inverter circuit. The circuit is a common emitter amplifier which works in saturation or in cut off region depending upon the input voltage. When V_{in} is in low level, say less than the transistor cut in voltage 0.6V in silicon type, the transistor goes to cut off condition and the collector current is zero. Therefore, V_{out} = +5V which is taken as high logic level. On the other hand, when V_{in} is in high level, the transistor saturates and $V_{out} = V_{sat}$ = 0.3V i.e low level.

Fig 2 — TRANSISTOR INVERTER
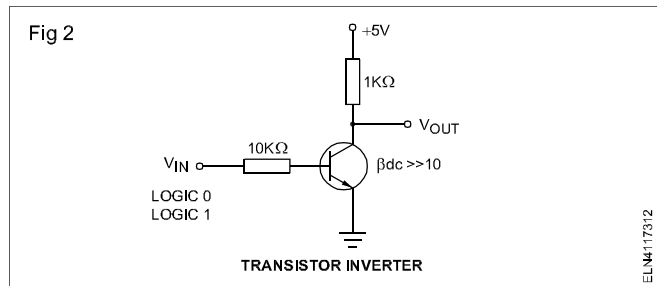
The table summarizes the operation

V_{in}	V_{out}
Low(0)	High(1)
High(1)	Low(0)

The logic expression for the inverter is as follows: Let the input variable be 'A' and the output variable be Y, then the output $Y = \overline{A}$.

OR and AND gate circuits

OR Gate

The output of an OR will be in 1 state if one or more of the inputs is in 1 state. Only when all the inputs are in 0-state, the output will go to 0-state. Fig 3 shows the schematic Symbol of an OR Gate :

Fig 3
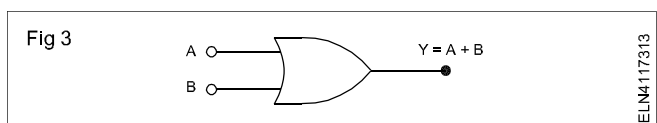
The boolean expression for OR gate is Y=A+B.

The equation is to be read as Y equals A ORed B. Two-input truth table given below is equivalent to the definition of the OR operation.

Truth table for OR gate

A	B	Y=A + B
0	0	0
1	0	1
0	1	1
1	1	1

Electrical equivalent circuit

The Fig 4a shows the electrical equivalent circuit of an OR gate. It is evident that if any one of the switch is closed, there will be output.

2 in-put OR gate using diode

The Fig 4b shows one way to build a 2-input OR gate, using diodes. The inputs are labeled as A and B, while the output is Y.

Fig 4
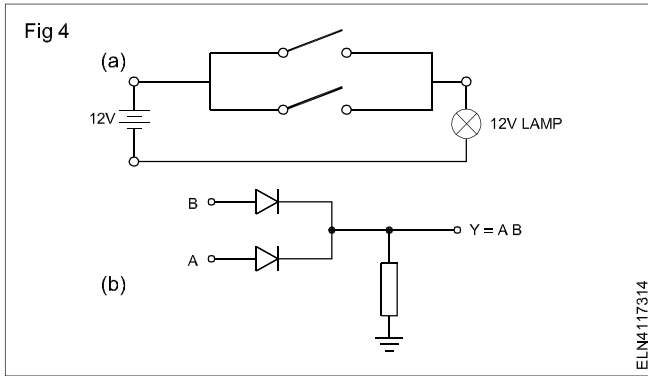
Assume   logic 0 = 0V (low)

logic 1 = +5V (high)

Since this is a 2 input OR gate, there are only four possible cases,

Case 1: A is low and B is low. With both the input voltage low, both the diodes are not conducting. Therefore the output Y is in low level.

Case 2: A is low and B is high, The high B input voltage (+5V) forward biases the lower diode, producing an output voltage that is ideally +5V (actually +4.3V taking the diode voltage drop 0.7V into consideration). That is, the output is in high level. During this condition, the diode connected to input A is under reverse bias or OFF condition.

Case 3: A is high and B is low, the condition is similar to case 2. Input A diode is ON and Input B diode is OFF and Y is in high level.

Case 4: A is high, B is high. With both the inputs at +5V, both diodes are forward biased, since the input voltages are in parallel, the output voltage is +5V ideally [+4.3V to a second approximation]. That is, the output Y-is in high level.

OR gates are available in the IC form. IC7432 is a T.T.L OR gate IC having 4 OR gates inside it.

Simple application of OR gate

Intrusion detection

Simplified portion of an intrusion detection and alarm system is two windows and a door. The sensors are magnetic switches that produce a high(1) output when windows and doors are opened and a low(0) output when closed. As long as the windows and the door are secured, the switches are closed and all three of the OR gate inputs are in low(0). When one of the windows or the door is opened, a high(1) output is produced on that input of the OR gate and the gate output goes high. It then activities an alarm circuit to warn of the intrusion.

AND gates

The AND gate has two or more inputs but only one output. All input signals must be held high to get a high output.

Even if one of the inputs is low, the output becomes low.

AND gate symbols for 2 input and 3 input gates are shown in Fig 5a and 5b.

Fig 5
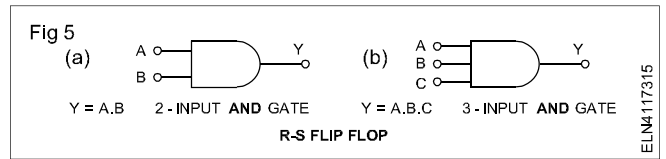
Truth table

Two input AND gate

A	B	Y=AB
0	0	0
0	1	0
1	0	0
1	1	1

Three input AND GATE

A	B	C	Y=ABC
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Electrical equivalent circuit of an AND gate

The output is available only when both the switches are closed. IC7408 is a T.T.L quad AND gate IC. (Refer data book for pin diagram). The electrical equivalent of AND gate and AND gate using diodes are shown in Fig 6a and 6b.

Fig 6
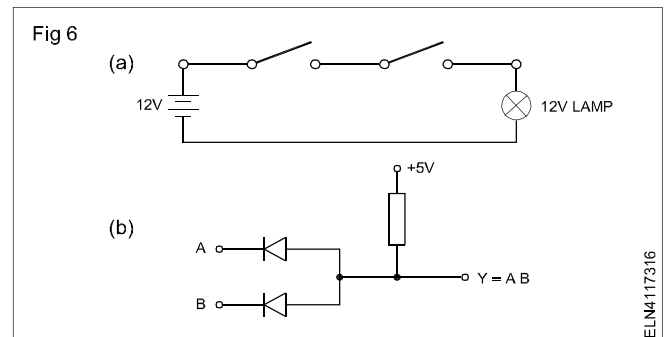
Two input AND gate using diode

I condition

A=0, B=0, Y=0 as in Fig 7.

Fig 7
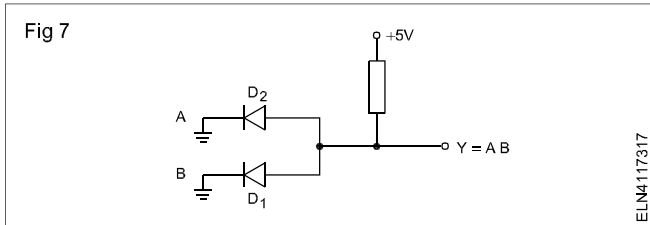
During the above condition I/P A and B are connected to ground to make logic low inputs. During this condition, both the diodes conduct, and pulls the O/P Y to logic-0.

II condition

A=0, B=1, Y=0 as in Fig 8.

Fig 8
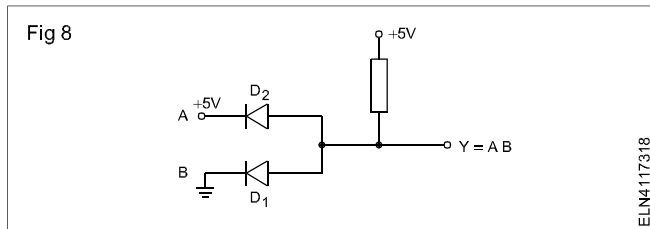
In the II condition shown in the figure above, diode D_1 is connected logic-0 input and diode D_2 is connected to +5V [Logic high]. Diode D_1 is in forward bias and conducts. Diode D_2 is having equal potential (+5V) at anode and cathode. So potential difference between anode and cathode is 0. Hence diode D2 does not conduct. The output Y is pulled down to logic zero, since D_1 is conducting.

III condition

A=1, B=0, Y=0 as in Fig 9.

Fig 9
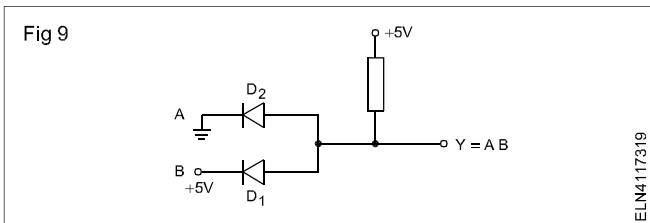
The III condition is similar to the II condition. D_2 is forward biased. D_1 is reverse biased. Hence output Y is pulled to logic-0.

IV condition

A=1, B=1, Y=1 as in Fig 10.

Fig 10
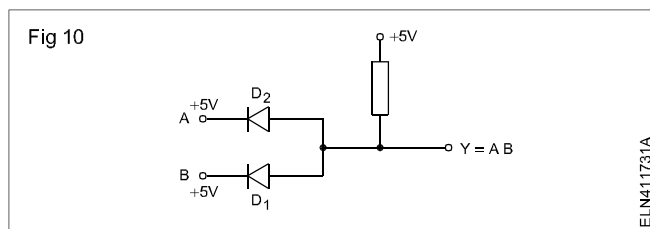
In this condition both the diodes are reverse biased. So both the diodes act as open circuit. Therefore output y is +5V i.e y is in logic-1 condition.

AND gate as an Enable/Inhibit device

A common application of the AND gate is to enable (i.e to allow) the passage of a signal (pulse waveform) from one point to another at certain times and to inhibit (prevent) the passage at other times.

In Fig 11a AND gate controls the passage of a signal (waveform A) to a digital counter. The purpose of this circuit is to measure the frequency of waveform 'A'. The enable pulse has a width of precisely 1 second. When the enable pulse applied at B is high, waveform A passes through the gate to the counter, and when the enabled pulse is low, the signal is prevented (inhibited) from passing through. Refer Fig 11b for the waveforms of the above process.

Fig 11
(a)

(b)
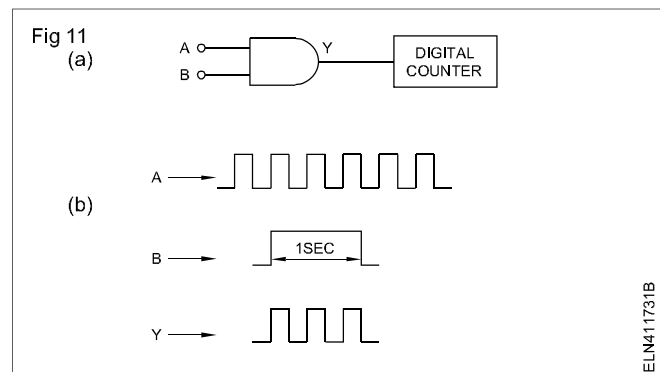
During the 1 second interval of the enabled pulse, a certain number of pulses in waveform A pass through the AND gate to the counter. The number of pulses counted by the counter is equal to the frequency of the waveform A. For example, if 1000 pulses pass through the gate in the 1 second interval of the enabled pulse, there are 1000 pulses/sec. That is, frequency is 1000Hz.

Combinational gate circuits - NOR and NAND

NOR Gate

In Fig 12a the output y of the circuit equals to the complement of A OR B, because the circuit is an OR gate followed by a NOT gate. To obtain high output [Logic-1], both the inputs should be tied to low input [Logic-0]. For the rest of the other three possibilities, output will be zero, the combination of this OR and NOT gate is called as NOR gate.
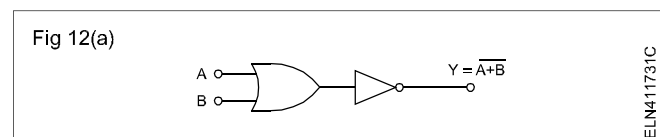
Fig 12(a)

Symbol (Fig 12b) :

Fig 12(b)
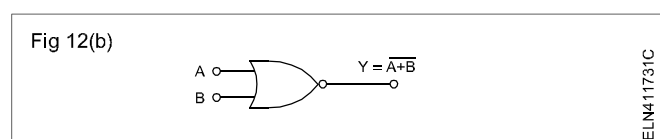
We can define a NOR gate as follows:

The output of a NOR gate is 0, even if one of the inputs is in logic-1. Only when both the inputs are in logic-0, the output is in logic-1.

Truth table

A	B	A + B
0	0	1
0	1	0
1	0	0
1	1	0

IC7402 is a T.T.L NOR gate IC. It contains 4 NOR gates. For pin details, refer data book.

NAND gate

An AND gate followed by a NOT gate forms the NAND gate as in Fig 13a. In this gate to get a low output (logic=0), all the inputs must be in high state and to get high output state, any one of the inputs or both inputs must be in low state.
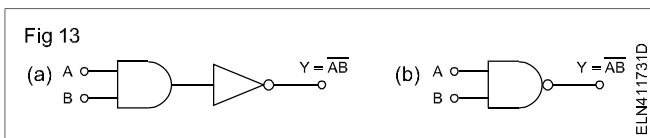
Fig 13

Fig 13b is the standard symbol for a NAND gate. The inverter triangle has been deleted and the bubble is moved to the AND-gate output.

Truth table for NAND gate

A	B	$Y = \overline{AB}$
0	0	1
0	1	1
1	0	1
1	1	0

Pulsed operation

Output waveform Y is low only for the time intervals when both inputs A and B are high as shown in the timing diagram Fig 14.

Logic pulser

Fig 15 shows the circuit diagram of logic pulser, the circuit essentially consists of NAND gates connected debouncer circuit and its output is Double inverted. The LED indicates, pulses ON or OFF status.

Fig 14

Fig 15

LOGIC PULSER
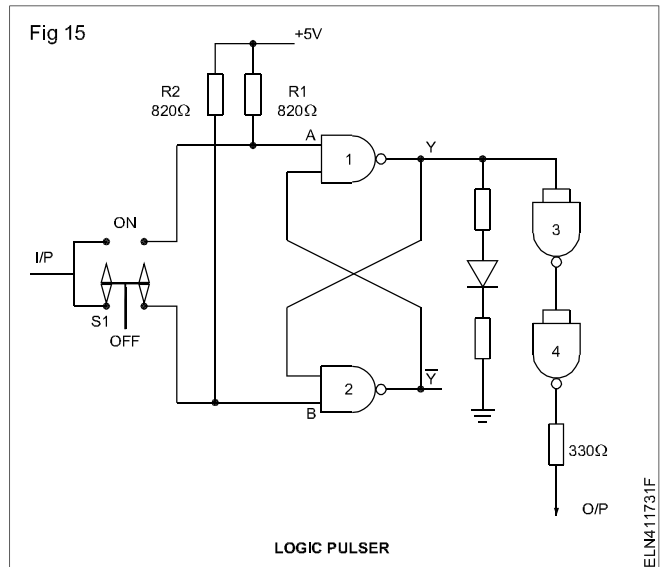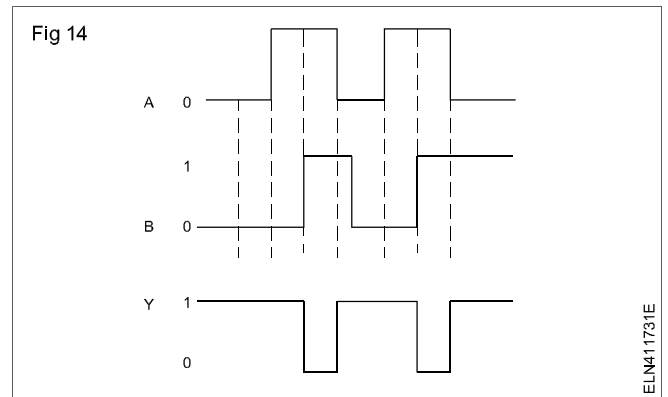
When switch S_1 is not pressed, (OFF position) B input of NAND gate No.2 is grounded, hence its output $\overline{Y}$ is forced to go logic HIGH. This HIGH output is feedback to NAND gate 1, A input of NAND gate 1 is also held HIGH through R_1 resistor (820Ω) and thus the output of NAND gate-1 'Y' is at low. This logic low output keeps LED in OFF condition and this logic low is again double inverted at the logic pulser tip through NAND gate 3 and 4 to get logic low level at pulser tip.

When S_1 is pressed to ON, A input of NAND gate is forced to go logic-low. Hence the output of this NAND gate is forced to go logic-HIGH. Therefore the 'Y' output is at logic-1, so LED glows and a logic-HIGH appears at probe tip. Also note that with HIGH at Y output, the inputs of NAND gate 2 are also at logic-HIGH and the output of NAND gate-2 is forced to go low. As long as switch S_1 is at ON position the probe tip is HIGH. When it is released it springs back to OFF position, and the output returns to a logic-LOW condition.

Wave shapes - oscillators and multivibrators

Objectives: At the end of this lesson you shall be able to
- **state the working principle and gain of oscillator**
- **explain the RC phase-shift oscillator and frequency calculation**
- **state the features, gain and frequency of Hartley, colpitts and crystal oscillators**
- **state the working principle and frequency calculation of bistable and monostable multivibrator using CRO.**

Oscillator: An oscillator is a circuit for producing voltages that vary in a regular fashion with respect to time. The output wave forms of oscillators are repeated exactly in equal successive intervals of time as in Fig 1a and Fig 1b.

Fig 1

(a)

SINUSOIDAL OSCILLATIONS

(b)

SQUARE WAVE

TRIANGULAR WAVE

SAWTOOTH (RAMP) WAVE
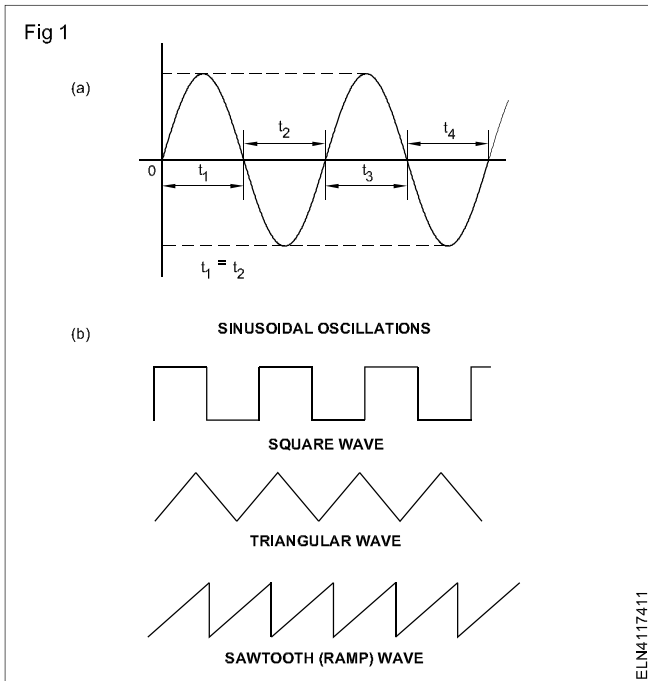
The output wave-form of an oscillator may be sinusoidal as in Fig 1a. Such oscillators are known as sine wave oscillators or harmonic oscillators.

The output of oscillators may be square, triangular or saw-tooth wave forms as in Fig 1b. Such oscillators are known as non-sinusoidal oscillators or relaxation oscillators.

It was discussed earlier that positive feedback results in converting an amplifier into an oscillator. To provide positive feedback the feedback signal should be inphase with the input signal such that it adds up with the input signal.

In practice, an oscillator will have no input AC signal at all, but it still generates AC signal. An oscillator will have only a DC supply. The oscillator circuit, makes use of the noise generated in resistors at the switching on time of dc supply and sustains the oscillations.

To build an oscillator, the following are essential;

- An amplifier
- A circuit which provides positive feedback from output to input.

The gain of an amplifier with feedback is given by,

$$A_{vf} = \frac{A_V}{1 - kA_V}$$

kA_v is known as the loop gain of the amplifier. In the case of the amplifiers when the sign associated with kA_v is negative, the denominator has value more than 1. And, hence the value of Avt will always be less than A_v (negative feedback). But, if the value of kA_v is made larger, such that, it approaches unity, and, if the sign associated with kA_v is negative then the value of the denominator decreases to less than 1, and hence, A_{vf} will be larger than A_v.

In case of oscillators, if the loop gain kA_v is made positive, i.e. by feeding back signal which is in-phase with the input signal, then there will be an output signal even though there is no external input signal. In other words, an amplifier is modified to be an oscillator by positive feedback such that it supplies its own input signal.

Example

An amplifier has a voltage gain of 40 without feedback. Determine the voltage gains when positive feedback of the following amounts is applied.

i) k = 0.01

ii) k = 0.02

iii) k = 0.025

Solution

i) $A_{vf} = \dfrac{A_V}{1 - kA_V} = \dfrac{40}{1 - 0.01 \times 40} = \dfrac{40}{0.6} = 66.7$

ii) $A_{vf} = \dfrac{A_V}{1 - kA_V} = \dfrac{40}{1 - 0.02 \times 40} = \dfrac{40}{0.2} = 200$

(iii) $A_{vf} = \dfrac{A_V}{1 - kA_V} = \dfrac{40}{1 - 0.025 \times 40} = \dfrac{40}{0} = \infty$ (Infinity)

In (iii) the gain of the amplifier become infinite when the loop gain $kA_v = +1$. This is known as the critical value of the loop gain kA_v. It is important to note that the output voltage cannot be infinite. Instead the amplifier will start working as an oscillator without the need of any separate input. If the feedback path contains a frequency selective network, the requirement of $kA_v = 1$ can be met at only one particular frequency, such that, the output of the oscillator will be a sinusoidal signal of a particular frequency. Such oscillators are known as sine wave oscillators.

One of the simplest form of sine wave oscillators is the phase shift oscillator. Fig 2 shows the principle behind an RC phase shift oscillator.

Fig 2
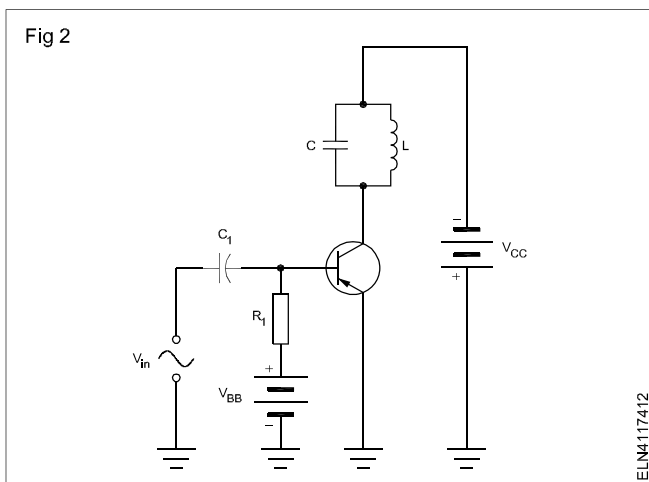
The feedback network shown in Fig 3 consists of resistors and capacitors which provide the required phase shift of 180°. Due to the presence of capacitors in the feedback network, the feedback network can be so designed to provides the required phase shift of exactly 180° at a particular frequency f given by,

Fig 3

$C_1 = C_2 = C_3$
$R_1 = R_2 = R' + R_{in}$

PROVIDES 60° PHASE SHIFT

$f = \dfrac{1}{2\pi RC\sqrt{6}}$
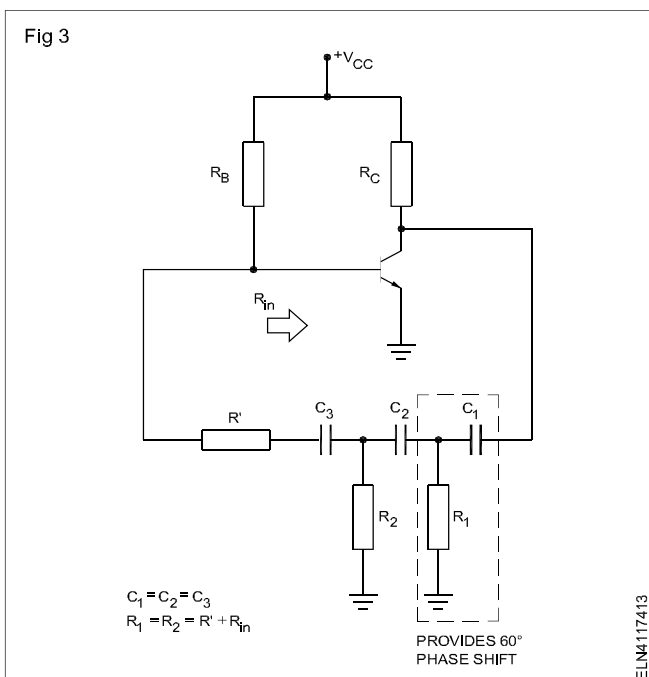
The other condition to be satisfied oscillations to occur is that the loop gain KA_v should be equal to unity. To satisfy this condition, using classical network analysis, it can be found that, the value of K should be, $k = 1/29$. Therefore, the voltage gain of the amplifier A_v stage must be greater than $1/k$ or greater than 29 so that kA_v becomes equal to 1.

Transistor RC phase shift oscillator: Fig 3 shows a single transistor phase shift oscillator using resistors and capacitors in a feedback network.

There are three sections of R and C in the feedback network. Each RC section provides a 60° phase shift at a specific frequency, resulting in a 180° phase shift as required for positive feedback. This satisfies one of the two required conditions for oscillations.

In Fig 3, the feedback signals coupled through a feedback resistor R^1 in series with the amplifier stage input Resistance R_{in}. resistor R^1 can be made variable for adjusting the oscillator frequency. For each of three sections of R_C phase shift network to produce 60° phase shift, it is necessary that $C_1 = C_2 = C_3$ and $R_1 = R_2 = R' + R_{in}$.

The other required condition for oscillation, i.e. loop gain kA_v to be unity is satisfied by the circuit at Fig 2, when β of the transistor used in the circuit is,

$h_{fe} = \beta = 23 + 29\dfrac{R}{R_C} = +4\dfrac{R_C}{R}$ ......(2)

where, $R_1 = R_2 = R$

When β is atleast the value given by equation (2) or greater than, the circuit at Fig 2 it will oscillate.

Practical transistor RC phase shift oscillator

Fig 4 shows a practical transistor RC phase shift oscillator which is similar to that shown in Fig 2.

In Fig 4 note that resistor R_3 (in Fig 2 it is denoted as R') used for frequency adjustments is connected in series with one of the resistors of the RC section. Resistor R_4 provides the necessary bias stabilisation for the transistor operation. Note that a small value capacitor C_4 is connected in parallel with the input. The purpose of C_4 is to bypass the unwanted high frequency oscillations to ground. The value of R_3 can be varied to adjust the frequency of oscillations. However, the variation that can be obtained by R_3 is limited.

For the circuit at Fig 3, the frequency of oscillation is given by,

Fig 4
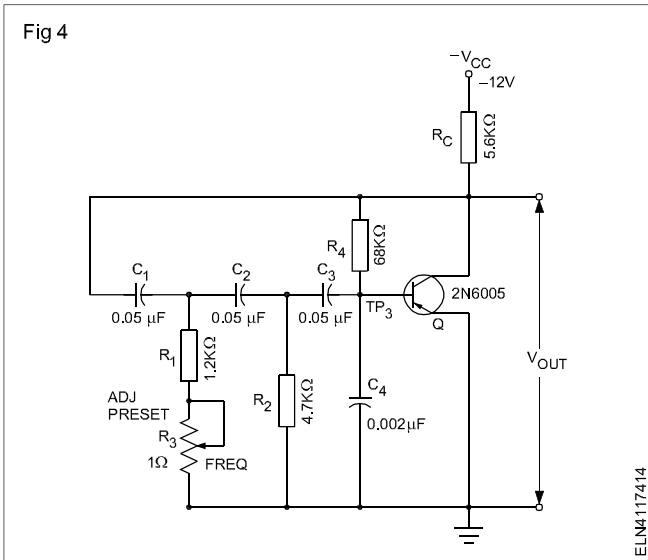
$$f = \frac{1}{2\pi C \sqrt{6R_1^2 + 4R_1R_C}}$$ ......(3)

where, $C = C_1 = C_2 = C_3$

The minimum value of hfe or β of the transistor used in the circuit at Fig 3 should be,

$$h_{fe} = \beta = 23 + 29\frac{R_1}{R_C} + 4\frac{R_C}{R1}$$

using the component values at Fig 3, the β of the transistor used should be a minimum of,

$$\beta = 23 + 29\frac{1.2K}{5.6K} + 4\frac{5.6K}{1.2K} = 47.89$$

> **The frequency of oscillations can be increased by decreasing the value of R or by decreasing the value of C.**

In the practical circuit at Fig 3, collector feedback bias is employed to ensure that the transistor will never go to saturation. Other biasing techniques such as voltage divider bias can also be used for DC biasing of the transistor. Since the frequency of oscillations is decided only by the feedback phase shift network, biasing resistors will not have any effect of the frequency of oscillations. The important point to be noted is that the β of the transistor should be higher than the minimum β given in equation 2 to have sustained oscillations.

Hartley oscillator

Principle of sinusoidal or harmonic oscillations: Fig 5a shows an inductor and a capacitor connected in parallel as a parallel LC resonant circuit. A parallel LC circuit is also known as tuned circuit or tank circuit.

In Fig 5a, when switch S is put into position A, the capacitor gets charged with the bottom plate being negative and the top plate positive. This means, energy is stored in the capacitor in the form of an electric charge.

When switch S is put into position B, as in Fig 5b, the capacitor starts discharging through the inductor, creating an expanding magnetic field around L. Since the inductor has the property of opposing any sudden change in current through it, the current builds up slowly.

Once the capacitor gets fully discharged, the magnetic field around L begins to collapse. The collapsing magnetic field, induces a voltage (back-emf) in L. This back emf tends to maintain the electron flow through L in the same direction as when C was discharging. Hence, this back emf in the inductor starts charging the capacitor with opposite polarity as in Fig 5c. After the magnetic field has totally collapsed, C would have got charged in the opposite direction as in Fig 5c.

Sinusoidal wave form: However, owing to the resistance in a practical inductor and the losses in the capacitor due to resulting I^2R (heat loss) the amplified of the oscillation decreases gradually (damped) and ultimately the oscillations die down as in Fig 5d.
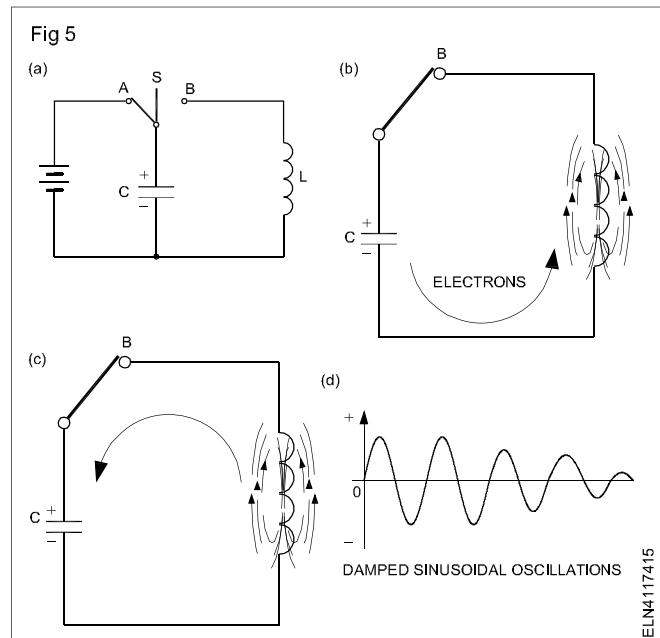
The frequency of oscillation produced by the resonant frequency is given by,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Overcoming losses in tank circuit for sustained oscillations: To avoid the damping of oscillations, when the energy fed into the circuit has been used up, it is necessary to supply more energy by charging the capacitor again. As shown in Fig 5a, by switching S between A and B at proper time, the oscillations can be maintained thus obtaining sinusoidal waveform of constant amplitude and frequency.

Another method of making the LC tank circuit to give undamped oscillations is, to connect the tank circuit in the output of an amplifier as in Fig 6.

Fig 6
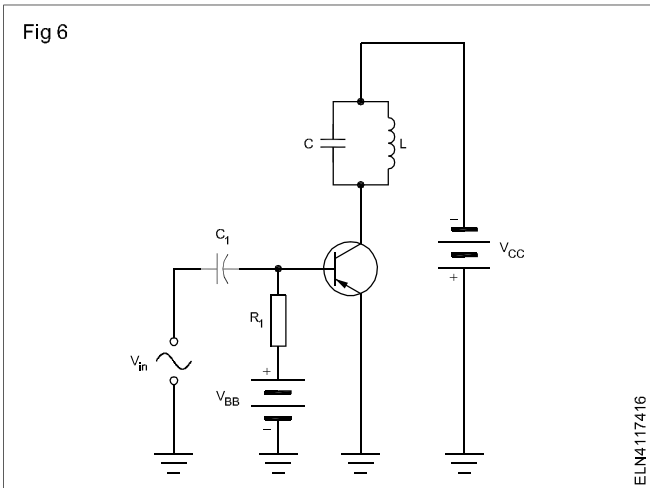
The amplifier is kept at cut-off by the dc supply V_{BB} which reverse-biases the base-emitter circuit. A sine wave is injected to the base circuit with such an amplitude that the collector current flows at the peak of the negative alterations of the input sine wave. This excites the LC circuit in the collector of the transistor and the tank keeps oscillating. If the input sine wave has the same frequency as the frequency of oscillations of the tank circuit, the oscillations in the LC tank is maintained.

Fig 7 shows a modified form of circuit at Fig 6. In Fig 5a transistor amplifier connected in such a way that it will cause undamped oscillations without requiring any external signal. Such a circuit is known as an oscillator.
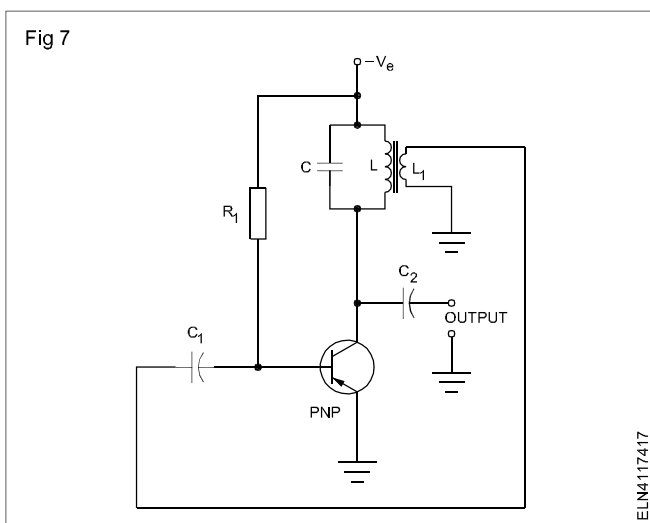
Fig 7

The oscillator circuit at Fig 7 is known as tickler-coil oscillator. Here L1 is inductively coupled to L. When power is first switched ON to the circuit, current flows in the transistor. As the current flows through L, it induces a voltage in L1 which is coupled to the base of the transistor and is amplified.

If the phase of the feedback voltage is adding, then there is an increase in the collector current. This action builds up a large current pulse which excites the LC tank into oscillations. The signal fed by L1 to the base of the transistor is a sine wave of the same frequency as that in the LC circuit and of proper phase to sustain the oscillations.

The signal induced in the base thus eliminates the need for an external input to the oscillator and the LC tank will oscillate as long as the DC power to the circuit is ON.

The feedback given to the amplifier in Fig 7 in the proper phase so as to sustain (keep going) oscillations is referred to as positive feedback or regenerative feedback.

Barkhausen criterion: The mathematical analysis for an amplifier to oscillate on its own is given below:

- In the amplifier shown in Fig 7, assume that the gain of the amplifier is A and the feedback factors is β. If the product of $A\beta$ is less than 1 ($A\beta < 1$), then the output signal will be a damped oscillations which will die down as is shown in Fig 8a.

- If $A\beta > 1$, the output voltage builds up as shown in Fig 8b. Such oscillations are called growing oscillations.

- If $A\beta = 1$, the output amplitude of oscillations remains constant as in Fig 8c.

Fig 8

a) DAMPED OSCILLATIONS

b) GROWING OSCILLATIONS

c) SUSTAINED OSCILLATIONS
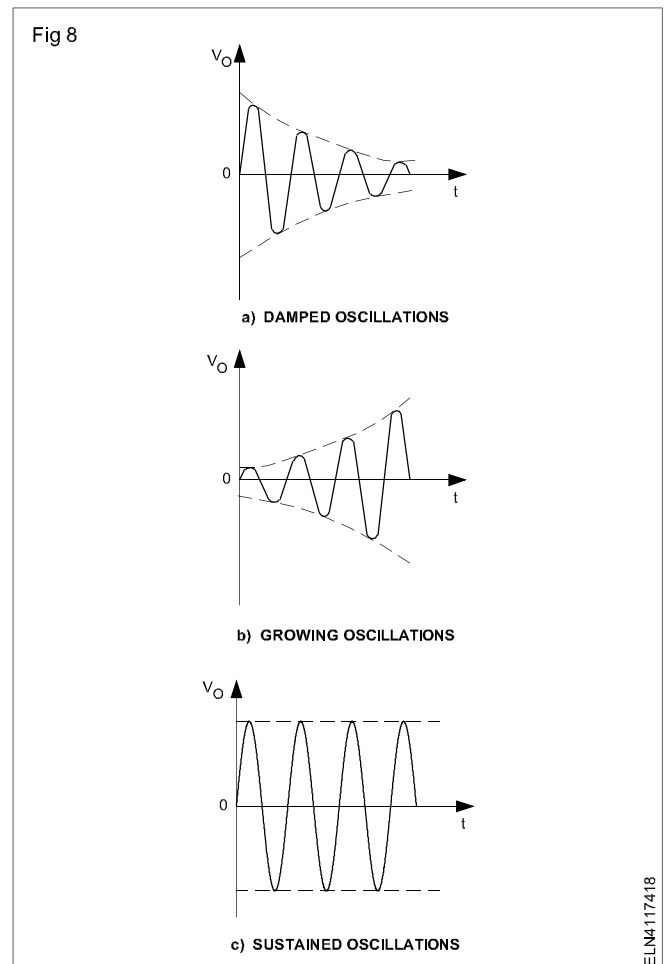
When the feedback is positive (regenerative), the overall gain of the amplifier with feedback (A_f) is given by,

$$A_f = \frac{A}{1 - A\beta}$$

When $A\beta = 1$, the denominator of the equation will be zero, and hence A_f = Infinity. The gain becoming infinity means, there is output without any input. i.e. the amplifier becomes an oscillator. This condition $A\beta = 1$, is known as Barkhausen criterion for oscillations.

Summarizing, the basic requirements for an oscillator are;

- A stable DC power supply source

- An amplifier

- A regenerative (positive) feedback from output to input

- A LC tank circuit to determine the frequency of oscillations

Starting signal for oscillators: As discussed above an oscillator gives alternating output voltage without an input signal once the amplifier is given a regenerative feedback. But in a practical oscillator circuit, to start off oscillations, no starting input signal is provided. However, the starting signal of an oscillator is generated by the noise voltage while switching on the oscillator circuit. Such noise voltages are produced due to the random motion of electrons in resistors used in the circuit.

Noise voltage contains almost all the sinusoidal frequencies of small amplitude. However, it gets amplified and appears at the output terminals. The amplified noise now drives the feedback network, which is a resonant tank circuit. Because of this tuned tank circuit, the feedback voltage $A\beta$ is maximum at a particular frequency f_r, which will be the frequency of oscillations.

Furthermore, the phase shift required for positive feedback is correct at this frequency f_r only. Thus although the noise voltage contains several frequency components, the output of the oscillator will contain a single sinusoidal frequency f_r the resonant frequency of the tank circuit.

To summarize, the following are the requirements of an oscillator circuit to take-off with oscillations and have sustained oscillations,

- there must be positive feedback.

- Initially the loop gain product $A\beta$ must be >1.

- After the circuit starts oscillating, the loop gain product $A\beta$ must decrease to 1 and remain at 1.

Hartley oscillator: One of the simplest of sinusoidal oscillators is the Hartley oscillator shown in Figs 9a and 9b.

As in Fig 9a is a series fed Hartley oscillator. This circuit is similar to the tickler coil oscillator shown in Fig 7, but the tickler circuit coil L_1 is physically connected to L, and is hence a part of L (like an auto-transformer). This oscillator is called series-fed because, the high frequency oscillations generated and the DC paths are the same, just as they would be in a series circuit. Series fed Hartley oscillators are not preferred due to their poor stability of oscillations.

Fig 9

a) SERIES - FED HARTLEY OSCILLATOR

b) PARALLEL - FED HARTLEY OSCILLATOR
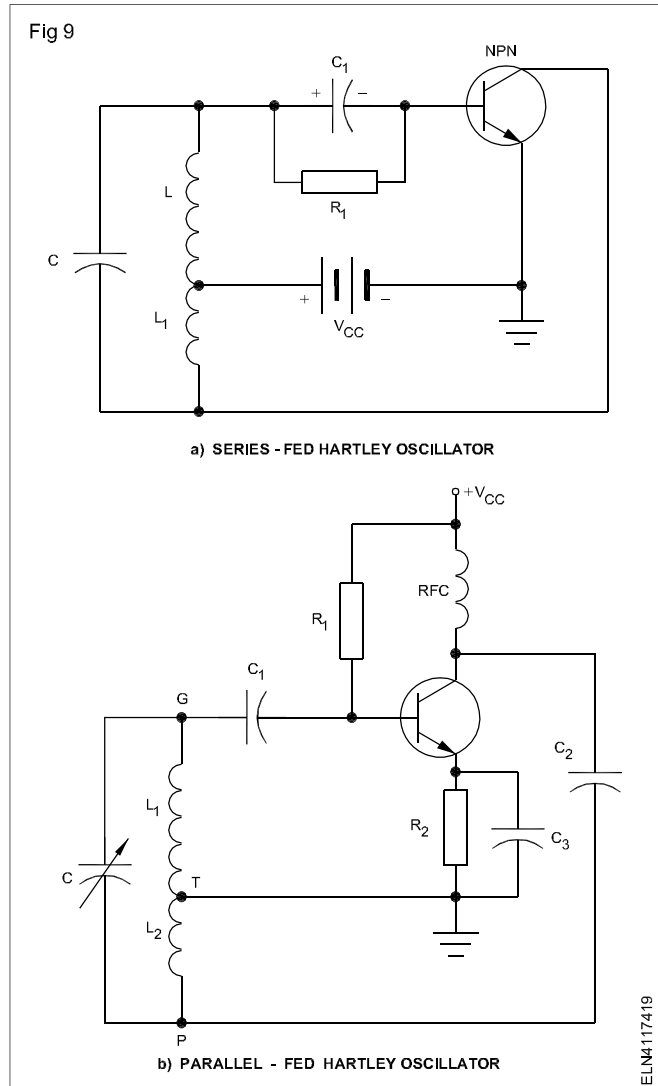
Fig 9b is parallel fed Hartley oscillator commonly used in radio receivers. Parallel fed Hartley oscillators are known for their high stability of oscillations.

The circuit at Fig 9b is actually an amplifier with positive (regenerative) feedback to have sustained oscillations. The capacitor C_2 and inductor L_2 form the path for RF current in the collector to ground circuit.

RF current through L_2 induces a voltage in L_1 in proper phase and amplitude to sustain oscillations.

The position of the tap at the junction of L_1 and L_2 determines how much signal is fed back to the base circuit.

The capacitor C and the inductors $L_1 + L_2$ forms the resonant tank circuit of the oscillator which determines the frequency of oscillations. Capacitor C can be made variable capacitor for tuning the oscillator to different frequencies. C_1 and R_1 form the RC circuit which develops the bias voltage at the base.

The RF choke at the collector keeps the high frequency ac signal out of the V_{cc} supply. In cheaper oscillator circuits the RF choke is omitted and is replaced by a resistor.

Resistor R_2 connected in the emitter provides DC stabilization. R_2 is by-passed by C_3 to prevent AC degeneration.

The Hartley oscillator coil has three connections. These are usually coded on the coil. If they are not, it is generally possible to identify them by a resistance check. The resistance between the taps T and P as in Fig 10, is small compared with the resistance between T and G., If the coil connections are not made properly, the oscillator will not work.

Fig 10
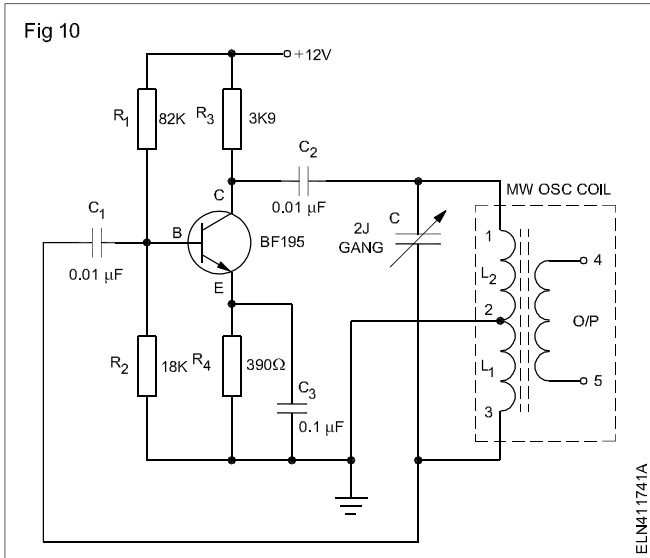
Checking oscillator frequency: The frequency of an oscillator can be computed if the values of L ($L = L_1 + L_2$) and C are known using the formula,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where, f is in hertz, L in henry, and C in farad.

The frequency of an oscillator may be measured in two ways,

• Using a direct read-out frequency meter also known as frequency counter which is most accurate, popular and easy to use.

• Using an oscilloscope with a calibrated time base to measure the period of the wave-form. From the measured period, 'T' frequency is calculated using the formula

$$f = \frac{1}{T}$$

where, f is the frequency in Hz and 'T' the time period in seconds.

A practical Hartley oscillator circuit using medium-wave oscillator coil as L is shown in Fig 10.

The advantage of using a medium wave oscillator coil for L is that the output can be taken out of the secondary winding (4 and 5) of the coil.

The transistor used is a silicon high frequency transistor (BF series) as the oscillator frequency is in the range of 1 MHz.

The divider biasing is provided to make the DC conditions such that the amplifier works as Class A. With the heavy feedback (large β), the large feedback signal drives the base of the transistor into saturation and cut-off. This large feedback signal produces negative DC clamping at the base, changing the operation from Class A to Class C. This negative clamping automatically adjusts the value of Aβ to 1. If the feedback is too large, it may result in loss of some of the output voltage because of the stray power loses.

When you build an oscillator, you can adjust the amount of feedback to maximize the output voltage. The trick is to use enough feedback to start under all conditions (different transistors, temperature, voltage etc.), but not so much that you lose more output than necessary.

The frequency of oscillations of the oscillator circuit at Fig 10 can be varied by varying the position of the shaft of the gang of the gang capacitor (C_4).

Colpitt's oscillator: Colpitt's oscillator is another type of sinusoidal oscillator or harmonic oscillator which uses a tank circuit for oscillations. Colpitt's oscillators are very popular and are widely used in commercial signal generators and communication receivers.

A typical Colpitt's oscillator is in Fig 11 is similar to a Hartley oscillator. The only difference is that the Colpitt's oscillator uses a split capacitor for the tank instead of a split inductor used in Hartley oscillators.

The parallel-fed or shunt-fed Colpitt's oscillator is in Fig 11, uses the common emitter configuration. The capacitors C_{1A} & C_{1B} from the voltage divider used to provide the feedback signal. The voltage drop across C_{1B} determines the feedback voltage. All other components in this circuit have the same function as in the Hartley circuit.

Fig 11
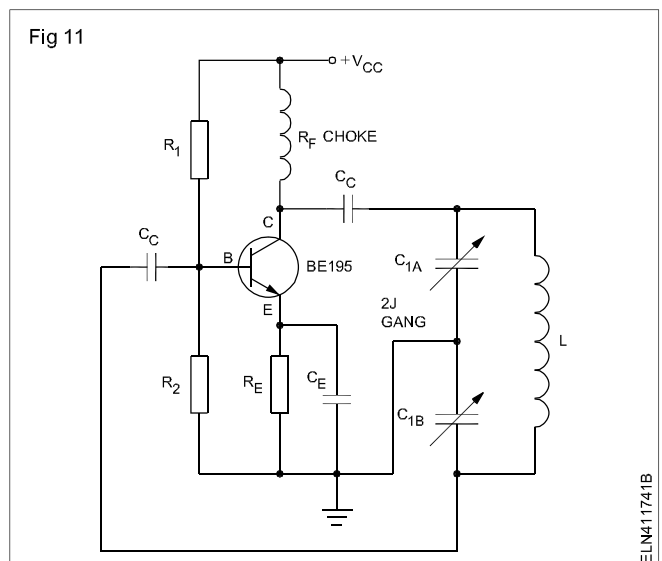
The frequency of oscillations of the Colpitt's oscillator is given by,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where,

f is the frequency of oscillation in hertz,

L is the inductance of the coil in henry

C is the total capacitance in farad given by,

$$C = \frac{C_{1A} \times C_{1B}}{C_{1A} + C_{1B}}$$

The frequency of oscillations can be changed by using a miniature ganged capacitor for C_{1A} & C_{1B}.

By varying the shaft of the ganged capacitor, both the capacitances C_{1A} and C_{1B} get varied, and hence, the frequency of oscillations of the oscillator varies.

Colpitt's oscillators are generally used for generating frequencies above 1 MHz.

A practical Colpitts oscillator circuit using a ganged capacitor for C_{1A} and C_{1B} and a medium wave oscillator coil for L is in Fig 12.

Fig 12
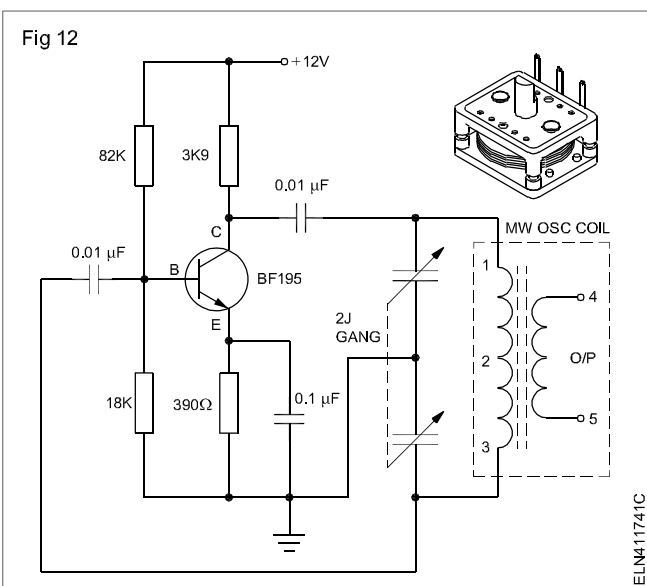
Crystal oscillators: The LC oscillator circuits such as Hartley and Colpitts have the problem of frequency instability. The most important reason for the frequency drift in LC oscillators is, the change in value of capacitance and inductance of the tank circuit that occurs when temperature changes.

As the temperature increases or decreases, the values of L and C deviate causing the circuit to oscillate at a frequency different from the desired resonant frequency. Other reasons for frequency deviation are, the leads of transistor, inter electrode and wiring capacitances.

The problem of frequency drift can be largely overcome by using high Q coils and good quality capacitors. But, with ordinary inductors and capacitors, Q-values in excess of a few hundred is very difficult or impossible to achieve.

Large improvements in frequency stability can be achieved by using a quartz crystal in the place of the conventional tuned circuit. Such oscillator circuits are referred to as crystal controlled oscillators.

Piezo-electric effect: It was discovered that certain crystals such as quartz and Rochelle salt, exhibit a special property known as piezo-electric property. A quartz crystal looks like a piece of thin frosted glass usually cut into 1/4 to 1 inch squares as in Fig 13.

Fig 13
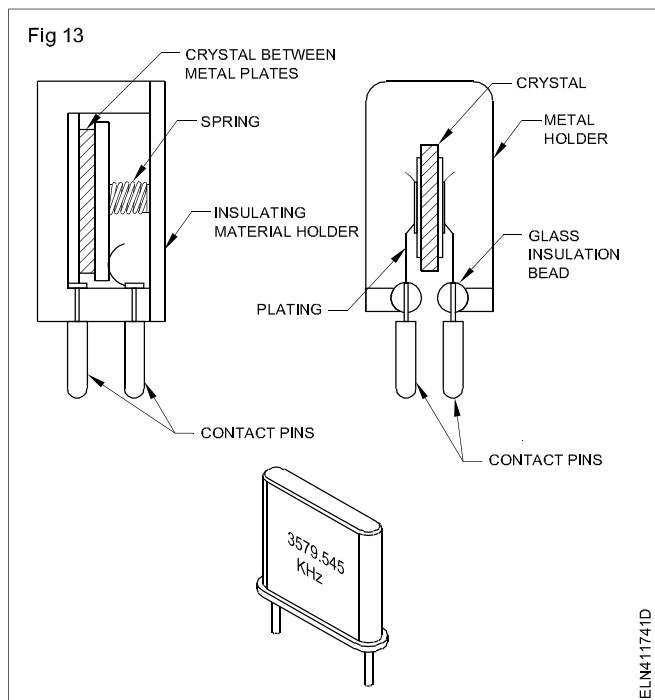
When such a crystal is held between two flat metal plates and pressed together, a small emf will be developed between the plates as if the crystal became a battery for an instant. When the plates are released, the crystal springs brings back to its original shape and an emf of opposite polarity is developed between the two plates. In this way, mechanical energy/force is converted to electrical energy by the crystal.

This property is made use of in the pick-ups for gramophone records. In a gramophone record, small mechanical vibrations are produced when the stylus tracks the groove on the gramophone plate. This vibrating force gives rise to corresponding voltages representing the recorded sound at the pick-up terminals.

In addition to the above property of the crystal, when an emf is applied across the two plates of the crystal, the crystal will distort from its normal shape. If an opposite polarity emf is applied, the crystal will reverse its physical distorted shape. In this way, these crystals also convert electrical energy into mechanical energy.

The above two reciprocal actions of a crystal are known as piezo-electric effect. Such crystals are housed in crystal holders as in Fig 13.

Amongst several crystals having this piezo-electric property, the quartz crystal is most popular because, mechanical oscillations are started in this crystal it takes a long time for the oscillations to die away. Quartz crystals therefore, have a very high mechanical Q.

So far as the electrical properties are concerned, a quartz crystal is equivalent to the LC resonant circuit is in Fig 14.
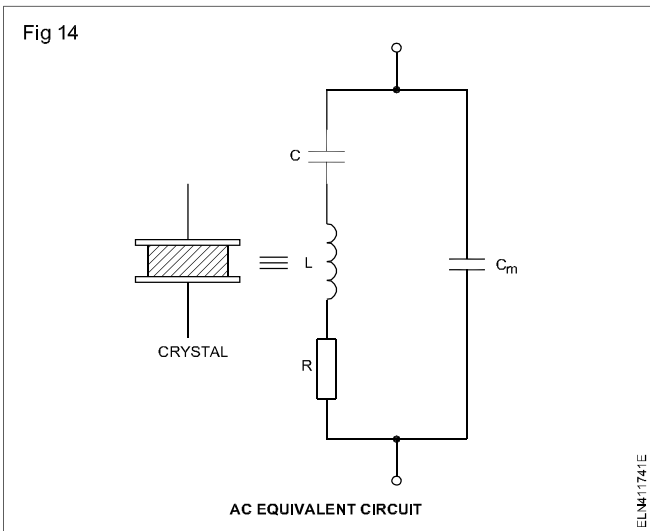
The values of L, R, C and C_m depend upon the physical size of the crystal and how the crystal is cut from the original mass. Capacitance C_m represents the mounting capacitance. For using the crystal in electronic circuits, two conducting electrodes are placed onto its two faces. Connecting leads are then joined to these electrodes. When the leads are connected to a source of oscillating voltage, mechanical vibrations are set up within the crystal.

If the frequency of the oscillating voltage is close to a resonant frequency of the crystal, then the crystal forces the oscillating voltage to coincide with the oscillating frequency of the crystal. Hence, in an oscillator, by using the crystal in the place of an LC resonant circuit, the frequency of oscillation is determined almost entirely by the crystal. Q values in excess of 20,000 are easily obtained with readily available crystals resulting in highly stable oscillating frequency.

Hence, when accuracy and stability of the oscillation frequency are important, a quartz crystal oscillator is used instead of Hartley or Colpitt's oscillators. The frequency range of crystals is usually between 0.5 to 30 MHz.

Pierce crystal oscillator: The pierce crystal controlled oscillator is in Fig 15 is often used because it requires very few components and has good frequency stability.

The pierce crystal oscillator is similar to the Colpitts oscillator but for the inductance coil replaced by a crystal. Here the crystal across the collector and the base terminals

of the transistor determines the oscillating frequency. As in a colpitts oscillator, capacitors C_1 and C_2 form a capacitive voltage divider for feedback. The ac voltage across C_2 provides the necessary positive feedback to the base.
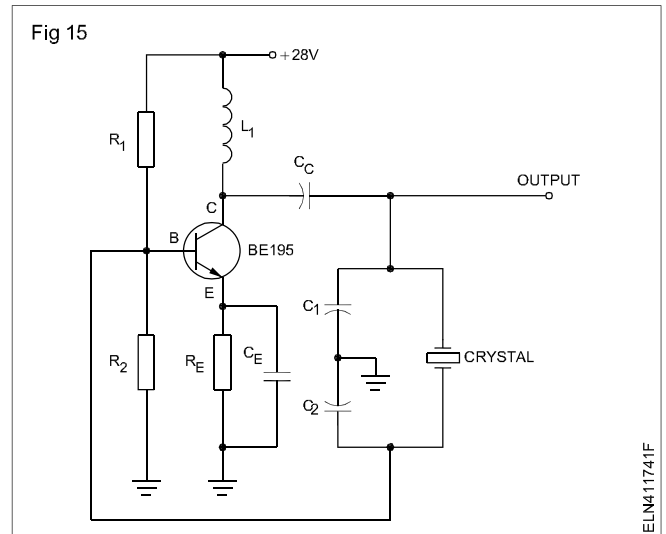
In Fig 15, the crystal acts like an inductor that resonates with C_1 and C_2. In the base circuit, the $R_1 R_2$ divider supplies forward bias voltage from the V_{CC}. Bias stabilization is provided by the $R_E C_E$ combination in the emitter circuit.

In Fig 15, if the crystal resonant frequency is, say 3579.545 Hz, then the oscillator oscillates at the same frequency and gives a sinusoidal output of 3579.545 Hz.

Crystal oscillators are generally used in,

• mobile radio transmitters and receivers

• broadcast transmitters

• test equipments such as signal generators where exact frequency and very high frequency stability are of utmost importance. The frequency drift in crystal controlled oscillators will be less than 1 Hz per 10^6 Hz.

Multivibrator

It is a free running oscillator which gives repetitive pulse wave form output, and other types of multi-vibrators which are classified depending upon the manner in which the two stages of the multi-vibrator interchange their ON and OFF states. They are:

• **Mono-stable multivibrator** (having one stable state).

• **Bistable multivibrator** (having two stable states).

Mono-stable Multivibrator

Fig 16 shows a typical mono-stable multi-vibrator also known as **mono-shot** or **one-shot**.

A mono-shot has one stable state with one transistor conducting and the other off. This state can be changed only temporarily by giving an input pulse generally known as **trigger** pulse to the transistor which is off. But this

changed state returns back to its original stable state after a period decided by the values of R and C.

Fig 16
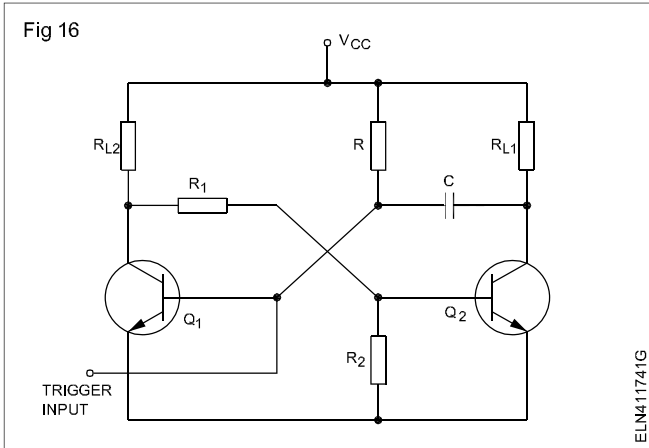
Fig 17 shows a practical mono-stable multi-vibrator with trigger input. Fig 17 also shows the wave-forms at different points of the circuit.

Fig 17
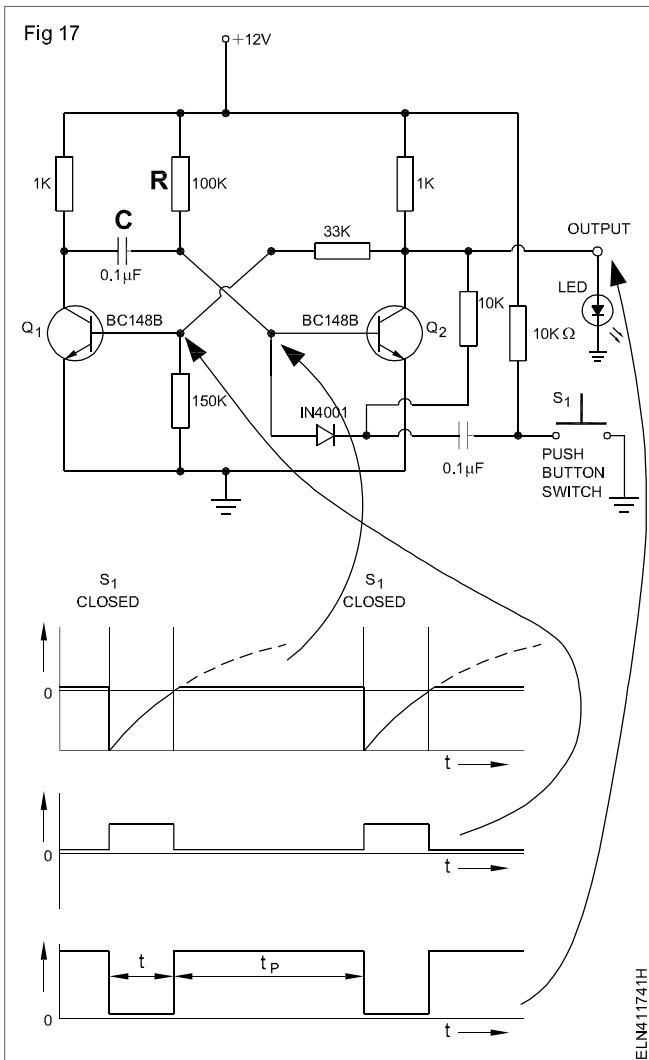
The period t for which Q_2 is kept off temporarily is given by,

t = 0.69 RC.

Mono-stable multi-vibrators are extensively used as timers in electronic timing control circuits.

Bistable multivibrator

An astable multi-vibrator automatically switches from one state to other (ON-to-OFF or OFF-to-ON...). Whereas, a bistable multi-vibrator will change the state(ON to OFF or OFF to ON) when triggered and remain in the new state (ON or OFF). This means, a bistable multi-vibrator has two stable states. Fig 18 shows a typical bistable multi-vibrator circuit.

The circuit at Fig 18 is completely symmetrical. The potential dividers R_1, R_2 and R_3, R_4 form identical bias network at the base of transistors. Each transistor is biased from the collector of the other transistor. Due to the slightest difference in parameters of the transistor, when the circuit is switched ON, any one of the two transistors will turn-ON, and the other remain in OFF condition.

In the circuit at Fig 18, the two identical CE amplifier stages are so connected that the output of one is fed to the input of the other, through resistors R_1, R_3 and shunted by capacitors C_1, C_2. The purpose of the capacitor is nothing but to speed up the switching characteristic of the circuit to get distortion-less output wave-form. Capacitors C_1 & C_2 are also known as **commutating capacitors**.

Fig 18
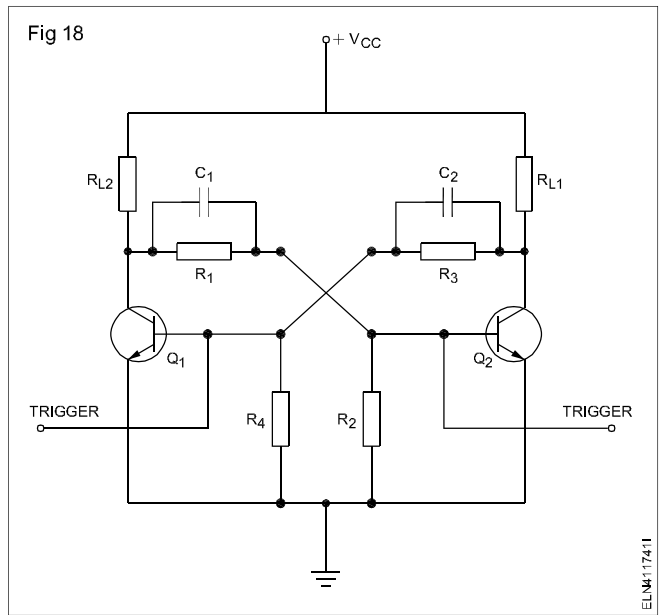
A bistable multi-vibrator is also known as a **flip-flop**. The output terminals are generally identified as Q & $\overline{Q}$ (Q-bar) as in Fig 19.

When Q is in high state (also known as **Logic-1** state in digital electronics), $\overline{Q}$ (Q-bar) will be in low state (also known as **Logic-0** state), and vice versa. This circuit is known as a flip-flop circuit because, if one output flips(high/logic-1) the other output automatically flops(low/logic-0). A flip-flop can be switched from one state to the other by applying a suitable triggering input. Flip-flops are used as a basic **memory cell** in digital computers for storing information. Flip-flops are used in various forms in almost all digital system as counters, frequency dividers and so on.

Fig 19
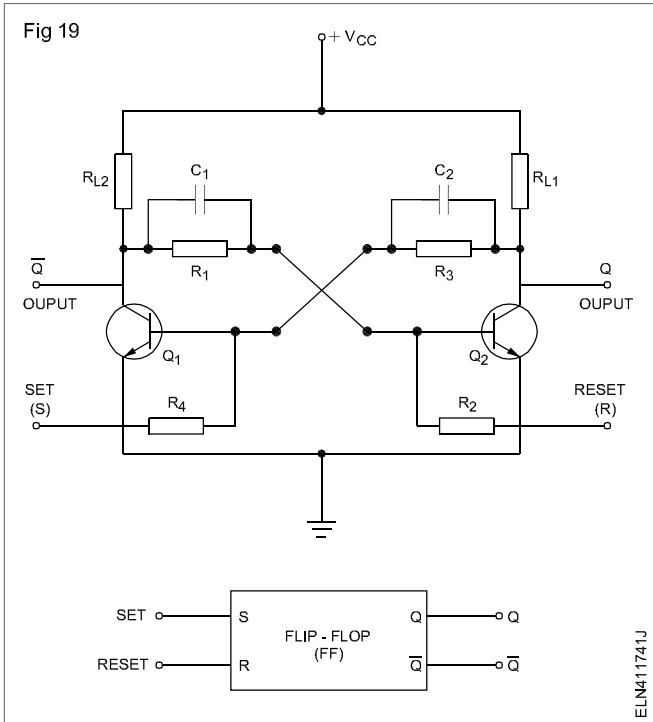
Practical bistable multi-vibrators with unsymmetrical and symmetrical triggering arrangement are shown in Fig 20a and 20b.

UNSYMMETRICALLY TRIGGERED
BISTABLE MULTIVIBRATOR

SYMMETRICALLY TRIGGERED
BISTABLE MULTIVIBRATOR
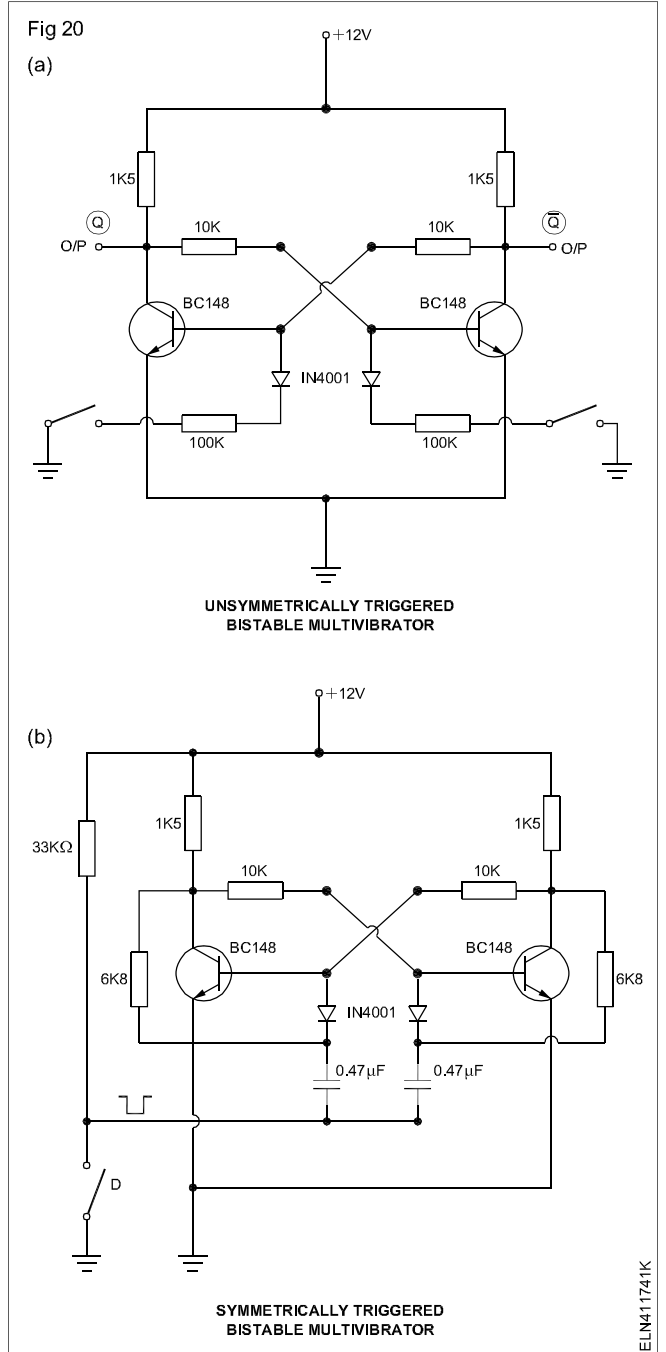
Control elements, accessories - layout of control cabinet

Objectives: At the end of this lesson you shall be able to
• **explain the layout marking methods and necessity**
• **state the methods of marking, cutting, drilling, fixing of accessories and components**
• **explain the methods of mounting and wiring the accessories**
• **state the various control elements used for control panel board**
• **list the different wiring accessories used in control panel wiring.**

Introduction

Preperation of layout drawing and marking on control cabinet is very much essential, we must have a clear vision of mounting components and their location on panel board/ control cabinet.

There is no such important method inpratice to make the layout on control cabinet. However a neat layout on control cabinet is very much required.

The display and indicating instruments should be selected on the top position of the cabinet. Heavy and rare operated devices such as fuse breaker etc; are to be fixed on the bottom of the cabinet.

The components and fixtures should have sufficient space in between to carryout future repair (or) replace requirements. But too much space should not be provided, that will increase the size of the cabinet unnecessarily. While finalising the layout plan the relevent IE rulers to be followed for better result.

Layout marking

Wiring diagrams for power and control circuit should be developed for sequence of operation of automatic star - delta starter with forward and reverse. Types of protection, control, indication and measuring accessories needed should be finalized.

To wire up the above starter in a control panel the well designed and easily understandable layout should be finalized. Layout of the finalized wiring diagram should developed keeping important features of the control panel in mind. While designing the control panel the outside dimensions, the swing area of cabinet doors and area required for maintenance and tools kit have to be considered.

Control panel may be often used near the process area with high temperature, humidity and dust hence the arrangement for cooling fan and dehumidifier along with filters and intake and exhaust vents should be needed.

Suitable size of control panel which can accommodate all the controlling, protective, measuring, indicating and

wiring accessories required for said wiring should be obtained or fabricated.

While selecting the control and protective accessories of the control panel the full load current of the individual load, total load and duty cycle, simultaneous operation of the load and 25% additional load capacity of the motors have to be considered.

The over load and short circuit protection may be given either ahead of the control panel by calculating the highest rating of the branch circuit or individual motors depends on space available, cost factor and sensitiveness of the operation.

The finalized layout may vary depends the individual design and mind application. However a sample layout marking for the above starter is given in the Fig 1.

TYPICAL LAYOUT MARKINGS
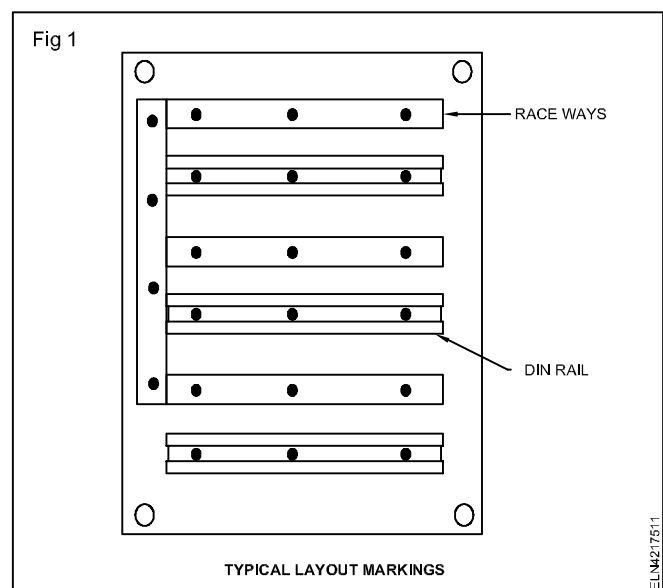
Once the panel layout is designed we must find out where and how to fit the accessories.

The finalized layout of accessories can be marked in the control panel using suitable marking device.

Cutting and drilling

The mounting or fixing holes along with necessary tap or die in suitable size (if any) can be prepared in the front door and inside of the control panel as in Fig 2.

CONTROL PANEL WITH RACEWAYS/DIN RAILS

Fig 2

CONTROL PANEL WITH MOUNTING AND FIXING HOLES

Fig 3

Din rail is a metal rail made from cold rolled carbon steel sheet with zinc plated or chromate bright surface finish used to mount the circuit breakers and control accessories without using screws as in Fig 2. DIN rail being fixed to the chassis before fitted the contactors and other accessories as in Fig 3.

The standard specification of widely available DIN rail is top hat rail EN 50022 which dimension is 35 mm width and a 15 mm or 7.5 mm depth. They can be cut in to the required length and then screwed or bolted inside the panel before mounting any accessories and wiring begins as in Fig 4.

FIXING OF DIN RAIL
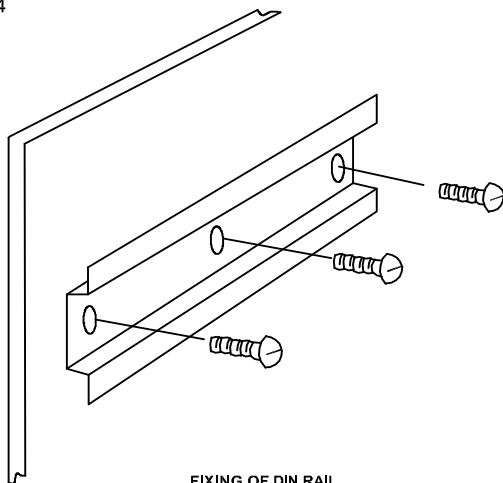
Fig 4

Race way is one form of cable ducting used to carry the wiring between components and keeping the wires neat. The leads wires and cables are laid inside the raceways brought out through the holes / slots in the sides and can be inspected by removing the cover of the raceways.

The minimum spacing between components and raceways should be 100 mm for 415V systems and 50 to 75 mm for less than 415V system. The next stage is to clip the accessories to the rail and wire them.

Mounting and wiring the accessories in control panel

The accessories can be mounted on the DIN rails allowing sufficient space for easy maintenance, wiring and troubleshooting. The mounting should not move or lean in the DIN rail due to vibration or strain due to cables.

Contactor can be either flush mounted to the chassis or DIN rail - mounted . Contactor mounting type over load relay which have three pin connectors engage into the contactor terminals may be used to reduce the mounting and wiring time and labour.

To mount the contactor on rail first place the back top groove on the top of rail and turn it downwards against the lower rail which will cause the spring of the contactor to retract and snap into place behind the rail. There is a slot in the spring clip of the contactor so that the clip can be retracted using small screw driver or connector to remove the contactor if required. To avoid fouling the underneath of the accessories use screws with low profile heads.

The contactor arrangements and terminals are usually labeled which conforms to BS 5583. For example 1 and 2 for NC contacts, 3 and 4 for NO contacts, odd numbers like 1, 3 and 5 for incoming terminals and even numbers like 2, 4 and 6 for outgoing terminals of the main contacts of contactors and OLR.

The conductor should be trimmed OFF to that the conductor does not insert more than the half way through the connectors. Single strand wire should be folded back to give additional thickness. The over tightening of screw have to be avoided otherwise this can crush the strand and give a weak connection.

All the internal wiring should be terminated in the top and external wiring in the bottom of the connectors to avoid the crossover of both wirings. Flexible conduit and cables have to be installed in such a way that the liquid or water if any can drain away from the fitting and grommets.

An earth terminal usually green or green yellow to be clamped to the rail and ensure the cabinet and door are earthed properly.

An insulated separator can be used to isolate the high voltage connections from others. End stops are used to clamps the connectors together and close the open

terminals on one end, sometimes the earth terminal will do the same job as in Fig 5.

The control panel should be grounded properly so that control panel should have proper earthing bolts / nuts. If more ground points are used a common earth plate should be fixed inside the cabinet as in Fig 5.

TERMINAL CONNECTORS / EARTH TERMINAL WITH SEPERATOR
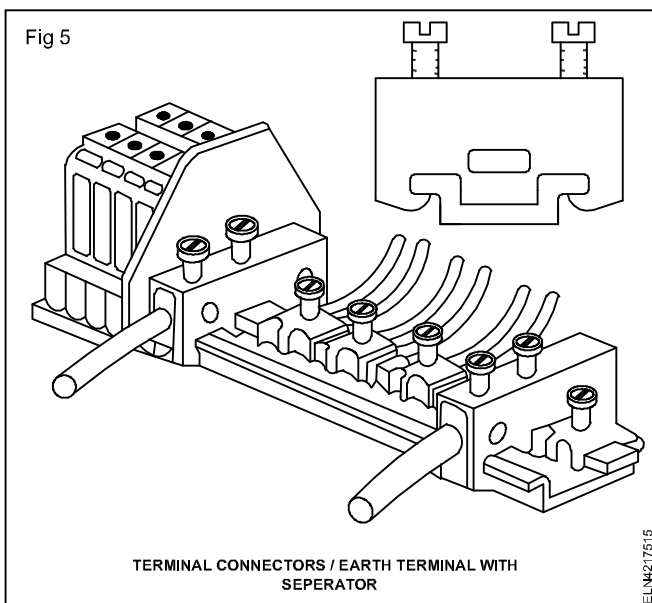
U loops of the cables as long as possible facing down and anchored on each side of the hinged doors and panel with screws or bolts and do not use adhesive. Place the sleeve and spiral flexible conduits of suitable size over the cables running between the hinged doors and panel as in Fig 6.

U LOOP OF CABLES

The care to be given to the bundle of wires which is mounted on the hinged doors should not restrict the opening and closing of the door or the doors should not damage the wires.

Minimize the use of cable ties if the raceways are used. They may be cut OFF during troubleshooting and rarely replaced.

Routing and bunching

Routing

Conductors and cables should run from terminal to terminal without any intervening joins and cross over. Extra length should be left at connector / terminals where assembly needs to be disconnected for maintenance and servicing. Multi core cable terminations have to be adequately supported to avoid undue strain on the terminals.

Different colour may be used to aid identification of group of controls and functions.

The associated earth and neutral conductor should be routed close to the respective live conductors to avoid undue loop resistance.

Select the race ways to leave some slacks or looping of the cable inside it. The wires inside the race way should not more than the half fill.

Bunching and tying

Run the wires in horizontal and vertical lines avoid diagonal runs as possible. Do not run the wire over the other devices or race ways. Uses of spring cage terminals instead of standard screw terminals can reduce the termination error, the wiring and maintenance time which in turn reduce the cost and labour.

To connect the accessories, cut the individual control wires to the proper lengths, strips the insulation, mark wire identification, insert ferrules at the ends of wires, use suitable lugs or thimbles.

The wires should be neatly bundled, run in the race ways and routed with smooth radius bends.

All the terminals, wires and components should have identification marks and labels. A good labelling and identification will reduce the errors in termination, testing, maintenance and repairs. A legible and durable label in an efficient and cost effective manner may be chosen.

To the possible extent the power and control wiring should be run in separate race way or cable management which will reduce the radio interference, trouble shooting time and make the future alteration if any is easier.

By taking some extra cares like pest control, dust control, adequate terminal pressure, selection of proper wires and accessories, it can be ensured that the control panel has no failure time and with moderate maintenance it will be trouble free panel for entire life.

Where the multiple earths are used it is necessary to use a common earth terminal or connectors as in Fig 5.

Tests

Before energizing the control panel all necessary tests should be carried out like open, short, earth continuity and earth soundness etc. The supply voltage and frequency are also to be checked.

Control elements

Difference between control panel and switch board

A panel board contains a single panel or a group of panel units as single panel that includes bus-bars, protective devices and control switches, instruments and more starters etc.

In a panel board, the interior are designed to place the accessories and wires in a cabinet or cut out box or partition and accessible only from the front.

A switch board consists of a large single panel or frame or assembly of switch gears, with or without instruments, but the term switch board does not apply to a group of local switches in the final circuit. Unlike panel boards, switch boards are generally accessible from the rear as well as from the front and are not intended to be installed in cabinets. However the terms, panel board and switch board, are used normally without much discrimination.

For wiring of control panel board the following control elements / components and accessories are required.

They are

- Isolating switch

- Push button switch

- Indicating lamp

- MCB (Miniature Circuit Breaker)

- Contactors

- Electro mechanical relays

- Thermal over load relays

- Time delay relay (timers)

- Rectifiers

- Limit switches

- Control transformers etc.

Control elements for control panel

1   Isolating switch (Fig 7)

Isolating switch (Isolator) is a manually operated mechanical switch which isolates/disconnects the circuit which are connected with it from the supply system as and when required. It should be normally operated at "OFF" load condition.

It is available in different current, voltage rating and size.

Fig 7

ISOLATING SWITCH

2   Push button switch (Fig 8)

Fig 8

PUSH BUTTON SWITCHES

Push button is a simple push switch mechanism for making or breaking the circuit as and when required. It is made out of hard plastic or metal. An indicating lamp is incorporated with the push button switch to indicate start or stop is also available.

3   Indicating lamp (Fig 9)

Fig 9

INDICATING LAMP WITH HOLDER

It is a low voltage, low wattage filament or neon or LED lamps used to indicate the various indication like availability of supply or motor **ON/OFF,** mains/motors fails or trip etc.

It is available in different size, colour and wattage. It should be generally fitted in the front side of the control panel with suitable holder.

4 MCB (Fig 10)

MINIATURE CIRCUIT BREAKER

Miniature circuit breaker (MCB) is an electro mechanical protective device which protect an electrical circuit from short circuit and over load . It automatically turns off, when the current flowing through it exceeds the maximum allowable limit.

5 Fuses

It is a protective device which is connected is series with the live wire to protect the circuit from short circuit and earth fault.

6 Contactors (Fig 11)

MINIATURE CIRCUIT BREAKER
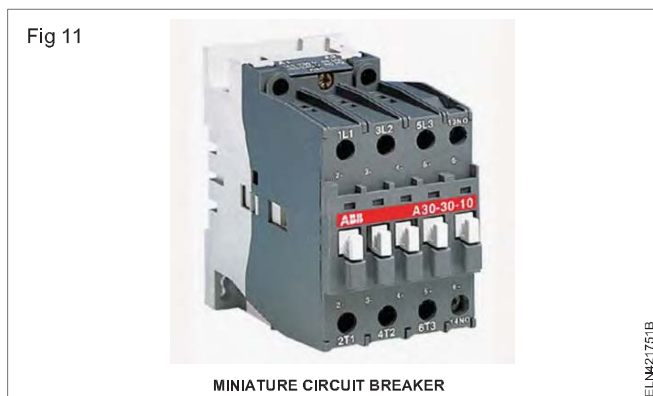
A contactor is an electrically controlled double break switch used for switching ON / switching OFF the electrical circuit, similar to a relay with higher current ratings. It is controlled by a circuit which has a much lower power level than the switched circuit.

7 Electro mechanical relays (Fig 12)

ELECTRO MECHANICAL RELAY

Electromechanical relays are electrically operated switches used to control a high powered circuit accessories using low power signal. When an electric current passes through its coil it produces a magnetic field that activates the armature to make or break a connection.

current passes through its coil it produces a magnetic field that activates the armature to make or break a connection.

8 Thermal overload relays (Fig 13)

THERMAL OVERLOADED RELAYS

It is a thermally operated electromechanical device that protects motors from over heating and loading.

9 Time delay relay (timers) (Fig 14)

TIMER

Time delay relays are simply the control relays in - built with a time delay mechanism to control the circuit based an time delay.

In time delay relays its contact will open or close after the pre-determined time delay either on energising or on de-energising its no volt coil. It can be classified into two types as ON delay timer and OFF delay timer.

10 Rectifiers (Fig 15)

RECTIFIER

A rectifier is a static device consists of one or more diodes that converts alternating current (AC) to direct current (DC). A diode is like a one-way valve that allows an electrical current to flow in only one direction.

11 Limit switches (Fig 16)

LIMIT SWITCHES

Limit switch is a switch with an actuator which is operated by the motion of a machine part or an object.

When an object or parts comes into contact with actuator, it operates the contacts of the switch to make or break an electrical connection. They are used to control the distance or angles of movement of any machine parts or axis or objects.

12 Control transformer

It is a transformer which is used to supply the power to the control or auxiliary circuit or equipment which does not intend for direct connection to the main supply.

13 Panel meter (voltmeter and ammeter)

They are the measuring instruments used to measure the various electrical parameter of the circuits such as voltage and current etc.

Wiring accessories for control panel wiring

1 PVC channel / Race ways (Fig 17)

PVC CHANNEL

It is an inspection type PVC enclosed channel which provides a pathway for electrical wiring inside the control panel. It has the opening slots on both sides to facilitate the good ventilation and visual inspection.

It protects the wires from dust, humidity, corrosion, water intrusion, heat, mechanical damage and physical threats.

2 DIN rail (Fig 18)

DIN RAILS

It is a zinc - plated or chromated metal rail which is used for mounting the control accessories like MCB, contactors and OLR etc, with out using screws inside the control panel.

3 G Channel (Fig 19)

'G' CHANNEL

It is a zinc - coated metal channel which is especially used for mounting the feed through or spring load or double deck terminal connectors without using screw inside the control panel.

4 Terminal connectors (Fig 20)

TERMINAL CONNECTORS

It is the set of insulated screw terminals at both sides used to connect the accessories of the control panel with external control switches, limit switches, input supply and motor terminals etc.

Terminal connectors with barrier strips and clamping plates provide a tight and electrically sound termination. It is available in various size, current and voltage ratings.

5 Wire ferrules (Fig 21)

WIRE FERRULES

Fig 21

It is a small circular ring made up of polymer plastics or rubber or fibre, used to easily identify the ends of wires which are to be connected into a particular terminals or accessories. It should be inserted on the both ends of a wire as collar or bracelet.

It is available is different size like 1 sq.mm, 1.5 sq.mm and 2.5 sq.mm etc generally in yellow colour printed with either numerical or alphabet letters on it.

6 Lugs and thimbles (Fig 22)

LUGS AND THIMBLES

Fig 22
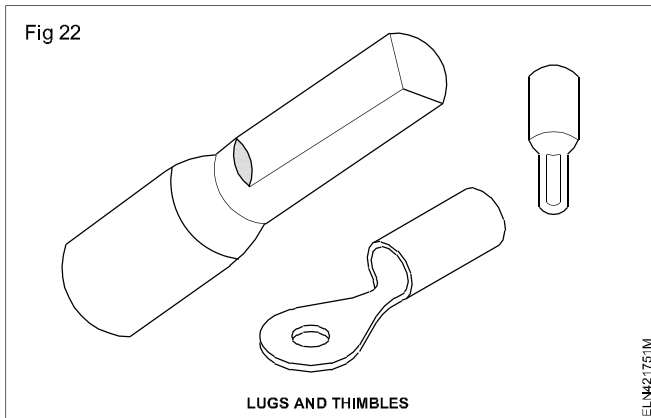
It is a cylindrical barrel along with circular rings or cylindrical rod or U shape or flat surface made up of aluminum or copper or brass, used to ensure the sound electric connection of the cable / wire on to the terminals. It prevent flare out of stripped and stranded cable, increase the conductivity of the connection, support the cable / wire and avoid the loose connection and sparking. Suitable crimping tool has to be used to connects them with cables / wires. It is available in different size like 1 sq.mm, 4 sq.mm, 25 sq.mm, 70 sq.mm, 125 sq.mm and so on.

• Thimbles may also be referred as sockets.

7 Cable binding straps and button (Fig 23)

It is made up of PVC or polymer belt with a small holes at regular intervals, used to tie up, bunching, binding and dressing the cable / wires with help of buttons.

It is reusable and good insulator to the heat and electricity. It is generally available 8mm, 10 mm and 12 mm width.

CABLE BINDING STRAPS AND BUTTON

Fig 23
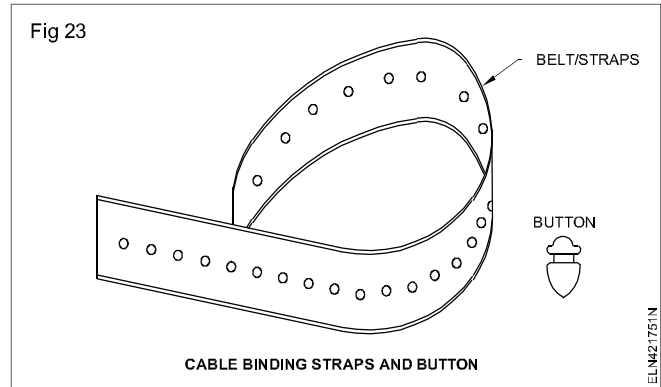
8 Nylon cable ties (Fig 24)

NYLON CABLE TIES

Fig 24
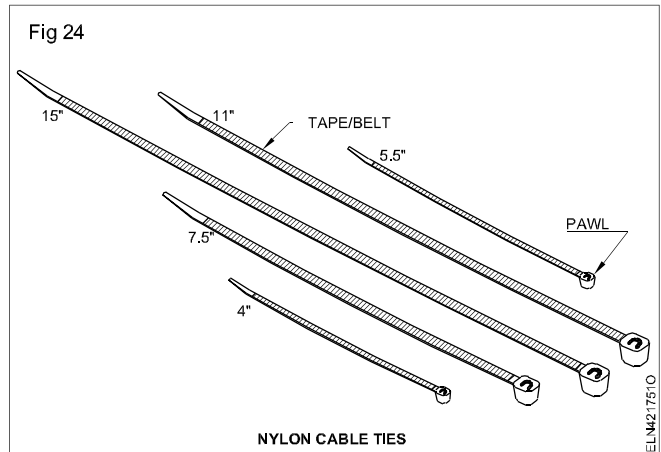
• It is a type of fastener used to hold or tie or bunch the wires / cable or group of cables.

• It is made of nylon tape or belt which has teeth that will engage with head of the pawl to form a ratchet and tightens the wires.

• In general the tie can not be loosened, or removed or reused. However some reusable ties are also available.

• it is available in different colour, length and width.

• Because of its low cost and easy to use, it is widely used in general purpose application also.

9 Sleeves (Fig 25)

WIRE SLEEVES

Fig 25

• It is flexible tubular / cylindrical insulator into which the electric wire or cable or group of cables can be inserted.

- Apart from the electrical insulation and easy identification of wires, it also protect the wires from abrasion, heat, chemical, physical damage and radio interference.

- It is available is different colour, style, materials like carbon fibre, fabrics, Teflon, fibre glass, nylon, poly ethylene (PET) wrap, braided metal and heat shrink sleeves.

10 Grommets (Fig 26)

Fig 26

GROMMETS
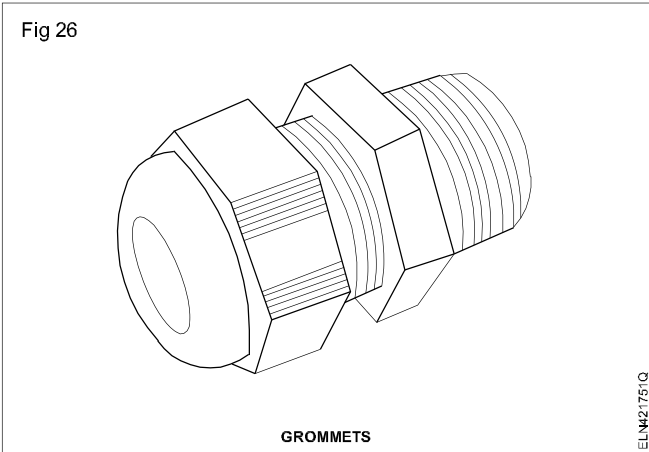
It is a type of bushing which is used to insulate and hold the cables when they pass through a punched / drilled holes of panels or enclosures. It is generally made of rubber, plastic, plastic coated metal and protect the cable from twist, tug, cut, break, strain, vibration etc and prevent the entry of dirt, dust, water, insects and rats into the panel. It may also called as glands.

11 Wire clips (Fig 27)

It is a type of fixing or fastening device which is used to fix and hold the cables or punch of cables in a secure manner.

Rotary type switches (Fig 28)

Rotary switches are most commonly used in lathes, milling and drilling machines due to their exact visual position and easiness in operation. These switches are operated by levers or knobs which in turn operate cams inside the switch to contact various terminals in sequence by the internal contact blocks. These cams and blocks are made of hard P.V.C. and are designed to withstand many operations. It is possible to get many circuit combinations by combining various cams and contact blocks. As the contact blocks, terminals and cams are spring-loaded, these switches should not be opened by inexperienced persons for repairs. Fig 28 shows 250V AC 15 Amps 2-pole three position flush mounting coin-slot operator.

Function: This switches can do a number of functions, depending upon the cover and contact block combinations. According they can be used for ON/ OFF switch, manual Forward / Reverse operation, Manual star delta switches, Pole changing switches, Selection switch for meaning instrument etc..

Fig 27

WIRE CLIPS

Fig 28

HAND OFF AUTO

ROTARY SWITCH
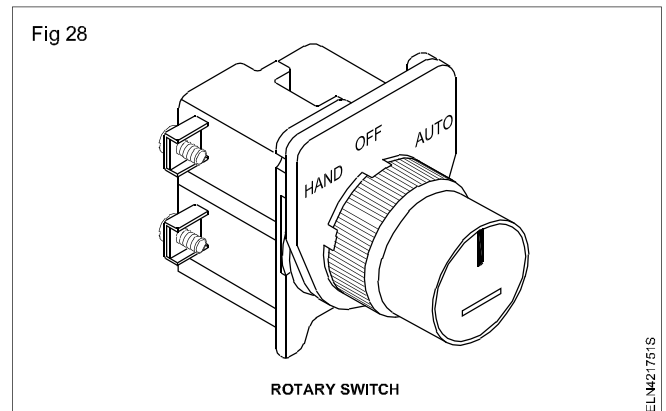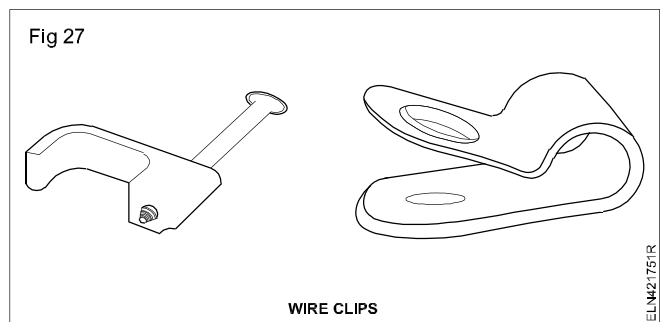
Power and control circuits for three phase motors

Objectives: At the end of this lesson you shall be able to
- **state the necessity of starters for a 3-phase induction motor to start and name the types of starters**
- **explain the basic contactor circuit with a single push-button station for start and stop**
- **state the function of DOL starter, semi and fully automatic start - delta strater**
- **explain the function of jogging inching forward and reverse control circuit**
- **explain the remote station control circuit**
- **explain the sequential control of motors.**

Necessity of starter: A squirrel cage induction motor just before starting is similar to a polyphase transformer with a short-circuited secondary. If normal voltage is applied to the stationary motor, then, as in the case of a transformer, a very large initial current, to the tune of 5 to 6 times the normal current, will be drawn by the motor from the mains. This initial excessive current is objectionable, because it will produce large line voltage drop, which in turn will affect the operation of other electrical equipment and lights connected to the same line.

The initial rush of current is controlled by applying a reduced voltage to the stator winding during the starting period, and then the full normal voltage is applied when the

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motor has run up to speed. For motors, up to 3 Hp, full normal voltage can be applied for starting. However, to start and stop the motor, and to protect the motor from overload currents and low voltages, a starter is required in the motor circuit. In addition to this, the starter may also reduce the applied voltage to the motor at the time of starting.

Types of starters: Following are the different types of starters used for starting squirrel cage induction motors.

• Direct on-line starter

• Star-delta starter - semi and fully automatic

• Step-down transformer starter

• Auto-transformer starter.

In the above starters, except for the direct on-line starter, reduced voltage is applied to the stator winding of the squirrel cage induction motor at the time of starting, and regular voltage is applied once the motor picks up the rated speed.

Selection of starter: Many factors must be considered when selecting starting equipment. These factors include starting current, the full load current, voltage rating of motor, voltage (line) drop, cycle of operation, type of load, motor protection and safety of the operator.

Contactors: The contactor forms the main part in all the starters. A contactor is defined as a switching device capable of making, carrying and breaking a load circuit at a frequency of 50 cycles per second or more. It may be operated by hand (mechanical), electromagnetic, pneumatic or electro-pneumatic relays.

The contactors shown in Fig 1 consist of main contacts, auxiliary contacts and no-volt coil. As per Fig 1, there are three sets of normally open, main contacts between terminals 1 and 2, 3 and 4, 5 and 6, two sets of normally open auxiliary contacts between terminals 23 and 24, 13 and 14, and one set of normally closed auxiliary contact between terminals 21 and 22.

Auxiliary contacts carry less current than main contacts. Normally contactors will not have the push-button stations and O.L. relay as an integrated part, but will have to be used as separate accessories along with the contactor to form the starter function. The main parts of a magnetic contactor are in Fig 1, and Fig 2 shows the schematic diagram of the contactor when used along with fused switches (ICTP), push-button stations and OL relay for connecting a squirrel cage motor for starting directly from the main supply. In the same way the direct on-line starter consists of a contactor, OL relay and push-button station in an enclosure.

Functional description

Power circuit: As in Fig 2, when the main ICTP switch is closed and the contactor K_1 is operated, all the three

windings U V & W of the motor are connected to the supply terminals R Y B via the ICTP switch, contactor and OL relay.

Fig 1

Fig 2
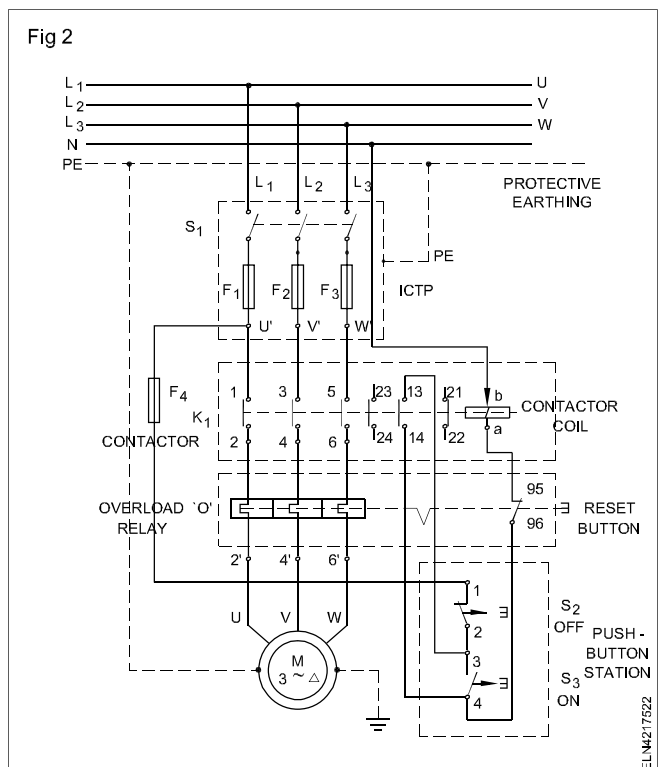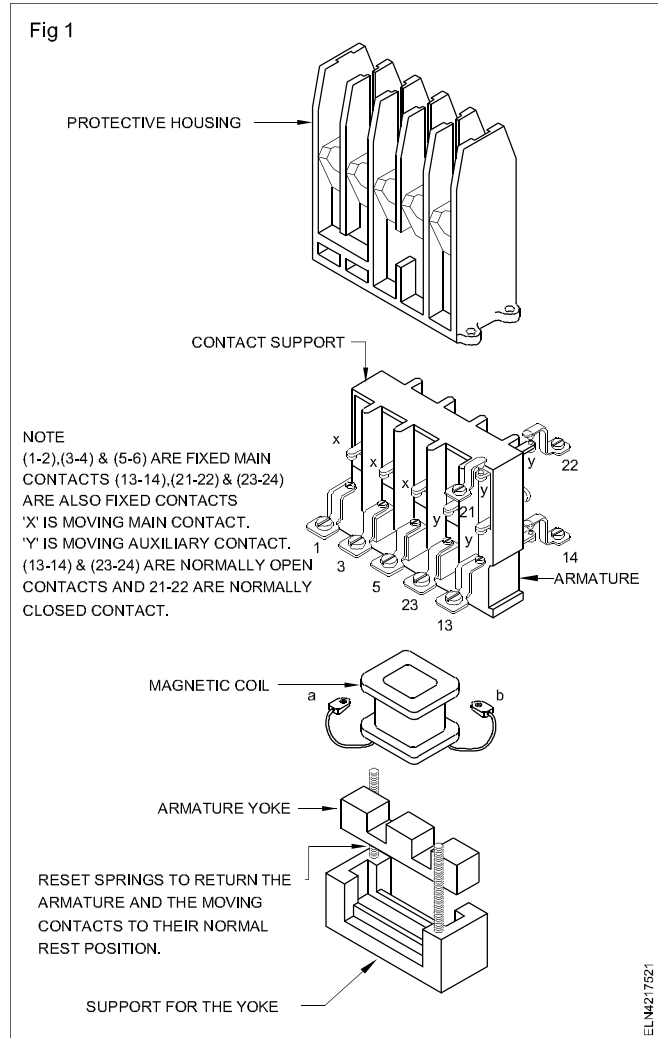
The overload current relay (bimetallic relay) protects the motor from overload (`motor protection'), while the fuses F1/F2/F3 protect the motor circuit in the event of phase-to-phase or phase-to-frame short circuits.

Control circuits

Push-button actuation from one operating location: As shown in the complete circuit Fig 2, and the control circuit Fig 3, when the `ON' push-button S_3 is pressed, the control circuit closes, the contactor coil is energised and the contactor K_1 closes. An auxiliary, a normally open contact 13,14 is also actuated together with the main contacts of K_1. If this normally open contact is connected in parallel with S_3, it is called a self-holding auxiliary contact.

CONTROL CIRCUIT
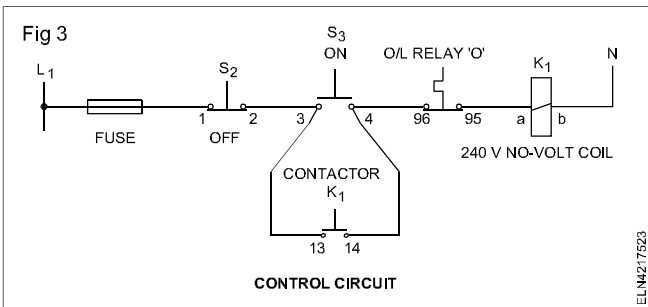
After S_3 is released, the current flows via this self-holding contact 13,14, and the contactor remains closed. In order to open the contactor, S_2 must be actuated. If S_3 and S_2 are actuated simultaneously, the contactor is unaffected.

In the event of overloads in the power circuit, the normally closed contact 95 and 96 of overload relay `O' opens, and switches off the control circuit. Thereby $K_1$ switches `OFF' the motor circuit.

Once the contact between 95 and 96, is opened due to the activation of the overload relay `O', the contacts stay open and the motor cannot be started again by pushing the `ON' button S_3. It has to be reset to normally closed position by pushing the reset button. In certain starters, the reset could be done by pushing the `OFF' button which is in line with the overload relay `O'.

Push-button actuation from two operating locations (remote control): If it is desired to switch a contactor OFF and ON from either of the two locations, the corresponding OFF push-buttons should be connected in series, and the ON push-buttons in parallel, as in the complete diagram Fig 4 and the control diagram Fig 5.

If either of the two ON push-buttons is actuated, K_1 is energised and holds itself closed with the help of normally-open contact 13 & 14 which is closed by contactor K_1. If either of the two OFF push-buttons is actuated, the contactor opens.

COMPLETE CIRCUIT DIAGRAM OF THE CONTACTOR AND THE 3 PHASE SQUIRREL CAGE INDUCTION MOTOR
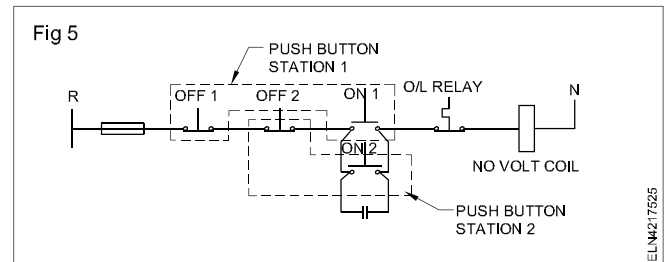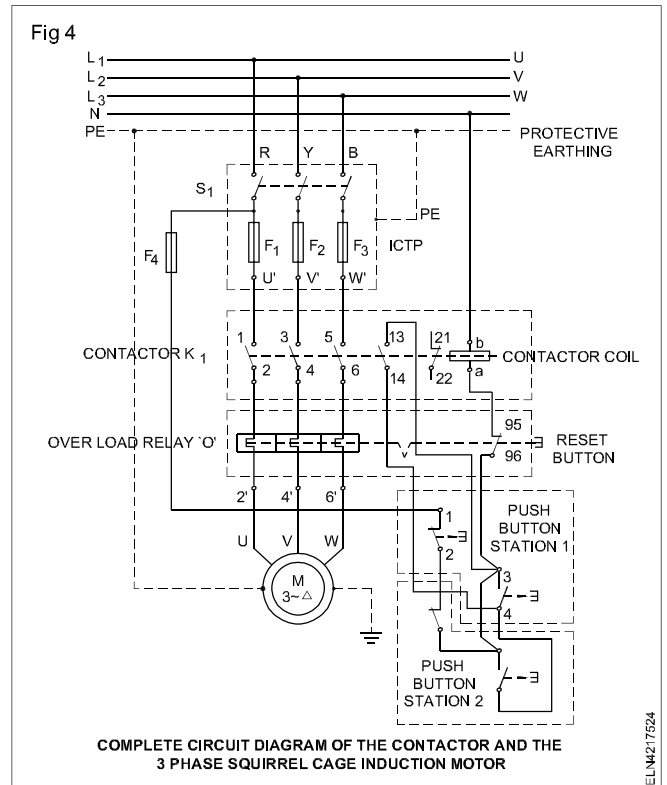
Tripping of starters: A starter may trip due to the following reasons.

• Low voltage or failure of power supply

• Persistent overload on the motor

No-volt coil: A no-volt coil consists of generally more number of turns of thin gauge of wire.

Coil voltages: Selection of coils depends on the actual supply voltage available. A wide variety of coil voltages like 24V, 40V, 110V, 220 V 230/250 V, 380V 400/440V AC or DC are available as standard for contactors and starters.

Troubleshooting in contactor: Table 1 gives the common symptoms their causes and remedies.

Table 1

Symptoms	Causes	Remedies
Motor does not start when the 'start' button is pressed. However on pressing the armature of the contactor manually, motor starts and runs.	Open in no-volt coil circuit.	Check the main voltage for lower than acceptable value. Rectify the main voltage. Check the control circuit wiring for loose connection. Check the resistance of the no-volt coil winding. If found incorrect replace the coil.
Motor starts when `ON' button is pressed. It however stops immediately when `ON' button is released.	Auxiliary contact in parallel with the start-button is not closing.	Check the parallel connection from `ON' button terminals to the auxiliary contact of the contactor. Rectify the defect.
		Check the auxiliary contact points of the contactor for erosion and pittings. Replace, if found defective.
Motor does start when the start-button is pressed. However, a humming or chattering noise comes from the starter.	Movable armature and fixed limb of electromagnet are not stably attracted.	Dust or dirt or grit between the mating surfaces of the electromagnetic core. Clean them. Low voltage supply. Find the cause and rectify the defect. Break in the shading ring in the case of AC magnet.
Failure of contactor due to too much heating of the `No' volt coil.	Higher incoming supply rating. No-volt coil rating is not high.	Higher supply voltage than normal. Reduce the incoming voltage. Voltage rating of the no-volt coil is less. Replace with standard rating, according to the main supply.
Motor does not restart immediately after tripping of OL relay even though OL relay was reset.	It takes a little time for the thermal bimetal to cool and reset.	Wait for 2 to 4 minutes before re-starting.
Coil does not get energised even though supply voltage is found across the no-volt coil terminals.	Open-circuited NVC. NVC burnt out.	Check the nylon strip on relay. Check the nylon button below the start button Replace, if necessary.
Relay coil has been changed. However motor does not start when the start-button is pressed.	Control circuit of relay open.	Check the control circuit for open. Clean the control station contacts. Overload relay not reset.
Humming or chattering noise.	Low voltage. Magnetic face between yoke and armature is not clean. Shading ring on iron core missing.	Feed the rated voltage. Clean the surfaces of yoke and armature. Provide shading ring in the iron core.

D.O.L. starter

A D.O.L. starter is one in which a contactor with no-volt relay, ON and OFF buttons, and overload relay are incorporated in an enclosure.

Construction and operation: A push-button type, direct on-line starter, which is in common use, is in Fig 6. It is a simple starter which is inexpensive and easy to install and maintain.

There is no difference between the complete contactor circuit explained in Exercise 4.2.175(i) and the D.O.L.starter, except that the D.O.L. starter is enclosed in a metal or PVC case, and in most cases, the no-volt coil is rated for 415V and is to be connected across two phases as in Fig 6. Further the overload relay can be situated between ICTP switch and contactor,or between the contactor and motor as in Fig 6, depending upon the starter design. Trainees are advised to write the working of the D.O.L. starter on their own by going through the

explanation given in Exercise 4.2.175(i) which is for a complete contactor circuit.

Fig 6

WIRING DIAGRAM OF A DIRECT ON-LINE STARTER WITH PROTECTIVE DEVICES
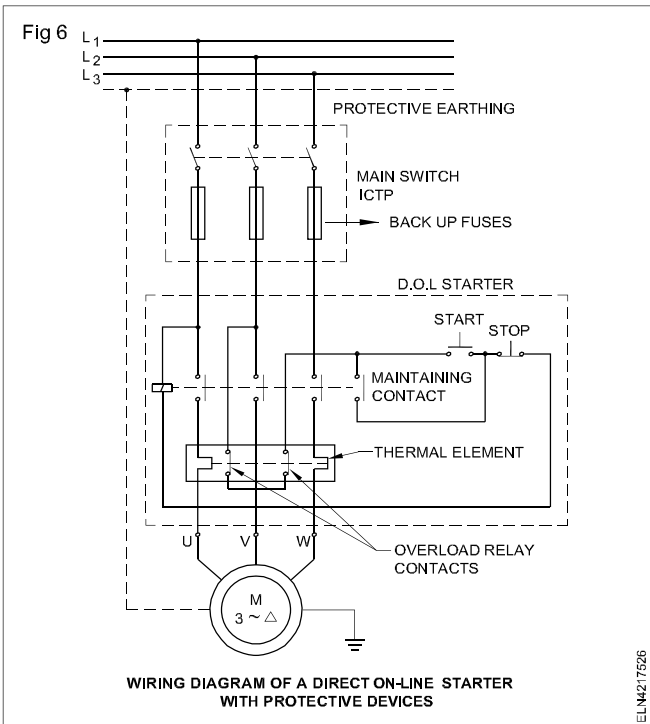
Forward and reversing of 3 phase induction motors

In many machines like large milling machine, it is essential to run the motor in both directions in forward & reverse. In lift also the forward & reverse operation is essential.

By changing the phase sequence of any two phases the direction of rotation of a 3 phase motor can be changed but it is not practically possible of interchanging any two phases of 3 phase supply when even needed. It consumes time and also damages the equipments.

So it is necessary to have a circuit for forward and reversing of 3 phase induction motors. (Fig 7)

The supply terminal L_1 is connected with motor terminal A_1 in both direction of runing (Fig 7)

Supply terminal L_2 & L_3 are connected with motor terminal B_1 & C_1 in forward direction. While the reverse contact energiser supply terminal L_2 connected with motor terminal C_1 and L_3 terminal connected with B_1 thus the sequence of phase changed the direction of rotation also changed.

Fig 7

POWER CIRCUIT
(a)

CONTROL CIRCUIT
(b)
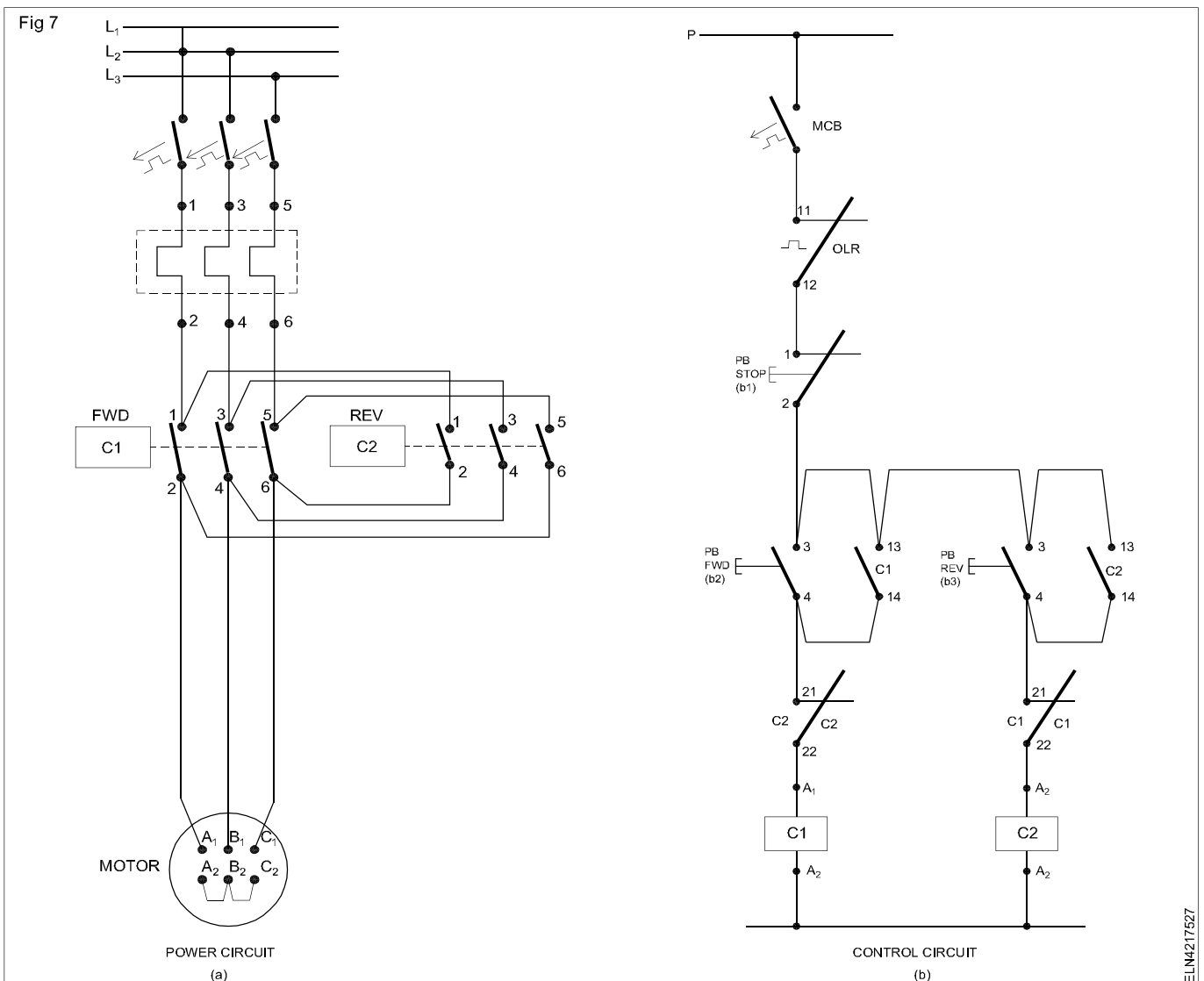
The inter locking protection is in corporated by normally closed (NC) contacts of forward and reverse contactors (Fig 7b) By this when forward contactor is working, if reverse push button is wrongly pressed, without any break the motor run in same direction continuously.

The direction only can be changed by switch OFF and press the reverse direction push button.

Table of relay ranges and back-up fuses for motor protection

Sl. No.	Motor ratings 240V 1-phase			Motor ratings 415V 3-phase			Relay range A	Nominal back-up fuse recommended
	hp	kW	Full load current	hp	kW	Full load current	a	c
1				0.05	0.04	0.175	0.15 - 0.5	1A
2	0.05	0.04		0.1	0.075	0.28	0.25 - 0.4	2A
3				0.25	0.19	0.70	0.6 - 1.0	6A
4	0.125	0.11		0.50	0.37	1.2	1.0 - 1.6	6A
5	0.5	0.18	2.0	1.0	0.75	1.8	1.5 - 2.5	6A
6	0.5	0.4	3.6	1.5	1.1	2.6	2.5 - 4.0	10A
7				2.0	1.5	3.5	2.5 - 4.0	15A
8	0.75	0.55		2.5	1.8	4.8	4.0 - 6.5	15A
9				3.0	2.2	5.0	4.0 - 6.5	15A
10	1.0	0.75	7.5	5.0	3.7	7.5	6.0 - 10	20A
11	2.0	1.5	9.5	7.5	5.5	11.0	9.0 - 14.0	25A
12	3.0	2.25	14	10.0	7.5	14	10.0 - 16.0	35A.

Semi-automatic star-delta starter

The standard squirrel cage induction motors with both ends of each of the three windings brought out (six terminals) are known as star-delta motors. If the starter used has the required number of properly wired contactors, the motor can be started in star and run in delta.

The proper use of manual star-delta starter demands a special skill in handling the starter. The sluggish operation of the manual lever often causes damage to the moving and fixed contacts in a manual star-delta starter.

The contactors are employed for making and breaking the main line connections. Figure 8 shows the wiring diagram and Fig 9 shows the line diagram of power circuit and the control circuit.

Operation: Refer to the control circuit and power circuit diagrams shown in Fig 9a,9b. When the start button S_2 is pressed the contactor coil K_3 energises through P_4, P_3 and K_1 normally closed contact 12 and 11. When K_3 closes, it opens the normally closed contact K_3 between 11 and 12 and makes contact between 10 and 9 of K_3. The mains contactor K_1 energies through P_4, 10 and 9 of K_3. Once K_1 energises the NO contact of K_1 point 8 and 7 establishes a parallel path to K_3 terminals 10 and 9.

WIRING DIAGRAM OF SEMI AUTO STAR DELTA STARTER
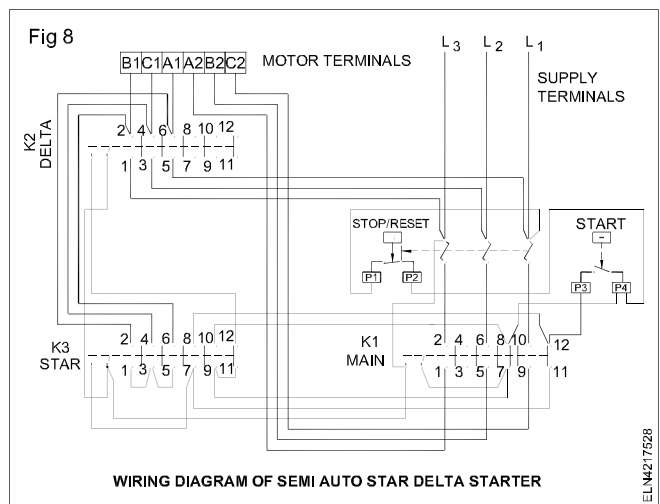
The star contactor K_3 remains energised so long as the start button is kept pressed. Once the start button is released, the K_3 coil gets de-energised. The K_3 contact cannot be operated because of the electrical interlock of K_1 and normally closed contacts between terminals 12 and 11.

Fig 9 (a)

POWER CIRCUIT

(b)

CONTROL CIRCUIT

(c)

ALTERNATIVE FORM OF CONTROL CIRCUIT
LINE DIAGRAM OF SEMI - AUTOMATIC STAR - DELTA STARTER

In star-delta motors all the winding are used and there are no limiting devices such as resistors or auto-transformers. Star-delta motors are widely used on loads having high inertia and a long acceleration period.

Overload relay settings : Three overload relays are provided on star-delta starters. These relays are used so that they carry the motor winding current. This means that the relay units must be selected on the basis of the winding current, and not the delta connected full load current. The motor name-plate indicates only the delta connected full load current, divide this value by 1.73 to obtain the winding current. Use this winding current as the basis for selecting and setting the motor winding protection relay.

Operation : Fig 10a, 10b & 10c shows the line diagram of the power circuit and the control circuit and alternative form of control circuit of the automatic star-delta starter. Pressing the start button S-energises the star contactor K_3. (Current flows through K_4 T NC terminals 15 & 16 and K_2 NC terminals 11 & 12). Once K_3 energises the K_3 NO contact closes (terminals 23 & 24) and provide path for the current to close the contactor K_1. The closing of contactor K_1 establishes a parallel path to start button via K_1 NO terminals 23 & 24.

Fig 11 shows the current direction and closing of contacts as explained above.

Fig 11 (a)

STAR CONTACT CLOSES FIRST

(b)

MAIN CONTACT CLOSES

― INDICATES THE DIRECTION OF MOVEMENT OF CONTACT
⇈ INDICATES CLOSING OF CONTACTOR

When the K_3 contactor get de-energised the normally closed contact of K_3 between terminals 11 and 12 establishes contact in the contactor K_2 - coil circuit. The delta contactor K_2 closes.

The operator has to observe the motor starting and reaching 70% of the synchronous speed for satisfactory starting and running of the induction motor.

Figure 9c shows the alternative form of drawing control circuit.

Automatic star-delta starter

Applications : The primary application of star-delta motors is for driving centrifugal chillers of large central air-conditioning units for loads such as fans, blowers, pumps or centrifuges, and for situations where a reduced starting torque is necessary. A star-delta motor is also used where a reduced starting current is required.

Fig 10

(a) POWER CIRCUIT

(b) CONTROL CIRCUIT

(c) ALTERNATIVE FORM OF CONTROL CIRCUIT

Similarly Fig 12 shows the action taking place after the timer relay operating the contact K_4T.

Fig 12

TIME DELAY CONTACT CHANGES
OPENING STAR CONTACT
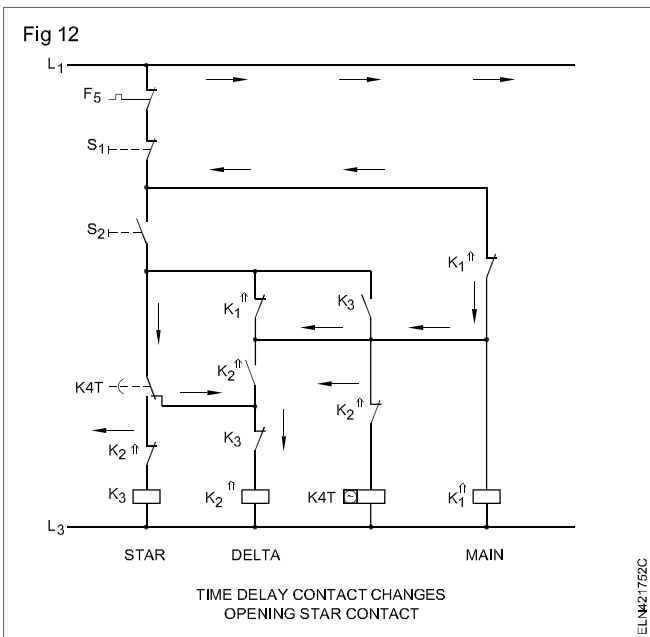
Fig 13 shows the connections established while the motor is running in delta with the contactors K_1 and K_2 closed.

Fig 13

DELTA CONTACT CLOSES
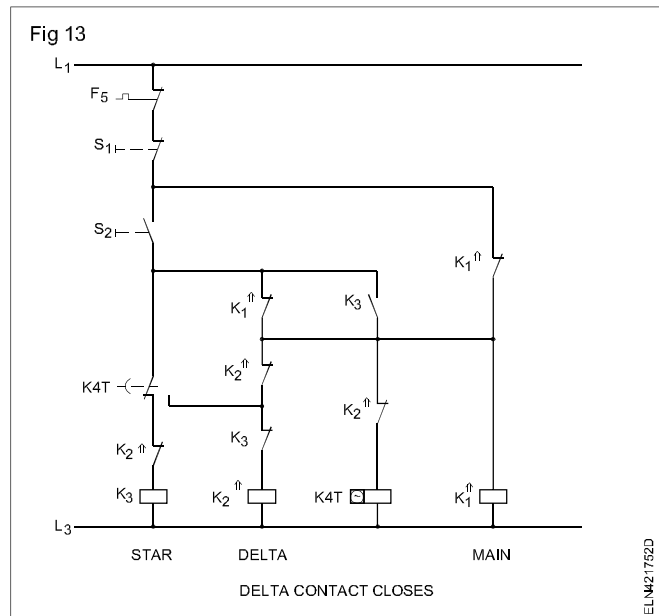
Automatic star - delta starter with forward and reverse control

It is a starter which is used to start the three phase motor in star and after some pre-determined time it automatically runs in delta either in forward or reverse direction depends upon the requirement. Like all other starters it reduces the starting current, protects the motor

from over load and disconnects the motor from supply during power failure.

The Fig 14 and 15 shows the power and control circuit of the automatic star-delta starter with forward and reverse operation.

Its main components are, five numbers of power contactors, one ON-delay timer, three numbers of push buttons and one thermal over load relay (OLR). The five power contactors are intended one each for forward direction (C_1), reverse direction (C_2), main contactor (C_3), star contactor (C_4) and delta contactor (C_5).

Six numbers of indicator lamps are also used to indicate the availability of the three supplies, availability control voltage and to indicate whether the motor is running either in forward or reverse direction. These neon indicators lamps are to be mounted in the front door of the control panel along with three push buttons.

Three push buttons are intended one each for stop push button with one NC (Normally Closed) contact, for forward and for reverse operation with one NO (Normally Opened) contact.

Fig 15

AUTOMATIC STAR-DELTA STARTER WITH FORWARD
& REVERSE-CONTROL CIRUIT

Fig 14

AUTOMATIC STAR-DELTA STRATER WITH FORWARD AND REVERSE-POWER CIRCUIT
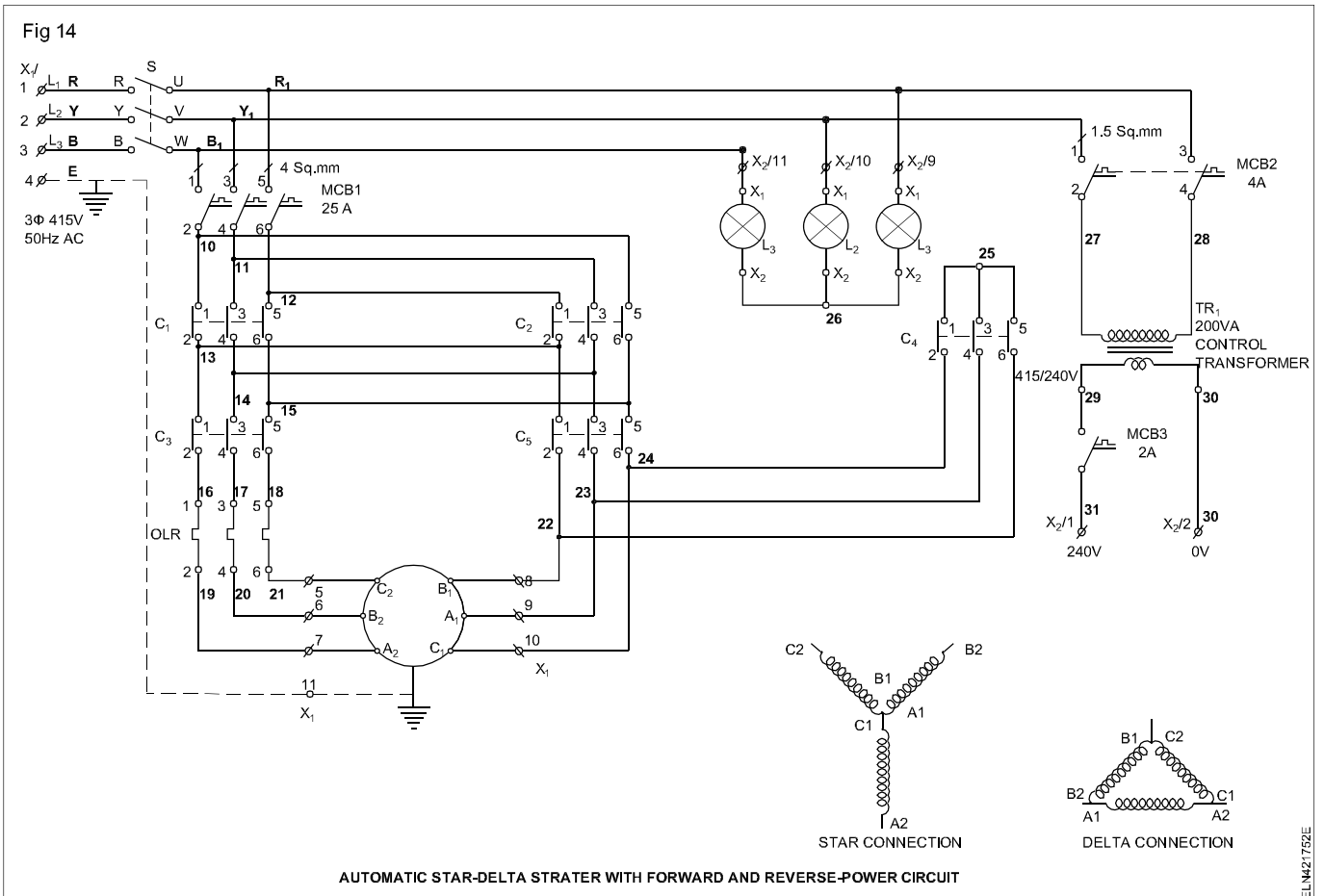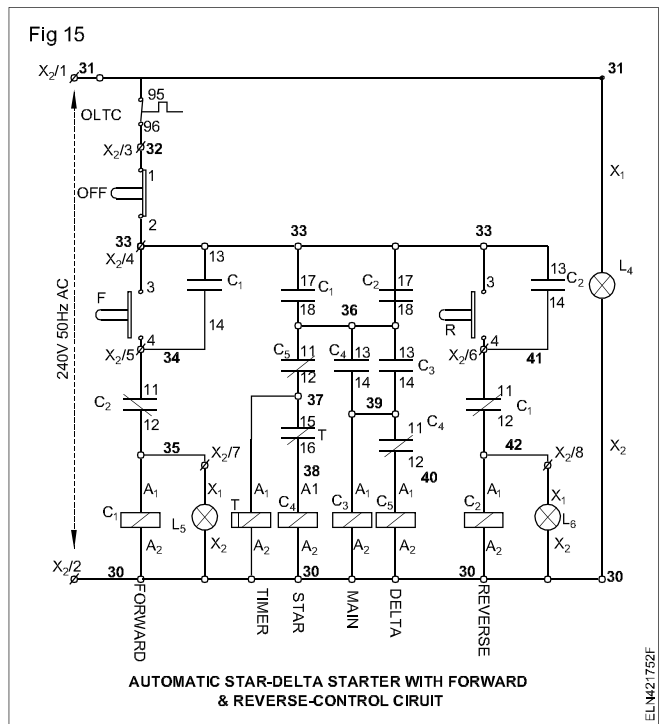
The choosing of control circuit voltage and power depends on the no volt coil rating of the contactor, whether it needs AC or DC. Here a separate 415/240V, 200 VA control transformer is used for control circuits.

The choice of contactor depends upon the type of supply voltage, load power, load characteristics and duty cycles. The standed duty cycles of the contactors is given below.

For AC loads

AC1 - Resistive load switching example heaters and furnace.

AC2 - Resistive and inductive load starting and stopping example slip ring induction motor.

AC3- High inductive load switching and breaking for continuous running operation.

AC4- High inductive load switching and breaking with frequent and short time operation i.e., intermediate operation like inching and jogging examples cranes, lifts and hoists.

For DC loads

DC1- Resistive loads except motor load

DC2- Starting and stopping of shunt motors.

DC3- Starting and stopping with inching and braking

DC4- Starting and stopping of series motors.

DC5- Starting and stopping of series motor with inching and plugging.

The auxiliary contact can be fitted to the top or to the sides of the contactors depend its design.

Working of starter : When the three phase supply is switched 'ON' by the isolator switch (S) the indicator lamps (L_1, L_2 and L_3) will indicate the availability of supply (Fig 14), the control transformer gets the supply through MCB2 and the indicator lamp (L_4) indicates the availability of control voltage.

Sequence of operations for forward direction

1   If forward push button (F) is pressed, the NVC of the forward contactor (C_1) gets control voltage through over load relay trip contact (OLTC), stop push button and NC contact of the C_2. Now the C_1 energized and get self holding through its own NO contact. So even after releasing the 'F' push button the C_1 will continuous in energized condition.

2   The one more NO contact of C_1 is closed, so the NVC of the star contactor (C_4) and timer get the control supply simultaneously through the delta and timer NC contact hence the C_4 and timer (T) getting energized.

3   The NO contact of C_4 closes and the NVC of the main contactor (C_3) getting energized. Now the motor is started in star in forward direction and the main contactor (C_3) is getting self holding through its own NO contact whereas the delta contactor (C_5) will not energize because of the NC contact of C_4 which connected in series with C_5 is already in open condition.

4   After some pre-determined time delay, the timer NC get open causes the C_4 to de-energize and the delta contactor (C_5) is getting energized though the NC contact of C_4. Now the motor is running in delta connection in forward direction.

5   When the motor is running in the forward direction, even by a mistake if the reverse push button (R) is pressed the reverse contactor (C_2) will not get the control voltage because of the interlock NC contact of C_1 is connected in series with C_2.

6   If the stop bush button (OFF) is pressed the C_1, C_3 and C_5 contactors get de-energized simultaneously and the motor stops. In other hand if either the OLTC open due to over load or the supply fails, the motor will stop. Then the motor could be started only by pressing either forward or reverse push button as required after resetting the OLTC and it could not get started automatically even if the OLTC getting reset after cooling down or the power resumes.

Sequence of operations for reverse direction

1   If the reverse push button (R) is pressed, the NVC (No Volt Coil) of the reverse contactor (C_2) get control voltage through over load relay trip contact (OLTC), stop push button and NC contact of the C_1. Now the C_2 energized and get self holding through its own NO contact. So even after releasing the "R" push button the C_2 will continuous in energized condition.

2   The one more NO contact of C_2 is closed, so the NVC of the star contactor (C_4) and timer get the control supply simultaneously through the delta and timer NC contact hence the C_4 and timer (T) getting energized.

3   The NO contact of C_4 closes and the NVC of the main contactor (C_3) getting energized. Now the motor is started in star in reverse direction and the main contactor (C_3) is getting self holding through its own NO contact whereas the delta contactor (C_5) will not energize because of the NC contact of C_4 which connected in series with C_5 is already in open condition.

4   After some pre - determined time delay, the timer NC get open causes the C_4 to de-energize and the delta contactor (C_5) is getting energized through the NC contact of C_4. Now the motor is running in delta connection in reverse direction.

5   When the motor is running in the reverse direction even by a mistake if the forward push button (F) is pressed the forward contactor (C_1) will not get the control voltage because of the interlock NC contact of C_2 in series with C_1.

6   If the stop push button (OFF) is pressed the C_2, C_3 and C_5 contactors get de-energized simultaneously and the motor stops. In other hand if either the OLTC open due to over load or the supply fails, the motor will stop. Then the motor could be started only by pressing either forward or reverse push button as

required after resetting the OLTC and it could not get started automatically even if the OLTC getting reset after cooling down or the power resumes.

Jogging (inching): In some industrial applications, the rotating part of a machine may have to be moved in small increments. This could be done by a control system called jogging (inching). Jogging is defined as the repeated closure of the circuit to start a motor from rest, producing small movements in the driven machine. By pressing the jog push-button the magnetic starter is energised and the motor runs; when the jog push-button is released, the motor stops.

When a jogging circuit is used, the motor can be energised only as long as the jog-button is depressed. This means the operator has instantaneous control of the motor drive.

Purpose of jogging/inching controls: Normally jogging (inching) controls are incorporated in the following machines for operational convenience shown against each.

- Lathe machine controls - for checking the trueness of the job and setting the tool initially.

- Milling machine controls - for checking the concentric running of the cutter at initial setting and also to set the graduated collar for depth of feed of the cutter.

- Grinding machine controls - for checking proper mounting of the wheel.

- Paper cutting machine - for adjusting the cut.

Apart from the above, the inch control is the prime control in cranes, hoists and conveyor belt mechanism so that incremental movements either vertically or horizontally could be achieved in the driven machinery.

Jogging may be accomplished by the following methods.

- Selector switch
- Push-button
- Push-button with a jog relay

Jogging control using a selector switch: By using a selector switch, the existing start button can be used as a jogging push-button in addition to its function as a starting push-button. The holding contacts of the contactor which are in parallel to the start-button are disconnected and the selector switch is placed in the jog position as shown by the circuit in Fig 16 and the panel layout in Fig 17.

Fig 16

CONTROL CIRCUITS WITH JOG-RUN SELECTOR SWITCH.

Fig 17

A PANEL OF A STATION IN WHICH THE START BUTTON CAN BE USED FOR INCHING OR JOGGING.
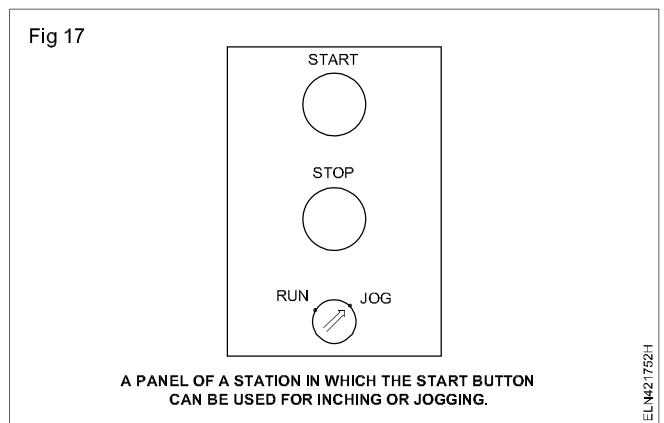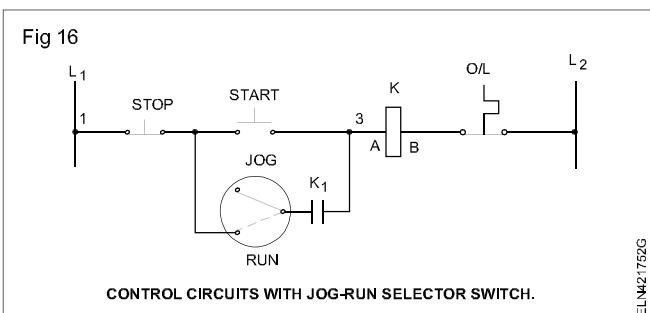
The motor can be started or stopped by jogging/inching the start button. The motor will operate as long as the start-button is held pressed.

Jogging control using a push-button: Fig 18 shows the control circuit of a D.O.L. starter connected to a start-jog-stop push-button station. When the `ON' push-button is pressed, coil K is energised as the no-volt coil circuit is complete through the normally closed `jog' button contacts 30 & 31, thereby closing the main contactor, and the motor runs. The self-holding auxiliary contact K_1 between terminals 13 and 14 gets closed, and keeps the no-volt coil circuit in function though the `ON' button is released.

Fig 18

CONTROL CIRCUIT WITH JOG PUSH-BUTTON
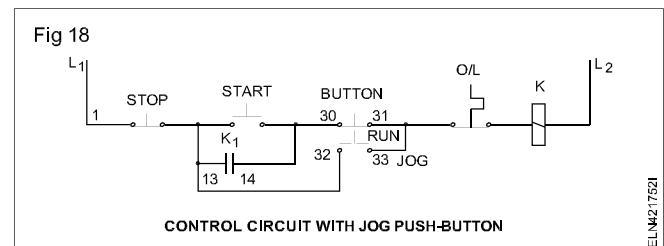
As soon as the jog push-button is pushed, as the circuit of the no-volt coil opens initially, the contactor is de-energised and the motor stops if it is running. Then the jog-button closes the bottom contacts 32 & 33, thereby the no-volt coil circuit closes and the motor runs as long as the jog-button is held pressed. By pushing and releasing the jog-button repeatedly, the motor starts and stops causing the driven machinery to `inch' forward to the desired position. On the other hand, pressing the start-button will make the motor to run normally.

Jogging control using a relay: Fig 19 shows the control circuit of a D.O.L. starter connected to a control relay with the other usual components. When the start button is pressed, the control relay coil CR is energised and closes the contacts R_1 and R_2, thereby momentarily completing the no-volt coil `K' circuit through relay contact R_2. This in turn closes the self-holding auxiliary contact K_1 of the no-volt coil relay K, and the motor runs continuously even though the pressure on the start-button is released.

Fig 19

LINE DIAGRAMS USING CONTROL RELAYS IN TYPICAL INSTALLATIONS
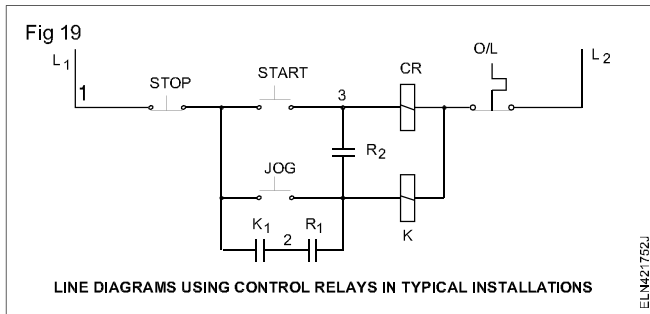
When the motor is not running, if the jog-button is pressed the no-volt coil, K circuit, is completed, and the motor runs only as long as the jog-button is held pressed as the holding circuit through R_1 is not completed for the starter coil as the control relay CR is not energised.

For a 3-phase, D.O.L. starter having the jog control through relay, four normally open contacts (3 for main and 1 for auxiliary) are required and the control relay should have two normally open contacts as in Fig 19.

Sequential control of motors

It is a kind of multiple motor's control in a specified manner by means of timer or limit switches or sensor depend the requirements of industries or application.

In this method generally the operation of two or more individual motors are controlled with respect to the specified time lapse or reaching of the specified level or completion of the specified operation. The operation of first motor will control the operation of the second or other motors and operation of second motor will control the operation of other motors and so on.

This type of the control system reduce the error due to human and man power, increase the accuracy of the operation cycle, minimize the ideal time of the machines and increase the efficiency and production of the industries.

The example of such sequential control system might be found in some of the industrial agitator system which explained in details below.

Industrial agitator

It is the machine consists of an electric motor along with impeller in its long shaft and fitted in the agitator tank which used in the chemical, food and pharmaceutical process industries to

• Mix the different type of liquid or chemical homogeneously.

• Improve the chemical properties of the liquid or substance.

• Keep and stir the stored liquid in the specified heat and properties.

Fig 20 show a typical industrial agitator used to remove the sludge and improve the chemical properties of the liquid or chemical before feeding to the process reactor. It has the feeding pump, agitator and discharge pump. The liquid to be treated is fed into the agitator tank through the feed pump which is started manually.

Fig 20

INDUSTRIAL AGITATOR SYSTEM
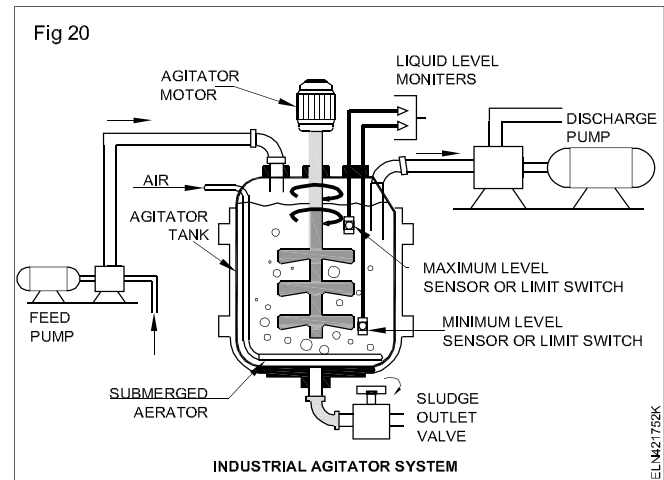
After some time lapse the agitator motor starts by means of timer and stir the liquid continuously till the level of the liquid reaches the minimum level. When the liquid level in agitator reaches the maximum level, the sensor or limit switch installed in the tank is switched off the feed pump.

After specified time lapse of starting the agitator motor the discharge motor is started by means of one more timer and discharge the liquid to further process. When the liquid level in agitator reaches the minimum level, the sensor or limit switch installed in the tank is switched OFF the discharge pump.

The agitator also have the submerged aerator through which the air is fed, a sludge discharge line with valve to discharge unwanted sludge, minimum and maximum level sensor or limit switches to maintain the liquid level in the tank.

A control panel with necessary wiring and protection are designed and installed to control the sequential control of all the three motors. The Fig 21 and 22 show the power and control circuit of the sequential control of the typical agitator system with three motors.

All the three motors have individual power circuit of DOL starter with over load and short circuit protection. The total control panel has an isolation switch to ON and OFF the supply. It has indicator lamps to indicate the availability of the power supply and control supply and also indicates the running status of feed pump, agitator motor and discharge pump.

Sequence of operations of the sequential control of the agitator system having three motors

When the start push button is pressed the NVC of the feed pump motor contactor (C_1) and timer 1 (T_1) is getting the control voltage through the stop push button, OLTC of OLR1 and NC contact of the maximum level limit switch.

Fig 21

POWER CIRCUIT FOR SEQUENTIAL CONTROL OF THREE MOTORS

Fig 22

CONTROL CIRCUIT OF SEQUENTIAL CONTROL OF AGITATOR SYSTEM WITH THREE MOTORS
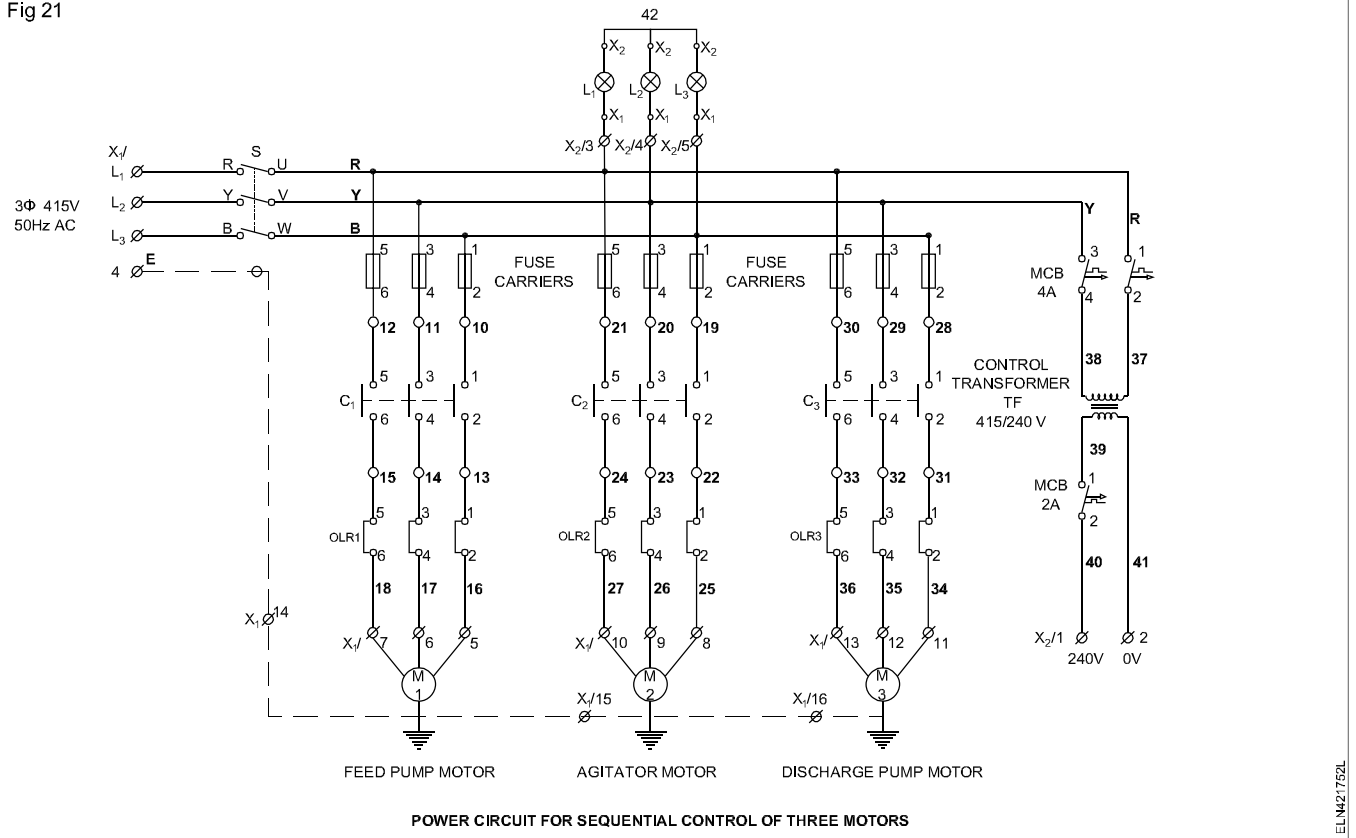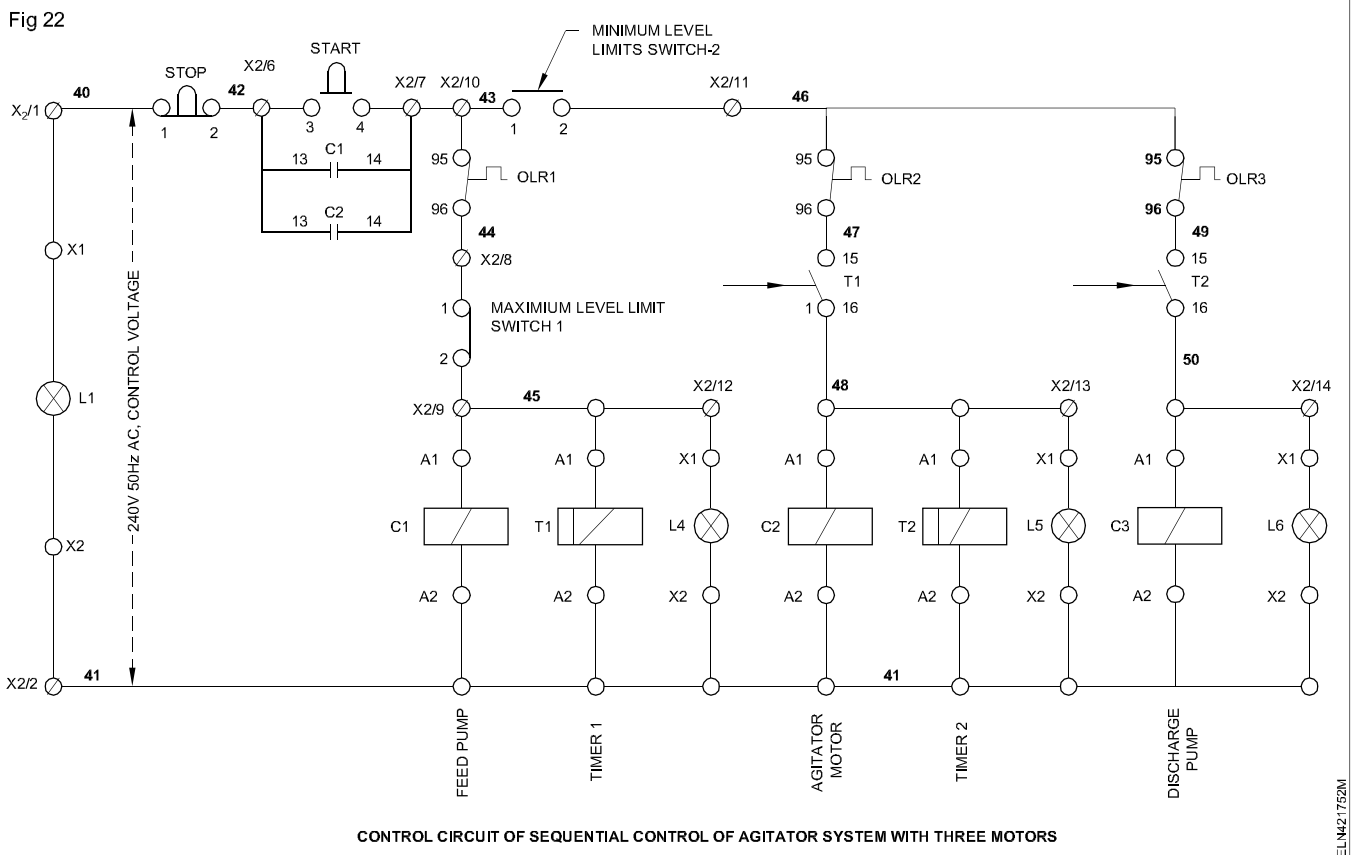
Now the C_1 and T_1 energized and get self holding through the NO contact C_1. So even after releasing the 'start' push button the C_1 and T_1 will continuously be in energized condition.

After some pre-determined time lapse the NO contact of the timer 1 closes and the NVC of the agitator motor contactor (C_2) and timer 2 (T_2) get control voltage through the minimum level limit switch and OLTC of OLR 2. Now

the C_2 energized and get self holding through its own NO contact. So even if the C_1 if get de-energized due to maximum level limit switch, the C_2 will continuously be in energized condition.

After the some time lapse the NO contact of the timer 2 closes and the NVC of the discharge pump motor contactor (C_3) is getting the control voltage and get energized.

If the liquid level of the agitator reduces to the minimum, the NO contact of the minimum level limit switch open causes C_2 and C_3 get de-energized.

When the all the three motors are working, in case if the OLTC of OLR1 opens the C_1 will only get de-energized and C2 and C3 continuously in energized condition through the self holding contact of C_2.

In case if the OLTC of OLR 2 opens due to over load the C_2 will only get de-energized if the C_1 is in energized condition. In other hand if the C_1 is already of OFF condition due to activation of maximum level limit switch, the C_3 also will get de-energized.

In case if the OLTC of the OLR3 opens due to over load the C_3 alone will get de-energized.

Installation of instruments and sensors in control panel and its performance testing

Objectives: At the end of this lesson you shall be able to
• **state the sensor main specification, application necessity and types**
• **state the specification and types of sensors required in panel board**
• **explain the performance testing of panel control board.**

Instruments in panel board

Industrial operation for any process requires many machines, apparatus for usual supply and maintain continuous production. Some machines requires operator always to operate many control on process for example a lathe machine is required always its operator assistance to do different job, turning, shaping etc, but in some cases the machine not required continuous manual operator for single job operations.

In a workshop AC motor or DC motor is to operate for many of its intended job. Once the machine starts it will continue to work for its assigned job and requires only ON and OFF operation. This operation may need many job completion in different places located in the work shop. This operation has to be controlled and monitored in time intervals and a constant watch also may require.

The instruments are used to measure the electrical quantities, which in turn gives the feed back of load conditions and performance. A motor draws a constant current, which can monitor by a ammeter connected to them similarly the rated voltage, frequency, power factor etc, are also to be checked through the meters. If number of machines and meters are more it is difficult to watch the parameters individual places. A panel board having this meters are installed helps to collect the data at one place where different machines are working.

Selection of meters are in accordance with the machine ratings and working voltage limits. A low range meter cannot be connected in a heavy load machine for its readings it may damage the meter and its wiring.

Sensors types, classification and its application

Sensors is a device that detects/measures a physical quantity. A motor is running with its rated rpm but some cases load variations on motor affects the rpm. The quality of the product may depend on the machine accuracy, then it is very important to run the motor at its rated rpm. Automatic rpm correction is possible with relevant circuits but a sensor has to feed back the working rpm to the control circuit. In this case a Tacho generator is the device to produce the feed back of rpm of motor. Tacho generator can be fixed on the shaft of the motor and the resultant feed back quantity(V or I) can be brought to the control panel board.

Similarly, the temperature measurement also can be done by suitable sensors. Since the temperature is the big problem for all electrical applications, a constant watch on the temperature helps to increase the life of the machine and a uniform production with specified quality. In this way temperature can be controlled by installing suitable sensor preferably with a thermistor-PTC or NTC will help to control the temperature within safe limits. The sensor element will kept in the winding and the cable is brought up in the control panel, to connect the temperature indicating unit for indication.

A sensor is a special kind of transducer which is used to generate an input single to a measurement, instrumentation or control system. The signal produced by a sensor in an electrical analogy of a physical quantity, like acceleration, temperature, pressure, distance, velocity, light, level etc.

Types of sensors: There are two types of sensors

a) Passive sensor

b) Active sensor.

a) **Active sensor:** Self generating sensor is that one can generate a signal without any external power source. Eg. photovoltaic cell, thermo couple, piezoelectric device .

b) **Passive sensor:** It requires external power supply to generate the signal. Eg. Diaphragm used to convert pressure or velocity, oscillations, or sound wave's into movements of a solid sheet.

Classification of sensors: It is classified into many categories according to the output, application etc. It is mainly divided into two groups, they are; a) Digital sensor and b) Analog sensor.

Digital sensor: The resolution of this sensor is most accurate and maximum speed. Its ability to detect a change in the sensed quantity is excellent. The output is always taken as 180, high and low, or yes or no.

Analog sensor: The resolution of this sensor in less accurate corporate to digital and it records very small changes or variations resulting more error. It is usually used to record very small changes, or variations.

Further, the sensors are mainly used to measure temperature and RPM in the electrical circuits. The following sensors are used to measure temperature. They are;

a) Thermo couple

b) RTD (Resistance Temperature Detector)

c) Thermistor

d) IR sensors (Infra Red)

e) Semi conductor sensors - VDR, LDR, Photo diode etc.,

The sensors used to measure RPM of motor; are in different types; they are

a) Shaft encoders (rotary type) 1-5000 pulses

b) Photoelectric (optical type)

c) Magnetic rotational speed (proximity type) - medium or low RPM.

d) Photo sensor reflection target- Tachometer - 20-20,000 range

Sensor assembly and measurements

Temperature measurement using resistance temperature detector (RTD) and $\sqrt{1}$ assembly with position adjustment, tachometer sensor assembly and a AC tachometer generator is in Fig 1. The AC is rectified by a bridge circuit. The amplitude and frequency of the induced emf are equivalent to the speed of the shaft. Thus either amplitude or frequency is used for measuring the angular velocity.

Performance testing of panel board

It is important to see that the panel board is to install carefully as it carrys a number of connection and controls. Any loose connection or wrong connection to any device will affect the performance and it may cost more.

While testing the performance make sure that all connections and wiring are correct and as per IE rules. Wrong connection and substandard materials will cause heavy damage to the panel board. The continuity of cable, earth resistance values are to be kept in the safe level as per IE rule normal.

Fig 1

R.T.D. RESISTANCE TEMPERATURE DETECTOR

A.C TACHOMETER GENERATOR
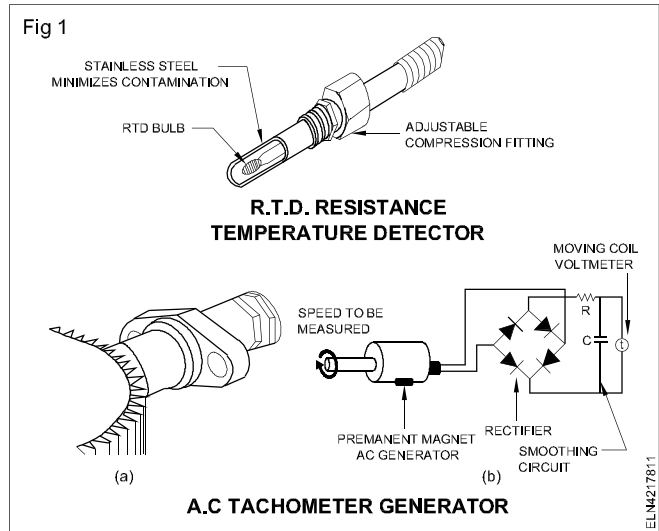
The panel board should be earthed properly and all metal parts have to be connected to earth. If the current in the panel board is heavy; a separate earthing has to be provided and maintained within the standard.

Connection to machine from panel board has to be made on short as possible. If the machine draws less current, line drop will be minimum and resultant power is low hence in cable is also low and even negligible. If the connecting cable length is much more than line loss will be too high and it will turn shorten the life of machine and cables connected. Running of cable can be made as per the situation and facilities. Keep away from direct sun light wet condition, and near fire or any other polluted areas.

A simple model panel board to the load power is given for your guidance in Fig 2.

Fig 2

PANEL BOARD CONNECTION TO MACHINES
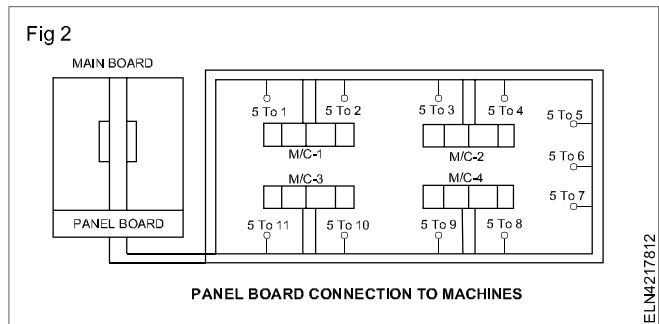
AC/DC drives

Objectives: At the end of this lesson you shall be able to
• **state the classification and working of AC & DC drives**
• **state the applications of AC & DC drives**
• **describe the block diagram, parts of DC drive and advantages and disadvantages of DC drives.**

Electrical drives

An electric drive can be defined as an electromechanical device for converting electrical energy into mechanical energy to feed motion to different machines and mechanisms for various kinds of process control.

Motion control is required in large number of industrial and domestic applications like transportation, systems, rolling mills, paper machines, textile mills, machine tools, fans, pumps, robots, washing machines etc.

Systems employed for motion control are called Drives, and may employ any of prime movers such as diesel or petrol engines, gas or steam turbines, steam engines, hydraulic motors and electric motors; Supplying mechanical energy for motion control Drives employing electric motors are known as Electrical drives.

Classification of electric drives

i   According to mode of operation

-   Continuous duty drives

-   Short time duty drives

-   Intermittent duty drives

ii According to means of control

-   Manual

-   Semi automatic

-   Automatic

iii According to number of machines

-   Individual drive

-   Group drive

-   Multi - motor drive

iv According to dynamics and transients

-   Uncontrolled transient period

-   Controlled transient period

V   According to methods of speed control

-   Reversible and non - reversible uncontrolled constant speed

-   Reversible and non - reversible step speed control

-   Variable position control

-   Reversible and non - reversible smooth speed control

Advantage of electrical drives

1   They have flexible control characteristics.

2   Drives can be provided with automatic fault detection systems. Programmable logic controller (PLC) and computers can be employed to automatically control the drive operation in a desired sequence.

3   They are available in wide range of torque, speed and power.

4   They are suitable to almost any operating conditions such as explosive and radioactive environments.

5   It can operate in all the four quadrants of speed - torque plane.

6   They can be started instantly and can immediately be fully loaded.

7   Control gear requirement for speed control, starting and braking is usually simple and easy to operate.

Choice (or) selection of electrical drives

-   Choice of an electric drive depends on the important factors are.

1   Steady state operating conditions requirements. Nature of speed torque characteristics, speed regulation, speed range, efficiency, duty cycle, quadrants of operation, speed fluctuations if any, rating etc.

2   Transient operation requirements

3   Values of acceleration and deceleration, starting, braking and reversing performance.

4   Requirements related to the source. Types of source and its capacity, magnitude of voltage, voltage fluctuations, power factor, harmonics and their effect on other loads, ability to accept regenerative power.

5   Space and weight restriction if any.

6   Environment and location.

7   Reliability

Group electric drive

This drive consists of a single motor, which drives one or more line shafts supported on bearings. The line shaft may be fitted with either pulleys and belts or gears, by means of which a group of machines or mechanisms

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may be operated. It is also some times called as **shaft drives.**

Advantages

A single large motor can be used instead of number of small motors.

Disadvantages

There is no flexibility. If the single motor used, develops fault, the whole process will be stopped.

Individual electric drive

In this drive each individual machine is driven by a separate motor. This motor also imparts motion to various parts of the machine.

Multi motor electric drive : In this drive system, there are several drives, each of which serves to actuate one of the working parts of the drive mechanisms.

e.g : Complicated metal cutting machine tools

Paper making industries.

Rolling machines etc.

A modern variable speed electrical drive system has the following components

- Electrical machines and loads
- Power modulator
- Sources
- Control unit
- Sensing unit

Electrical machine

Most commonly used electrical machines for speed control applications are the following.

DC machines

Shunt, series, compound, DC motors and switched reluctance machines.

AC machines

Induction, wound rotor, synchronous, permanent magnet synchronous and synchronous reluctance machines.

Special machines

Brush less DC motors, stepper motors, switched reluctance motors are used.

Power Modulators (Controller)
Functions

- It modulates flow or power from the source to the motor is imparted speed - torque characteristics required by the load.
- During transient operation, such as starting, braking and speed reversal, it reduces the motor current with in permissible limits.
- It converts electrical energy of the source in the from of suitable to the motor.
- It selects the mode of operation of the motor (i.e) motoring and braking.

Types of power modulators (Controllers)

- In the electric drive system, the power modulators can be any one of the following.
- Controlled rectifiers (AC to DC converter)
- Inverters (DC to AC converters)
- AC voltage controllers (AC to DC converters)
- DC choppers (DC to DC converters)
- Cyclo converters (Frequency conversion)

Electrical sources

Very low power drives are generally fed from single phase sources. Rest of the drives is powered from a 3-phase source. Low and medium power motors are fed from a 415V supply. For higher ratings, motors may be rated at 3.3KV, 6.6 KV and 11 KV. Some drives are powered from battery.

Sensing unit

- Speed sensing (from motor)
- Torque sensing
- Position sensing
- Current sensing and voltage sensing (from lines or from motor terminals from load)
- Temperature sensing

Control unit

Control unit for a power modulator are provided in the control unit. It matches the motor and power converter to meet the load requirements.

Comparison between DC and AC drives

DC Drives	AC Drives
The power circuit and control circuit are simple	The power circuit and control circuit are complicated
It requires frequent maintenance	Less maintenance
The commutator makes the motor bulky, costly, and heavy	These problems are not there in these motors and are inexpensive, particularly squirrel motors
Fast response and wide speed range of control, can be achieved smoothly by conventional and solid state control	In solid state control the speed range is wide and conventional method is stepped and limited
Speed and design ratings are limited due to commutations	Speed and design ratings have upper limits

Applications

• Paper mills

• Cement mills

• Textile mills

• Sugar mills

• Steel mills

• Electric traction

• Petrochemical industries

• Electrical vehicles

Another one type of electric drive is 'Eddycurrent drive'

Eddy current drives

An eddy current drive consists of a fixed speed motor and an eddy current clutch. The clutch contains a fixed speed rotor and an adjustable speed rotor separated by a small air gap. A direct current in a field coil produce a magnetic field that determines the torque transmitted from the input rotor to the output rotor. The controller provides closed loop speed regulation by varying clutch current, only allowing the clutch to transmit enough torque to operate at the desired speed. Speed feedback is typically provided via an integral AC tachometer.

Eddy current drives are slip - controlled systems the slip energy of which is necessarily all dissipated as heat. Such drives are therefore generally less efficient than AC/DC-AC conversion based drives. The motor develops the torque required by the load and operates at full speed. The power is proportinoal to torque multiplied by speed. The input power is proportional to motor speed and times, operating torque while the output power is output speed and times operating torque. The difference between the motor speed and the output speed is called the **slip speed**. Power proportional to the slip speed times operating torque is dissipated as heat in the clutch.

Working principle of DC drives

In DC motors, the speed is proportional to the armature voltage and inversely proportional to the field current .

And also, the armature current is proportional to the motor torque. $N \propto \dfrac{E_b}{I_f}$ and $I_a \propto T$ Therefore, by increasing or reducing the applied voltage, the speed of the motor is varied. However, it is possible up to the rated voltage. If the speed greater than the base speed is required, the field current of the motor has to be reduced.

By reducing the field current, the flux in the motor reduces and it reduces the armature counter emf. Further, this armature current increases the motor torque and the speed will increase. These are the two basic principles employed in DC drives to control the speed of the motor.

In armature controlled DC drives, by varying the armature voltage, variable speed is obtained as in Fig 1.

Fig 1
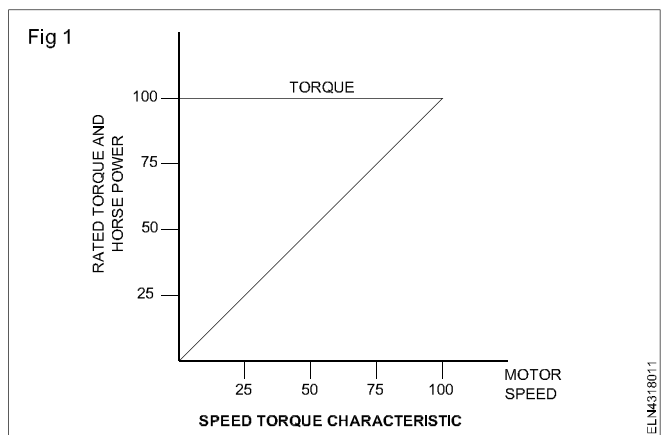
Generally, a fixed field supply is provided in these DC drives. As the torque is constant (which describes a load type) over the speed range, the motor output horse power is proportional to the speed. The motor characteristics of this drive are in Fig 1.

Constant torque operation

In case of armature and field controlled drives, the armature voltage to the motor is controlled for constant torque-variable HP operation up to the base speed of the motor. And for the above base speed operation, drive switches to the field control for constant HP- reduced torque operation up to maximum speed as in Fig 2 In this case,

reducing the field current increases the speed of the motor up to its maximum speed as in Fig 2.

Fig 2

N V_B T-CHARECTERISTICS
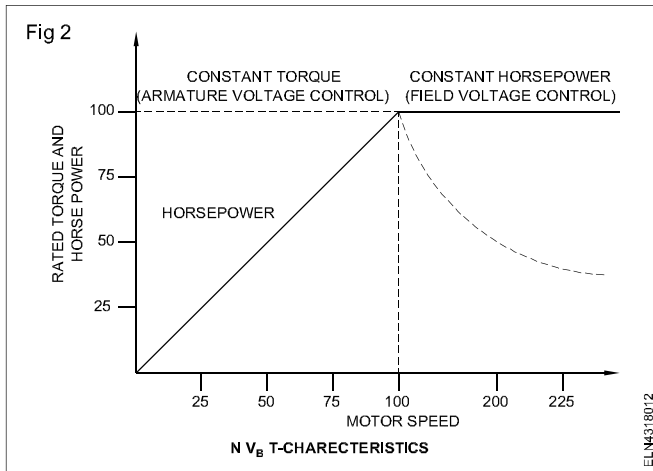
In most instances the shunt field winding is excited, with a constant - level voltage from the controller . The SCR (silicon controller rectifier), also known as thyristor, which converts the alternating current (AC) of the power source to variable DC output which is applied to the armature of a DC motor. Speed control is achieved by regulating the armature voltage to the motor.

A thyristor bridge is a technique commonly used to control the speed of a DC motor by varying the DC voltage. Important to note that the voltage applied to a DC motor can not be greater than the rated name plate voltage.

The tachometer (feedback device) converts actual speed in to an electrical signal that is summed with the desired reference signal. The output of the summing junction provides an error signal to the controller and a speed correction is made.

In modern DC drives, SCRs are completely replaced by MOSFET s and IGBTs in order to achieve high speed switching so that distortion to the AC incoming power and currents during switching is eliminated. Hence, the drive becomes more efficient and accurate.

Silicon controlled rectifier (SCRs) are widely used thyristors for large DC motor drives in its power conversion unit. An SCR conducts when a small voltage applied to its gate terminal. Its conduction continues till the starting of negative cycle and it turned OFF automatically once the voltage across the SCR goes through natural zero till next gated signal.

The purpose of using these SCRs in DC drives is to convert the fixed AC supply to variable DC supply that controls the motor speed. Some SCR DC drives are supplied from single phase AC supply and use four SCRs in the form of bridge for the DC rectification. In case of high power DC drives, a three phase supply with six SCRs is used for DC rectification.

In case of four quadrant operation (forward motoring, forward braking, reverse motoring and reverse braking) of the DC drive, a bridge rectifier consisting of 12 SCRs

with a three phase incoming supply is used. During each quadrant operation, SCRs are triggered at a phase angle in order to provide required DC voltage to the motor.

Drive operation

The drive applications can be categorized as single - quadrant, two - quadrant, three-quadrant or four- quadrant; the chart's four quadrants (Fig 3) are defined as follows.

Fig 3

ELECTRIC MOTOR SPEED-TORQUE CHART
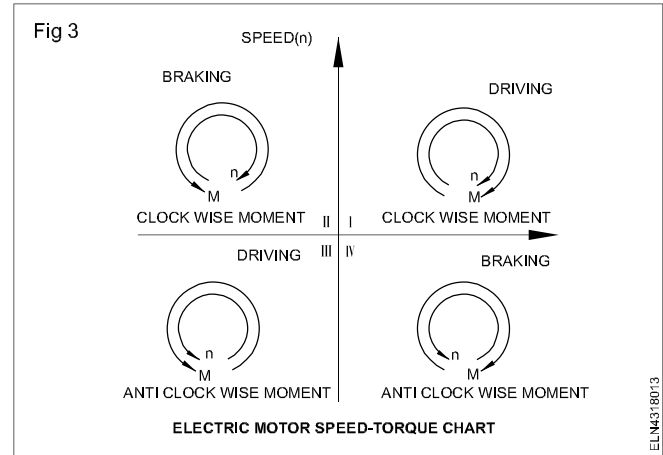
Quadrant I : Driving or motoring forward accelerating quadrant with positive speed and torque

Quadrant II : Generating or braking, forward braking-decelerating quadrant with positive speed and negative torque.

Quadrant III: Driving or motoring, reverse accelerating quadrant with negative speed and torque.

Quadrant IV : Generating or braking, reverse braking - decelerating quadrant with negative speed and positive torque.

Most applications involve single quadrant loads operating in quadrant I, such as in variable - torque (e.g. centrifugal pumps or fans. etc.

Certain applications involve two - quadrant loads operating in quadrant I and II where the speed is positive but the torque changes polarity Some sources define two - quadrant drives as loads operating in quadrants I and III where the speed and torque is same (positive or negative) polarity in both directions.

Certain high - performance applications involve four - quadrant loads (Quadrants I to IV) where the speed and torque can be in any direction such as in hoists, elevators and hilly conveyors. Regeneration can occur only in the drive's DC link bus when inverter voltage is smaller in magnitude than the motor back - EMF and inverter voltage and back - EMF are the same polarity.

The connection of SCRs for four quadrant operation of the drive) from incoming three phase AC supply to the DC output is in Fig 4. In this, the motoring SCR bridge and regeneration SCR bridge achieve the drive four quadrant

operation by receiving the appropriate gate signals from (analog or digital) controller.

Fig 4

3 PHASE SCR BRIDGE RECTIFIER
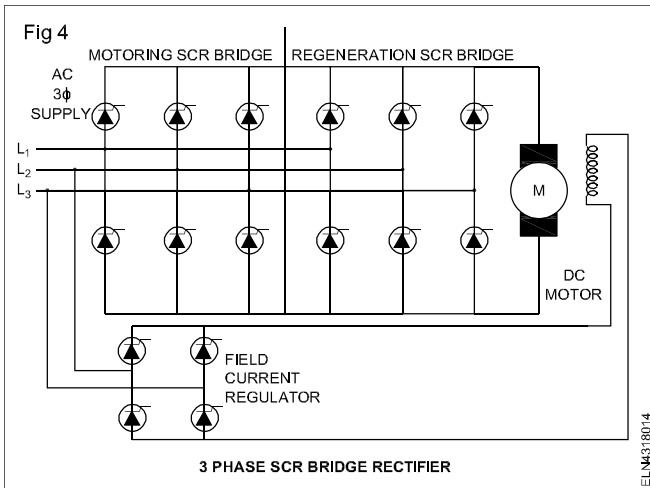
If the SCRs were gated with a phase angle of zero degrees, then the drive function as a rectifier which feeds the full rectified rated DC supply to the motor and by varying the firing angle to the SCRs, a variable DC supply is applied to the motor.

The DC output voltage waveform is related to the AC waveform for above circuit is in Fig.5. This average DC output voltage is obtained for 40°, 32° and 24° firing phase angles. By this way, the average output is controlled by varying the firing phase angles to the SCRs.

Fig 5

AC INPUT & DC OUTPUT WAVE FORMS
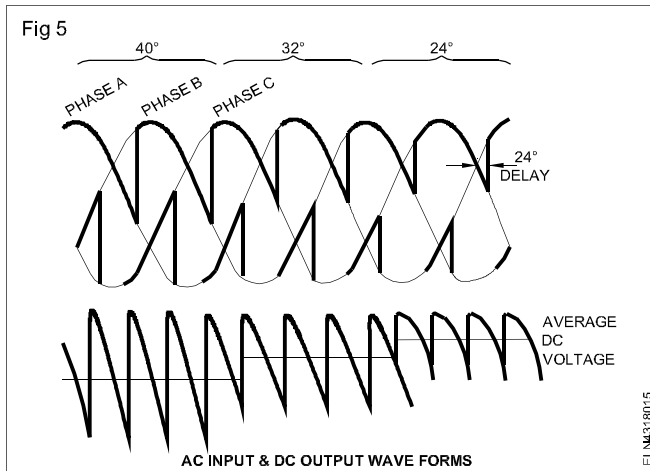
As the field winding also requires the regulated DC supply, only four SCRs are used in the field bridge converter. This is because field never requires a negative current and hence another set of SCRs is not required, which were used in armature for reversing the motor.

Block diagram of DC drive

The block diagram of a DC drive system is in Fig 6

DC drive input : Some thyristor based DC drives operate on a single phase supply and use four thyristors for full wave rectification. For larger motors 3 phase power supply is needed because the waveforms are much smoother. In such cases, six thyristors are needed for full wave rectification.

Fig 6

COMPONENTS OF A DC DRIVE SYSTEM
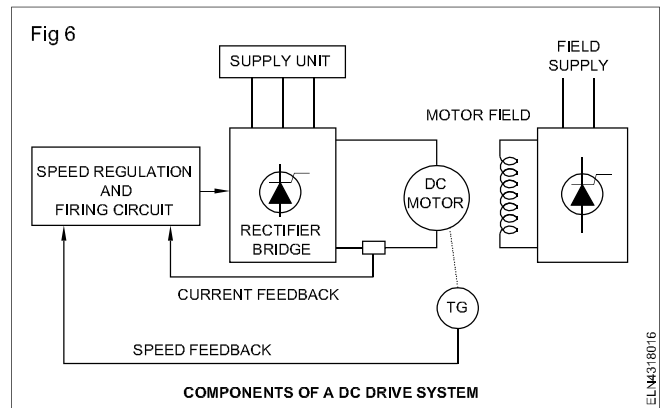
Rectifier Bridge : The power component of a controlled DC drive is a full wave bridge rectifier which can be driven by three phase or single phase supply. As mentioned above the number of thyristor may vary depends on the supply voltage.

A six - thyristor bridge (in case of three phase converter) rectifies the incoming AC supply to DC supply to the motor armature. The firing angle control of these thyristors varies the voltage to the motor.

Field Supply Unit (FSU) : The power is to be applied to the field winding is much lower than the armature power.

In many cases a two - phase supply is drawn from the three phase input (that supplies power to the armature) and hence the field exciter is included in the armature supply unit.

The function of the field supply unit is to provide a constant voltage to the field winding to create a constant field or flux in the motor. In some cases, this unit is supplied with thyristors to reduce the voltage applied to the field so as to control the speed of the motor above the base speed incase of permanent magnet DC motors, the field supply unit is not included in the drive.

Speed Regulation unit : It compares the operator instruction (desired speed) with feedback signals and sends appropriate signals to the firing circuit. In analog drives, this regulator unit consists of both voltage and current regulators. The voltage regulator accepts the speed error as input and produces the voltage output which is then applied to the current regulator.

The current regulator then produces required firing current to the firing circuit. If more speed is required, additional current is drawn from the voltage regulator and hence thyristors conduct for more periods. Generally, this regulation (both voltage and current) is accomplished with proportional -integral- derivative controllers.

The field current regulator is also provided where speed greater than the base speed is required.

Parts of DC drive

DC drives of various brands with different ratings are available in the market. It is generally assembled in a metallic enclosure. The front panel has the power terminals,

control terminals, keypad for controlling the drive etc. It has provision for connecting to PC for programming the drive.

The main parts of DC drive are given below.(Fig 7)

PARTS OF DC DRIVE
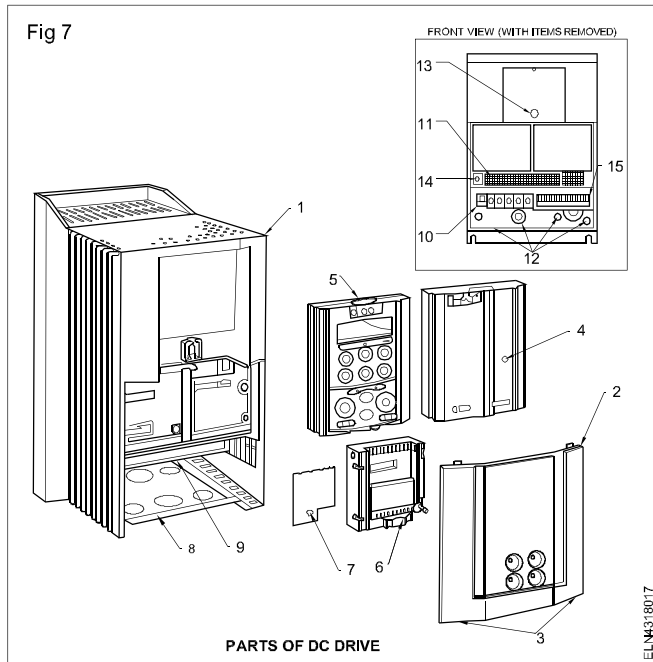
1 Main drive assembly

2 Terminal cover

3 Terminal cover retaining screw

4 Blank cover

5 Keypad

6 COMMS technology box (optional)

7 Speed feedback technology card (optional)

8 Gland plate

9 Power terminal shield

10 Power terminals

11 Control terminals

12 Earthing / grounding points

13 Keypad part

14 Programming part

15 Auxiliary power, external contactor, blower and isolated thermistor terminals

Power and control terminals

In DC drive, the front panel has the power terminals L1, L2 and L3 where 3 phase input supply of 415V can be connected.

There are control terminals given for speed adjust potentiometer, Torque adjust potentiometer, START/RUN/STOP switch, JOG/RUN/ switch, AUTO/MAN switch, FORWARD/REVERSE switch etc. Terminal A1 & A2 and

B_0 & B_1 are meant for armature and field connections respectively. Names and locations are illustrated in Fig 8

CONTROL TERMINALS OF DC DRIVE
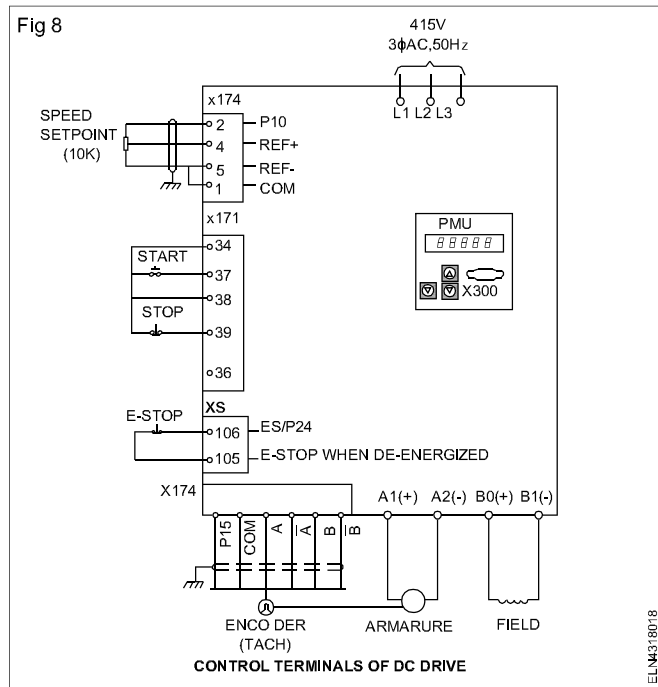
Advantages of DC drive

• DC drives are less complex with a single power conversion from AC to DC.

• DC drives are normally less expensive for most horsepower ratings.

• DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose.

• Cooling blowers and inlet air flanges provide cooling air for a wide speed range at constant torque.

• Accessory mounting flanges and kits for mounting feedback tachometers and encoders.

• DC regenerative drives are available for applications requiring continuous regeneration for overhauling loads. AC drives with this capability would be more complex and expensive.

• Properly applied brush and commutator maintenance is minimum.

• DC motors are capable of providing starting and accelerating torques in excess of 400% of rated value.

• Some AC drives may produce audible motor noise which is undesirable in some applications.

Disadvantages of DC drive

• More complicated because of commutators and brushes.

• Heavier than AC motors.

• High maintenance is required.

• Large and more expensive than AC drive.

• Not suitable for high speed operation.

Speed control of 3 phase induction motor by VVVF/AC drive

Objectives: At the end of this lesson you shall be able to
• **state about AC drives (VFD/VVFD) and changing of speed of AC motor by AC drive**
• **explain the operation of AC drive with block diagram**
• **list out the advantages and disadvantages of AC drive**
• **explain the components / parts and power and control terminals of AC drive**
• **state the parameter setting - speed control changes of direction of AC & DC drives / VFD/VVVFD (variable frequency drive/ variable voltage variable frequency drive)**
• **state the speed control of universal motor.**

Variable Voltage Variable Frequency Drive (VVVFD)

The AC drive industry is growing rapidly and it is now more important than ever for technicians and maintenance personnel to keep AC drive installations running smoothly. AC drives change the speed of AC motor by changing voltage and frequency of the power supplied to the AC motor. In order to maintain proper power factor and reduce excessive heating of the motor, the name plate volts / hertz ratio must be maintained. This is the main task of VFD (Variable frequency drive).

Applications of AC drives

1   AC drives are used to stepless speed control of squirrel cage induction motors mostly used in process plants due to its ruggedness and maintenance free long life.

2   AC drives control the speed of AC motor by varying output voltage and frequency through sophisticated microprocessor controlled electronics device.

3   AC drive consists of rectifier and inverter units. Rectifier converts AC to DC voltage and inverter converts DC voltage back to AC voltage.

Changing of speed of AC motors by using AC drive

From the AC motor working principle, that the synchronous speed of motor N_s in rpm, is dependent upon frequency. Therefore by varying the frequency of the power supply through AC drive, it can control the synchronous speed.

Speed (rpm) = Frequency (Hertz) x 120 / No. of poles.

Where

Frequency = Electrical frequency of the power supply in Hz., No. of poles = Number of electrical poles in the motor stator. Thus the speed of AC motor can conveniently be adjusted by changing the frequency applied to the motor. There is also another way to make the AC motor work on different speed by changing the no. of poles, but this change would be a physical change of the motor. The VFD provides the controls over frequency and voltage of motor input to change the speed of a motor. Since the frequency is easily variable as compared with the poles variation of the motor. AC drives are frequently used.

Constant V/F ratio operation

If the same voltage is applied at the reduced frequency, the magnetic flux would increase and saturate the magnetic core, significantly distorting the motor performance. The magnetic saturation can be avoided by keeping the ϕ_m constant.

All AC drives maintain the voltage -to- frequency (V/F) ratio constant at all speeds for the reason that follows. The phase voltage V, frequency F and the magnetic flux ϕ of motor are related by the equation.

$V = 4.444\, f\, N\, \phi_m$

or

$V/f = 4.444 \times N\, \phi_m$

Where N = number of turns per phase

ϕ_m = magnetic flux

Moreover, the AC motor torque is the product of stator flux and rotor current. For maintaining the rated torque at all speeds the constant flux must be maintained at its rated value, which is basically done by keeping the voltage - to - frequency (V/f) ratio constant.

An AC drive is capable of operating a motor with constant flux (Φ) from approximately zero (0) to the motor's rated nameplate frequency (typically 50Hz). This is the constant torque range. As long as a constant volts per hertz ratio is maintained the motor will have constant torque characteristics. AC drives change frequency to vary the speed of a motor and voltage proportionately to maintain constant flux. The Fig1 is the graph illustrates the volts per hertz ratio of a 415 volt, 50 hertz motor. To operate the 415 volt motor at 50% speed with the correct ratio, the applied voltage and frequency would be 207.5V volts, 25 Hz. The voltage and frequency ratio can be maintained for any speed up to 50Hz. This usually defines the upper limits of the constant torque range.

Some applications require the motor to be operated above base speed. The nature of these applications requires less torque at higher speeds. Voltage, however, cannot be higher than the available supply voltage. This can be

illustrated as in Fig 2. Voltage will remain as 415 volts for any speed above 50Hz. A motor operated above its rated frequency is operating in a region known as a constant horsepower. Constant volts per hertz and torque is maintained up to 50Hz. Above 50Hz the volts per hertz ratio decreases. The V/Hz ratio at 25 Hz is 8.3, at 50Hz is 8.3, at 70Hz is 5.93 and at 90Hz is 4.61. Flux (Φ) and torque (T) decrease. Operation of the motors above rated nameplate speed (base speed) is possible, but is limited to conditions that do not require more power than the nameplate rating of the motor. This is sometimes called "field weakening" and, for AC motors, means operating at less than rated V/Hz and above rated nameplate speed.

Fig 1

$V/Hz = 415/50 = 207.5/25$
$= 8.3V/Hz$

V/F RATIO CHART

Fig 2

V/F CHART
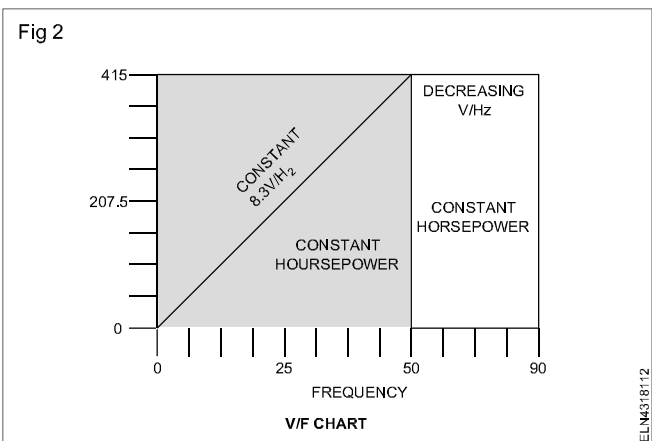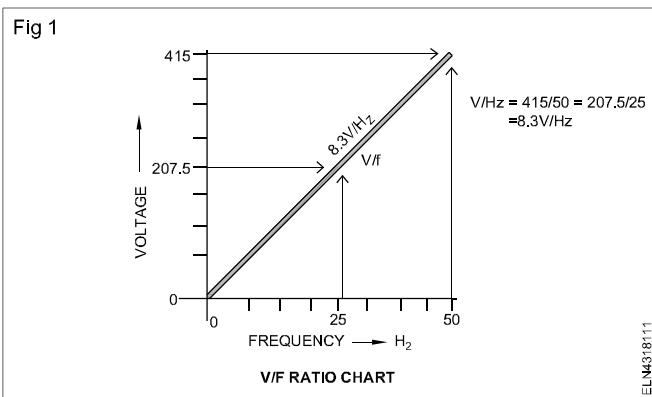
Block diagram of AC drive

The Insulated - Gate - Bipolar- Transistor (IGBT) is in the past two decades come to dominate VFD as an inverter switching device.

IGBTs (insulated gate bipolar transistor) provide a high switching speed necessary for PWM (Pulse width Modulation) inverter operation. IGBTs are capable of switching ON and OFF several thousand times a second. An IGBT can turn on in less than 400 nanoseconds and off in approximately 500 nanoseconds. An IGBT consists of a gate, collector and an emitter. When a positive voltage (typically +15 VDC) is applied to the gate the IGBT will turn on. This is similar to closing a switch. Current will flow between the collector and emitter.

An IGBT is turned off by removing the positive voltage from the gate. During the off state the IGBT gate voltage is normally held at a small negative voltage (-15 VDC) to

prevent the device from turning on. So the gate can control the switching on/off operation of an IGBT.

Fig 3 shows the block diagram of AC drive and Fig 4 shows the internal connection diagram. There are three basic sections of the AC drive; the rectifier, DC bus, and inverter.

Fig 3

BLOCK DIAGRAM OF AC DRIVE

Fig 4

INTERNAL CONNECTION OF AC DRIVE
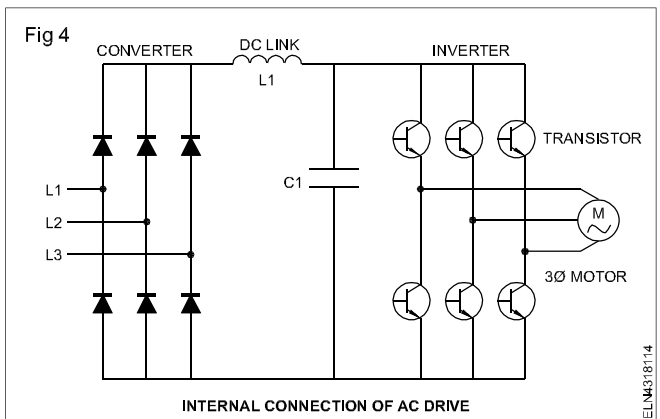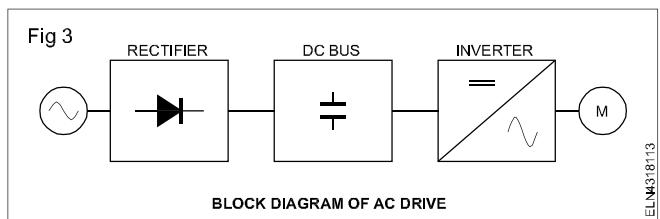
The rectifier in an AC drive is used to convert incoming AC power into direct current (DC) power. Rectifiers may utilize diodes, silicon controlled rectifiers (SCR), or transistors to rectify power . An AC drive using transistors in the rectifier section is said to have an "active front end.

After the power flows through the rectifiers it is stored on a DC bus. The DC bus contains capacitors to accept power from the rectifier, store it, and later deliver that power through the inverter section. The DC bus may also contain inductors, DC links, chokes, or similar items that add inductance, thereby smoothing the incoming power supply to the DC bus.

Inverter : An inverter is a device which converts DC into AC. The inverter contains transistors that deliver power to the motor. The "Insulated Gate Bipolar Transistor" (IGBT) is a common selection in modern AC drives. The IGBT can switch on and off several thousand times per second and precisely control the power delivered to the motor. The IGBT uses a method named "Pulse Width Modulation" (PWM) to simulate a current sine wave at the desired frequency to the motor.

The following example, explains how one phase of a three-phase output is developed and controlled. Switches replace the IGBTs for convenience. A voltage that alternates between positive and negative is developed by opening and closing switches in a specific sequence. For example, during steps one and two A+ and B- are closed. The output voltage between and A and B is positive. During step three A+ and B+ are closed. The difference of potential from A to B is zero. The output voltage is zero.

During step four and five A- and B+ are closed. The output voltage from A to B is negative. During step 6. A- and B-closed. The difference of potential A to B is again zero.

The same action from step 1 to 6 is repeated from step 7 onwards. This will continue. The Fig 5 shows the internal connection of inverter which converts DC into AC. The Fig 6 shows the output wave form of inverter. Only one single waveform due to switching action between A and B is shown. There are other two waveforms between B & C and A & C together which form a 3 phase AC supply. The magnitude and frequency of output voltage is dependent on the speed of the switching action of IGBTs.

Fig 5

INVERTER CONNECTION

Fig 6

OUTPUT WAVE FORM OF INVERTER
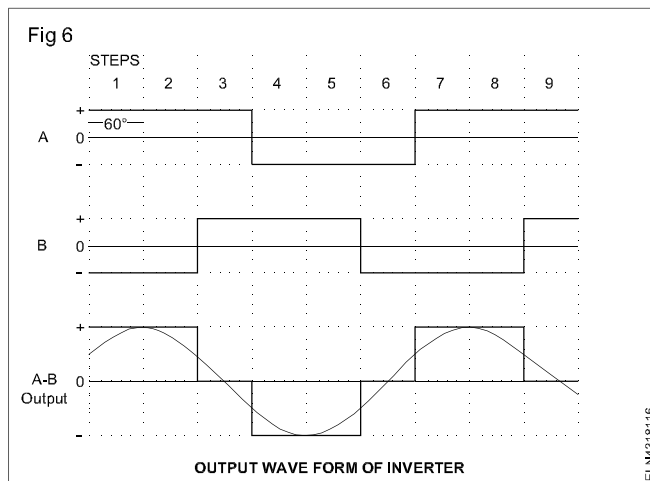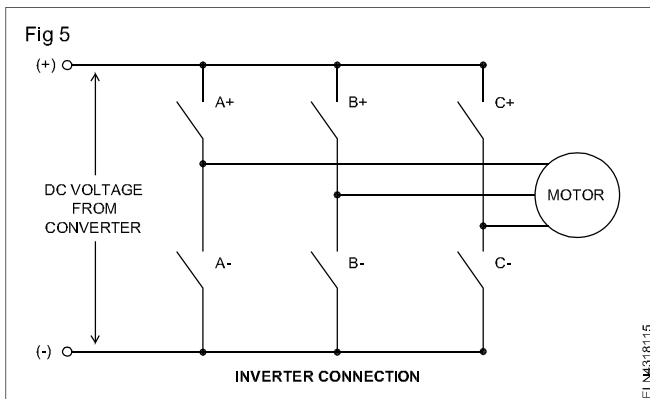
Advantages and disadvantages of AC drive

Advantages

• They use conventional low cost 3 phase AC induction motors for most applications

• AC motors require virtually no maintenance and are preferred for application where the motor is mounted in an area not easily reached for servicing or replacement.

• AC motors are smaller, lighter, more commonly available and less expensive than DC motors.

• AC motors are better suited for high speed operation (over 2500 rpm) since there are no brushes, and commutation is not a problem.

• Whenever the operating environment is wet, corrosive or explosive, special motor enclosures are required.

• Special AC motor enclosure types are more readily available at lower prices.

• Multiple motors in a system must operate simultaneously at a common frequency/speed.

Disadvantages

• A standard motor can not adequately cool its winding at slow speed or handle the irregular electrical waveform from the AC drive.

• An AC drive requires installation of motor with heavier windings.

• AC drive has complicated electronics circuit, so fault rectification is costly.

• AC drives produce a simulated waveform, not a perfect sine wave. That degrade the power equality.

Components of AC drive

A variable frequency drive is a device used in a drive system consisting of the following three main sub-systems. AC motor, main drive controller assembly, and drive / operator interface as in Fig 7.

Fig 7

COMPONENTS OF A.C DRIVE
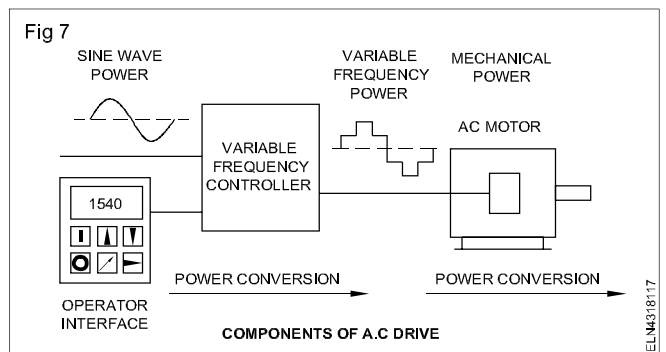
AC motor

The AC electric motor used in a VFD system is usually three - phase induction motor. Some types of single - phase motors can be used, but three - phase motors are usually preferred. Various types of synchronous motors offer advantages in some situations, but three - phase induction motors are suitable for most purposes and are generally the most economical motor choice. Motors that are designed for fixed - speed operation are often used. Elevated - voltage stresses imposed on induction motors that are supplied by VFDs require that such motors are designed for definite - purpose inverter-fed duty.

Controller

The VFD controller is a solid - state power electronics conversion, system consisting of three distinct sub-systems, a rectifier bridge converter, a direct current (DC) link, and an inverter. Voltage - source inverter (VSI) drives are the most common type of drives. Most drives are AC to AC drives in that they convert AC line input to AC inverter output. However, in some applications such as common DC bus or solar applications, drives are configured as DC-AC drives. The most basic rectifier converter for the VSI drive is configured as a three -phase, six -pulse, full-wave diode bridge.

In a VSI drive, the DC link consists of a capacitor which smooths out the converter's DC output ripple and provides a stiff input to the inverter. This filtered DC voltage is converted to quasi-sinusoidal AC voltage output using the inverter's active switching elements. VSI drives provide higher power factor and lower harmonic distortion than phase- controlled current - source inverter (CSI) and load - commutated inverter (LCI) drives.

In variable -torque applications suited for volts - per- Hertz (V/Hz) drive control. AC motor characteristics require that the voltage magnitude of the inverter's output to the motor be adjusted to match the required load torque in a linear V/Hz relationship. For example, 415V, 50Hz motors, this linear V/Hz relationship is 415/50=8.3V/Hz.

Although space vector pulse- width modulation (SVPWM) is becoming increasingly popular, sinusoidal PWM (SPWM) is the most straight forward method used to vary drives motor voltage (or current) and frequency. With SPWM control quasi- sinusoidal, variable - pulse-width output is constructed from intersections of a saw-toothed carrier signal with a modulating sinusoidal signal which is variable in operating frequency as well as in voltage (or current).

An embedded microprocessor governs the overall operation of the VFD controller. Basic programming of the microprocessor is provided as user - inaccessible firmware. User programming of display, variable, and function block parameters is provided to control, protect, and monitor the VFD, motor, and driven equipment.

Operator interface

The operator interface provides a means for an operator to start and stop the motor and adjust the operating speed. Additional operator control functions might include reversing, and switching between manual speed adjustment and automatic control from an external process control signal. The operator interface often includes an alphanumeric display and /or indication lights and meters to provide information about the operation of the drive.

An operator interface keypad and display unit is often provided on the front of the VFD controller shown in the Fig 7. The keypad display unit can often be cable - connected and mounted a short distance from the VFD controller. They are also provided with input and output (I/O) terminals for connecting push buttons, switches, and other operator interface devices or control signals. A serial communications port is also often available to allow the VFD to be configured, adjusted, monitored, and controlled using a computer.

Operation of AC drive

When the VFD is started the applied frequency and voltage are increased at a controlled rate or ramped up to accelerate the load. This starting method typically allows

a motor to develop 150% of its rated torque while the VFD is drawing less than 50% of its rated current from the mains in the low - speed range. A VFD can be adjusted to produce a steady 150% starting torque from standstill right up to full speed. However, motor cooling deteriorates and can result in overheating as speed decreases such that prolonged low -speed operation with significant torque is not usually possible without separately motorized fan ventilation.

With a VFD, the stopping sequence is just the opposite as the starting sequence. The frequency and voltage applied to the motor are ramped down at a controlled rate. When the frequency approaches zero, the motor is shut off. Additional braking torque can be obtained by adding a braking circuit (resistor controlled by a transistor) to dissipate the braking energy.

Part of AC drive (Fig 8a & 8b)

a) AC DRIVE

b) FRONT VIEW OF AC DRIVE
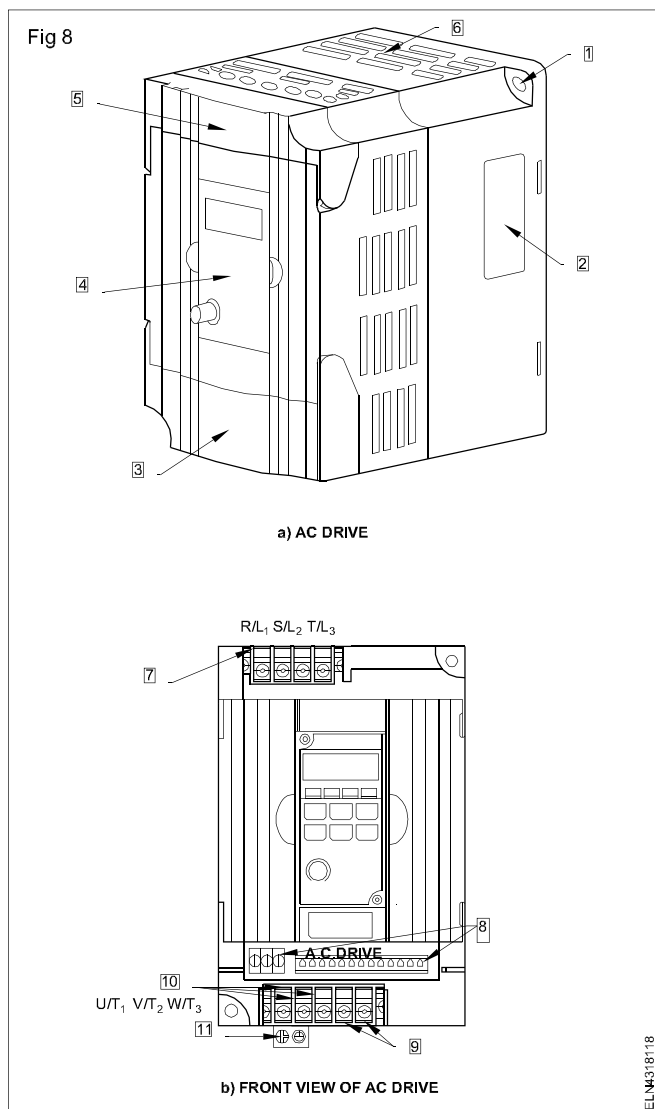
AC drives of various brand with different ratings are available in the market. It is generally assembled in a metallic enclosure. The front panel has the power input and output terminals, control terminals, keypad (operator interface) for controlling the drive etc. It has provision for connecting to PC for programming the drive.

The main parts are given below and shown in Fig 8a and 8b.

1 Mounting screw holes

2 Name plate label

3 Bottom cover

4 Digital keypad

5 Upper cover

6 Ventilation hole

7 Input terminals

8 Control Input/Output terminals

9 External brake resistor terminal

10 Output terminals

11 Grounding

Power and control terminals

In AC drive, the front panel has the input power terminals viz R/L_1, S/L_2 and T/L_3 where 3 phase AC 415V, 50Hz supply is connected. The 3 phase induction motor is connected of output power terminals viz. U/T1, V/T2 and W/T3.

There are control terminals viz M0, M1, M2, M3, GND, +10V, AV1 etc. for starting/stopping/ reversing and speed control actions. Names and locations are given in Fig 9

Fig 9

CONNECTION DIAGRAM OF AC DRIVE & MOTOR
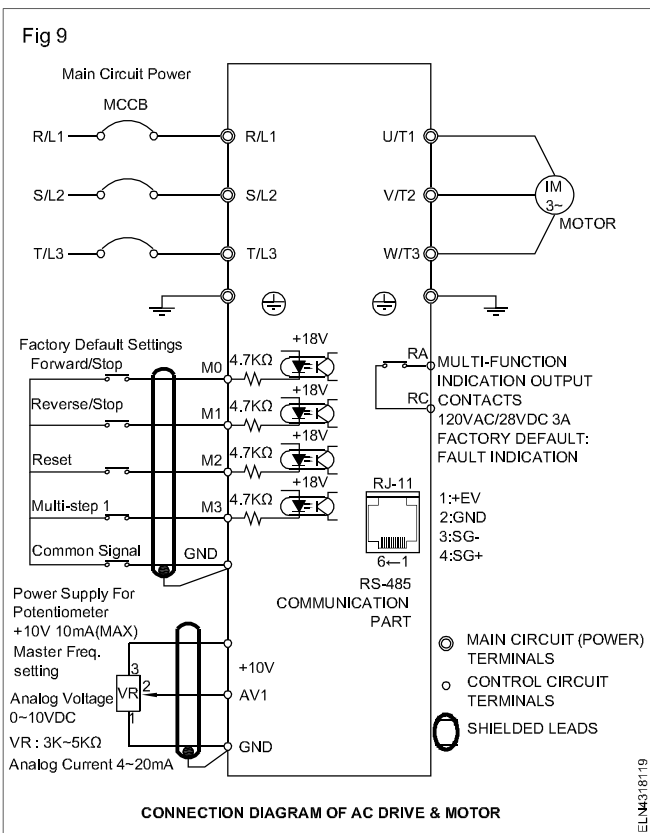
Parameter settings of DC drive

As discussed in previous chapter, the speed of DC motor is directly proportional to the armature voltage (E_b) and

inversly proportional to the field current(I_f) and also the armature current (Ia) is proportional motor torque.

In armature controlled DC drives, the drive unit provides a rated current and torque at any speed up to rated speed.

The Fig 10 shows **Basic Operator Panel (BOP)** keypad provided on the front panel meant for controlling the drive.

Fig 10

BASIC OPERATOR PANEL (BOP) KEY PAD
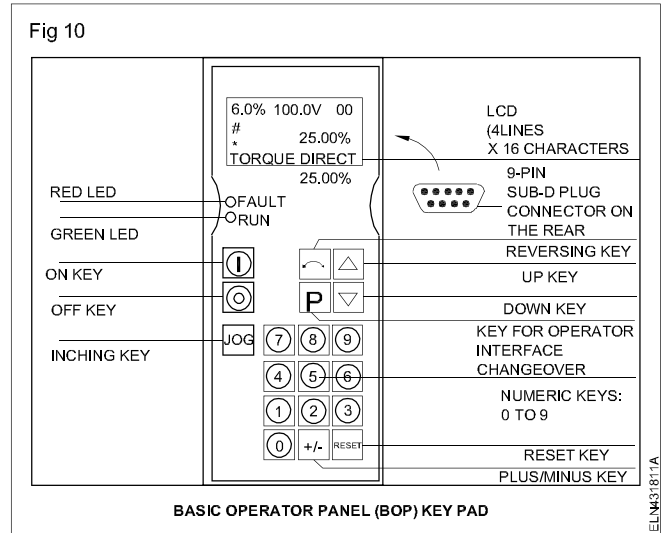
The LCD is used to monitor the parameter. To start the motor, 'ON' key is to be pressed, and to stop the motor 'OFF' key is to be pressed. There is 'JOG' key provided for inching operation.

There is a key 'P' given for operator interface, changing over the parameter setting can be done by using this key in association with (Δ) key and key (∇). Parameters like, voltage current, Torque etc will be displayed turn by turn on each pressing of 'P' key /button.

The (Δ) or (∇) keys are used to increase or decrease the values. Numeric keys are also can be used to enter the values directly.

LED indicators are provided to indicate the status of drive. Green LED indicates the system running where as Red LED indicates when fault is occurred.

Programming of DC drive is possible through, personal computer (PC) also. For this purpose a connector for connecting PC through interfacing cable is provided at the rear panel.

> **There may be variations in terms of names of key, display setting etc for different brands.**

Operation of motor through DC drive

Fig 11 shows the operation of controls arrangement which is called as basic operator panel (BOP) .

The input supply connections and armature and field connections are well illustrated in Fig 11. Input 3 phase AC, 415V, 50Hz supply can be connected L_1, L_2 and L_3. The armature is connected across A_1 and A_2 where as the

field is connected across B_0 and B_1 (The terminal names may vary depends on the type and make) an equipment ground conductor (Ground wire) must be connected to the controller mounting panel. Separate equipment grounding conductors from other major components Viz, motor, drive enclosure isolation transformer case (if used) in the system must also be connected continuously to a control connection point.

CONTROL ARRANGEMENT OF BOP
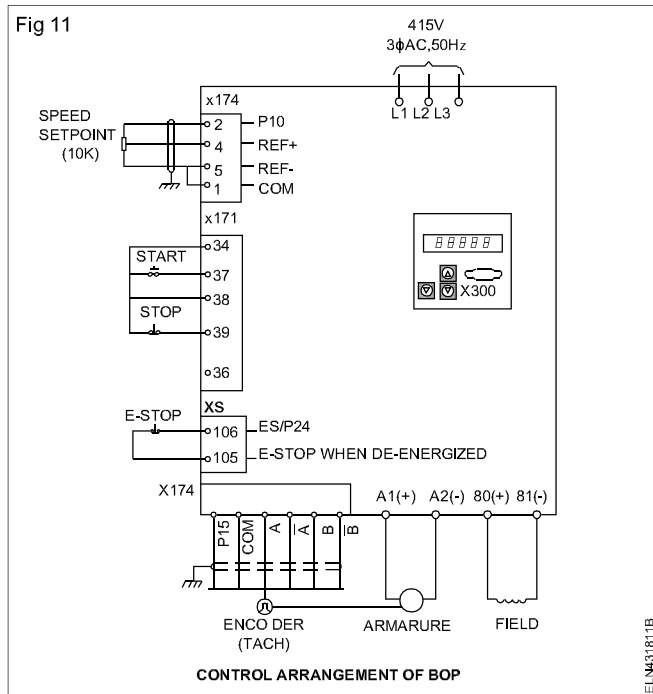
The AC input supply is provided should match the voltage and frequency given on the controller's name plate. Improper voltage may damage the equipment and insufficient current will cause erratic operation of the drive.

The shielded cable is recommended for the tachometer and all low level signal circuit to eliminate the possibility of electrical interference.

In some DC drives a speed adjusting potentiometer is provided to vary motor speed by controlling armature input voltage after the controller has been started. Some time a torque adjusting potential meter is used in place of speed adjusting potentiometer. It controls motor torque by controlling the DC current in the motor armature.

Starting and controlling the speed of DC motor

When the 'ON' button in BOP is pressed, the motor will start running. The desired speed can be attained by using 'P' button and Δ & ∇ buttons.

When the "OFF" button is pressed the motor will stop but AC line voltage remains connected to the controller and full field voltage is present. Armature voltage is reduced to zero. When pressing the "ON" button again the motor will accelerate to the preset speed.

Inching operation

For inching operation the 'JOG' position should be selected. Then the controller will operate only as long as the "ON" button is held pressed.

Changing the direction of rotation

In some model a 'reversing switch' is provided to change the direction of rotation of the motor. This switch is responsible for changing the polarity at the motor armature connection. First start the motor by pressing 'ON' button. The motor will run in forward direction. To change the direction of rotation, press "OFF" button and ensure that the motor is completely stopped. Now press the reversing button and then press the "ON" button. The motor will now run in the reverse direction. The reversing key has a provision which prevents direct transfer from one direction to the other.

Precautions during installation, connection and operation of DC drive

*   Ensure all screws are tightened to the proper torque rating.

*   During installation, follow all local electrical and safety codes.

*   Ensure that appropriate protective devices (circuit breaker MCB or fuses) are connected between the power supply and DC drive.

*   Make sure that the drive is properly earthed.

*   Do not attach or remove wiring when power is applied to the DC drive.

Parameter setting of AC drive

As explained earlier the speed (N) of AC induction motor is directly proportional to the voltage (V) and frequency (f) of the applied power supply. Within the base speed limit, the torque (T) can be kept constant by maintaining a constant voltage / frequency (V/F) ratio. By increasing of speed to above base speed limit is also possible but at the cost of the torque.

(VFD /VVVFD (Variable Voltage Variable Frequency Drive) drives are used for efficient speed control of AC motors. The advantages of using drives to control the speed is already explained.

The AC drive has a front panel which includes two parts. Display panel and keypad. The display panel is provided with the parameter display and shows operation status of the AC drive. Keypad provides programming interface between users and AC drives. The Fig 12. shows the location of buttons and display unit on the front panel of AC drive.

Fig 12

DISPLAY UNIT OF AC DRIVE
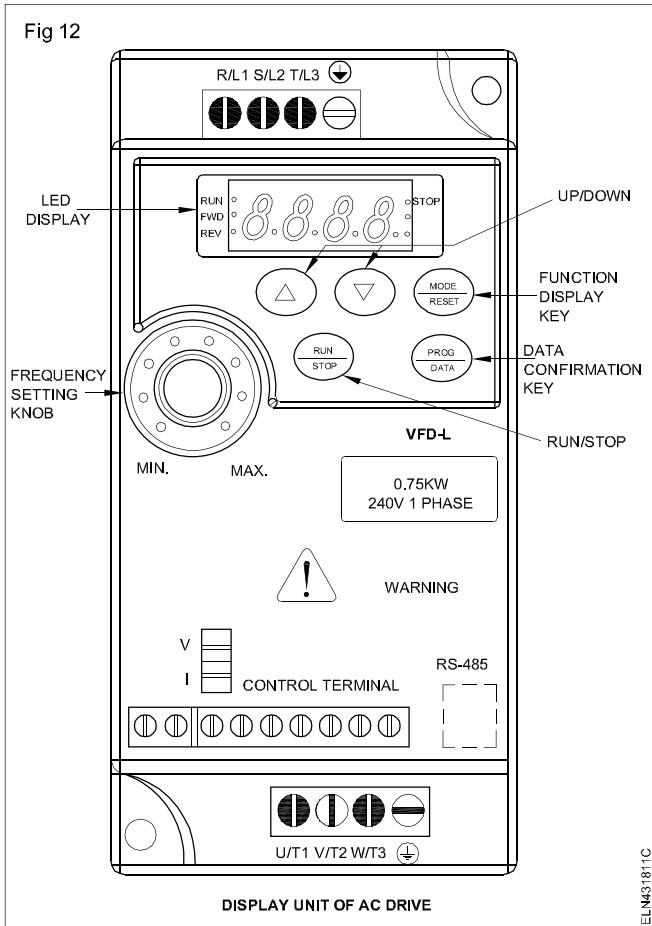
Mode /Reset button

By pressing this button repeatedly the display will show status at the AC drive such as the reference frequency and output current. If the drive stops due to a fault, correct the fault first, then press this button to reset the drive.

Prog/Data button

By pressing this button will store the entered data or can show factory stored data.

Run/Stop button

To 'start' or 'stop' the AC drive operation this button is to be pressed.

This button can only be used to 'stop' the AC drive, when it is controlled by the external control terminals.

UPΔ / down ∇ button

By pressing the 'Up' or 'Down' button momentarily parameter setting can be changed. These key may also be used to scroll through different operating values or parameters. Pressing the 'Up' or 'Down' button momentarily it will change the parameter setting in single unit increments. To quickly run through the range of settings, press 'Down' and hold the button.

Frequency setting knob

By using this knob, the frequency variation can be done.

'RS 485' communication port

Programming of AC drive can be done through personal computer (PC) also. For this, the drive should be interfaced with PC through 'RS 485' port.

LED displays are also given in the display unit to indicate the status of drive like 'RUN', 'FWD' and 'REV'.

Operation of AC motor through drive

The motor and drive connections are well illustrated in Fig 13. A 3$\emptyset$, 415V, 50Hz AC supply is connected to the drive input terminals R/L$_1$, S/L$_2$ & T/L$_3$. Similarly output terminals of this drive is such as U/T$_1$, V/T$_2$ & W/T$_3$ are connected to 3 phase induction motor. (The terminal names may vary depends on the type and make)

CONNECTION DIAGRAM OF AC DRIVE AND MOTOR
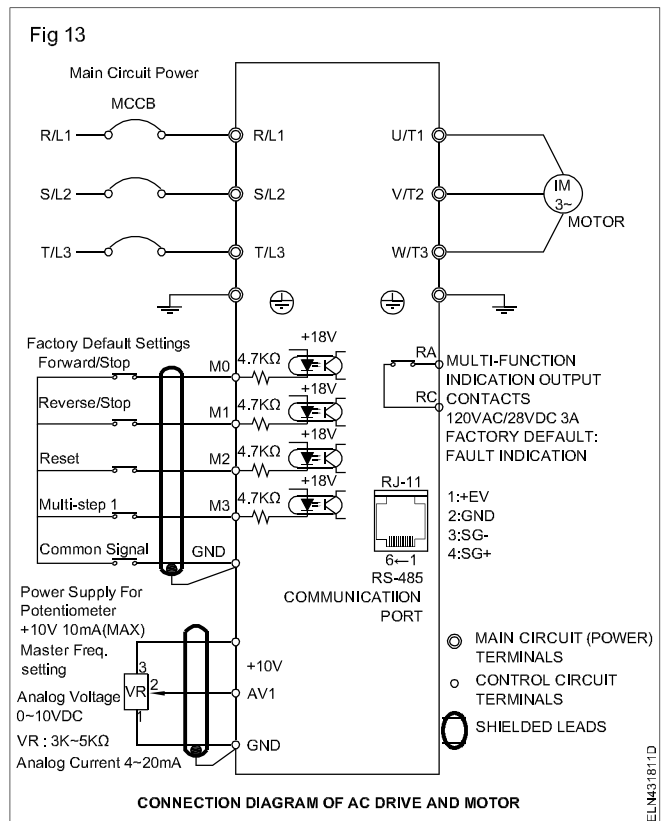
Both input end and output ends are earthed separately.

Changing of speed

The AC input supply provided, should match the voltage and frequency given on the nameplate. Improper voltage may damage the drive.

Programming can be done through 'MOD/RESET' button in association with Δ and ∇ button and the drives speed can be changed by using these buttons. The drive is started through 'RUN'/STOP' button.

The motor can be run at different speed by programming for the required speed.

Changing the direction of rotation

The direction of rotation can be changed. To do this, press 'RUN/STOP' button. When the motor is completely stopped, select 'rev' parameter and press 'RUN/STOP' button again. Now the motor will run in opposite direction.

Same procedure can be followed to change the direction of rotation of double cage induction motor also.

Precautions to be observed during installation, connection and operation of AC drive

- Do not connect the AC power to the U/T1, V/T2, W/T3 terminals, as it will damage the AC drive.

- Ensure all screws are tightened to the proper torque rating.

- During installation, follow all local electrical and safety codes.

- Ensure that the appropriate protective devices (circuit breaker or fuses) are connected between the power supply and AC drive.

- Make sure that the leads are connected correctly and the AC drive is properly grounded. (Ground resistance should not exceed 0.1Ω)

- Use ground leads that comply with standards and keep them as short as possible.

- Multiple VFD-L units can be installed in one location. All the units should be grounded directly to a common ground terminal.

- Make sure that the power source is capable of supplying the correct voltage and required current to the DC drive.

- Do not attach or remove wiring when power is applied to the AC drive.

- Do not monitor the signals on the circuit board while the AC drive is in operation.

- If filter is required for reducing EMI (Electro Magnetic interference), install it as close as possible to AC drive.

Speed control of universal motors using SCR : Majority of domestic appliances like electric drilling machine, mixer etc., incorporate universal electric motors. Any of the half wave or full wave controls discussed earlier can be used to control speed of universal motors. Universal motors have some unique characteristics which allow their speed to be controlled very easily and efficiently with a feedback circuit is in Fig 14.

The circuit at Fig 14a provides phase controlled half wave power to the motor; that is, one the negative half cycle, the SCR blocks current flow in the negative half cycle, the SCR blocks current flow in the negative direction causing the motor to be driven by a pulsating direct current

whose amplitude is dependent in the phase control of the SCR. The operation of the circuit shown in Fig 14 is as follows.

Fig 14
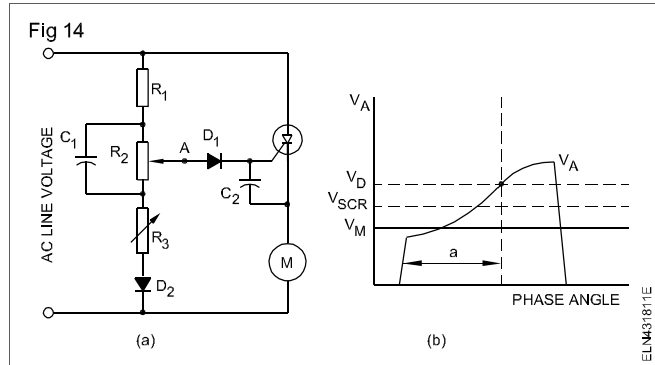
- Assuming that the motor is running, the voltage at point A in the circuit must be larger than the forward drop of diode D_1, the gate to cathode drop of the SCR, and the emf generated by the residual mmf in the motor, to get sufficient forward flow to trigger the SCR.

- The wave form at point A (V_A) for one positive half cycle is in Fig 14b and with V_{SCR}, V_D and motor generated emf V_M. The phase angle at which the SCR would trigger is shown by the vertical dotted line.

- For any reason if the motor speed increases, then V_M will increase, the trigger would move upwards and to the right along the curve so that the SCR would trigger later in the half - cycle thus providing less power to the motor, causing it to slow down. Similarly, if the motor speed decreases, the trigger point will move to the left and down the curve, causing the SCR to trigger earlier in the half cycle providing more power to the motor thereby speeding it up.

- Resistors R_1, R_2, R_3 along with diode D_1 and C_1 forms a ramp generator. Capacitor C_1 is charged by the voltage divider R_1, R_2 and R_3 during the positive half cycle. Diode D_2 prevents negative current flow during the negative half cycle, therefore C_1 discharges through R_2 and R_3 during negative half cycle. Varying the value of R_2 varies the trigger angle α.

A practical version of the circuit for controlling the speed of universal motors is in Fig 15.

CIRCUIT DIAGRAM OF UNIVERSAL MOTOR SPEED CONTROLLER
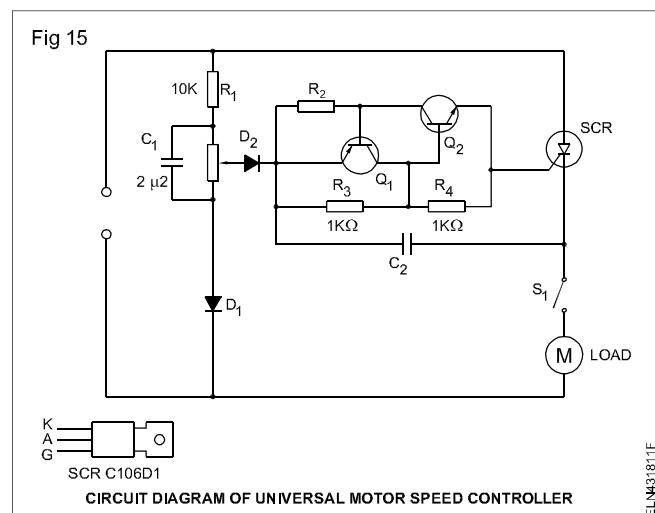
As can be seen, the circuit at Fig 15 is quite similar to that at Fig 14 but for the addition of two transistors and a few resistors.

In Fig 6, the action of Q_1 - Q_2 is to provide adequate gate current to trigger the SCR into conduction.

Q_1 - Q_2 and their associated resistors acts as a voltage sensitive switch. In each half cycle, C_2 is able to charge via R_1. As soon as voltage across C_2 rises to suitable value. Q_1 and Q_2 both switch- on and partially discharge C_2 into the gate of the SCR, thus delivering a pulse of

high current to the SCR gate, independent of any current drive limitations of RV1. The Q_1 - Q_2 and C_2 network thus enables virtually any SCR to be used in the circuit almost irrespective of its sensitivity characteristics.

The universal motor speed control circuit is in Fig 15 enables the motor speed to be smoothly varied from zero to 75% of maximum via a single control. It also incorporates built - in feedback compensation to maintain the motor speed virtually constant at any given speed setting, regard-less of load changes.

Voltage stabilizer and UPS

Objectives: At the end of this lesson you shall be able to
• **state the basic concept of stabilizer**
• **draw the block diagram and explain the function of each blocks**
• **state the working various types of voltage stabilizers**
• **state the basics of UPS system**
• **explain the block diagram of OFF line UPS and its various controls and functions**
• **explain the block diagram ON line UPS and advantages and disadvantages.**

Voltage stabilizer

It is an electrical supply device controlled by electronic circuit which gives the constant output voltage irrespective of the variation in the high input supply voltage or disconnect the output circuit if the input voltage is very low or very high.

Every electrical device is designed to operate at a certain rated voltage for optimum efficiency and maximum length of service. Power supply voltages should not drop or rise by more than 5% of rated voltage as per IS.

The effect of voltage variations in commonly used electrical appliances are given below.

Sl.No.	Name of the equipment	Low voltage	High voltage
1	Incandescent lamp	Lamp efficiency decreases if the voltage is decreased.	Life of the lamp decreases or the lamp fuses in extreme cases.
2	Fluorescent lamp	If voltage is too low, lamp will not light up.	Life of the tube/choke decreases.
3	Electric stove, electric iron, water heaters, toasters etc.	Increases the heating time as heat produced is low.	Shortens the life of heating elements or heating elements burnt out.
4	Fans, vacuum cleaners	Efficiency decreases.	Life of the equipment is decreased
5	Washing machines, refrigerators and air-conditioners	Motor of the machine will draw more current from the line that results in overheating of the motor which may lead to burn out.	The motor insulation may fail and draw excess current which can lead to burn out.
6	Radios and television sets	Poor quality of reception, picture will not be clear in the television sets.	Life of the equipment is decreased

Some of the electronic equipment such as colour television sets are designed by the manufacturers with built in electronic stabilizers like Switch Mode Power Supplies (SMPS). Hence there is no need to provide an additional external stabilizers for these equipments.

Types of AC voltage stabilizers

1 Stepped voltage stabilizer

   a) Manual

   b) Automatic relay type

2 Servo voltage stabilizer

3 Constant voltage transformer

Stepped voltage stabilizer

In the stepped voltage stabilizer, an auto-transformer is used for regulating the output voltage. A manually operated

switch as in Fig 1 regulates the output voltage in the manual type. In automatic relay type stabilizers a sensing circuit actuates the relays which regulates the output voltage. The schematic diagram is in Fig 2 is for an automatic relay type stabilizer.

MANUAL STABILIZER

Fig 2

BLOCK DIAGRAM OF VOLTAGE STABILIZER
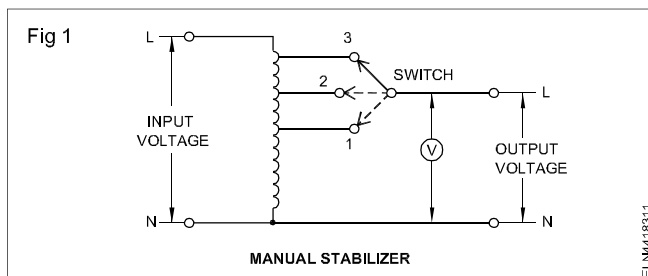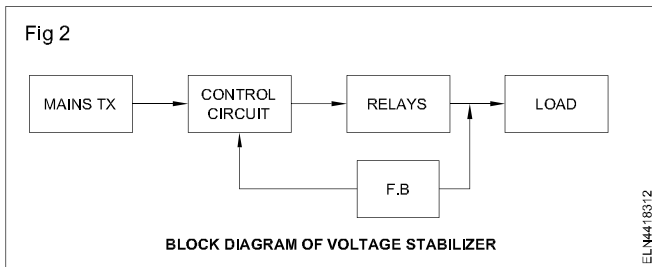
Mains Tx

This transformer supplies two level voltage i.e, low voltage and high voltage, which is to be supplied according to the needs. Some stabiliser working in buck boost operation to meet special application for load requirements. The auxiliary supply also provides for control circuit requirements by the mains transformer.

Control circuit

In the ordinary voltage stabilisers, control circuit regulate the relay operation, irrespect or output voltage. When input voltage falls below the set voltage H.T side relay will operate and incase high voltage condition LT side relay will operate and maintain the stipulated operate voltages. The relay operation controls by controlling relay coil supply which is set for separate DC regulated voltage levels.

Relays

It is a electromagnetic relay which operates two different coil voltage. the DC coil voltage decides which relay has to be operate depends on the input AC voltage supplied to the transformer. Fig 3 shows an automatic relay type stabilizer.

Fig 3

AUTOMATIC STABILIZER RELAY TYPE
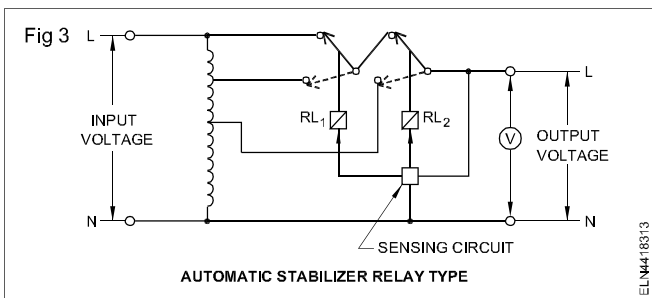
Feed back

In non automatic voltage stabiliser DC voltage are taken on the feed back quantity, which operates the relay coil. The coil DC voltage will be two different voltage to activate the relay in case of low and high voltage AC input conditions.

Load

Load can be anything connected to the stabiliser. Some electrical equipments requires a constant input voltage to operate. such case a stabiliser is required. But in automatic stabiliser have the disadvantage of transient line (Change over to one voltage to other voltage level) which may cause the stabiliser to OFF condition few milli seconds.

Stepped voltage stabilizer - manual type : Fig 4 shows an auto-transformer in which the output voltage increases as the tap changing switch S_1 is turned clockwise. The output voltage can be seen by connecting a voltmeter in the output side as in Fig 4. Increasing or decreasing the output voltage near to the set value is possible by rotating the tap changing switch S_2 in the appropriate direction within ±10% of the desired output voltage. A push-button switch S_1 enables to measure the incoming voltage.

Fig 4

STEPPED VOLTAGE STABILIZER-MANUAL
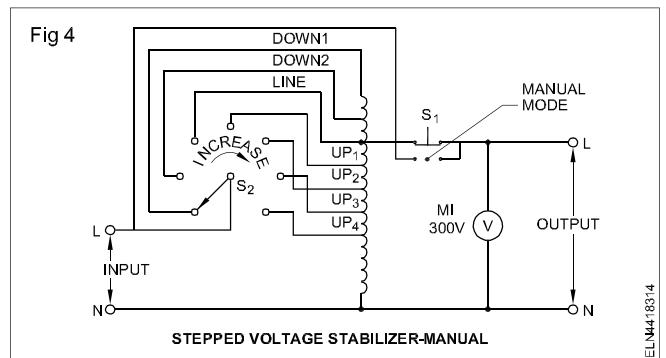
Stepped voltage stabilizer - automatic type : Fig 5 shows a stepped voltage stabilizer of the automatic type operated by relays. T_1 is an auto-transformer with multiple tappings. S_1 and S_2 are two secondaries for relay operation. The secondary voltage of S_1 is rectified and filtered for the use of the sensing circuit while voltage S_2 is rectified and filtered for the use of the relay operation. P_1 and P_2 are pre-set resistors (variable resistors) used for adjustment. R_1, P_1 and R_2 provide sensing voltage to the zener diode. DZ_1 and R_3P_2 and R_4 to the zener diode DZ_2. Q_1 and Q_2 are two transistors used as switches. RL_1 and RL_2 are two relays.

Fig 5

STEPPED VOLTAGE STABILIZER-AUTOMATIC
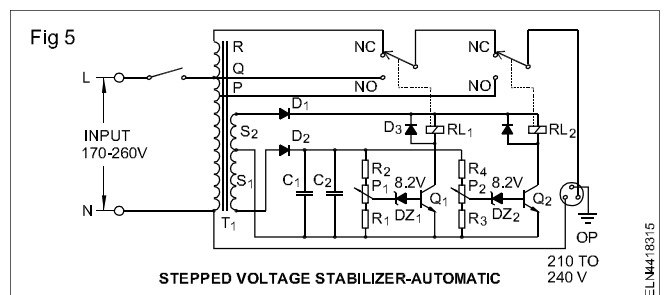
When the input voltage is low, say less than 200V, both DZ_1 and DZ_2 do not conduct as the voltages at the preset tappings are less than their zener diode voltages. This causes both transistors to cut off and the relays are in the off position. At the off position of the relays, NO contacts of both the relays connect terminal R of the auto-transformer to output which results in booster output voltage.

When the input voltage increases above 210V, but below 240V voltage across S_1 increases proportionally. This increases the pre-set tap voltage, thereby the zener diode DZ_1 conducts and hence make the transistor Q_1 to ON. The relay RL_1 operates and connects the supply voltage directly to the output through NO. contact of RL_1 and NC contact of RL_2. By this operation the output voltage will be the same as the input voltage.

When the input supply voltage increases above 240V the zener diode DZ_2 gets voltage from P_2 and hence conducts which makes Q_2 to ON. This results relay RL_2 energise and output is taken from NO. point of RL_2. The output voltage reduces or bucks.

Usually 12V DC relays with the required current ratings of contacts are preferred for stabilizers. Diodes or capacitors are used across the relay coil to protect the transistors from reversed induced emf when the relays become OFF. LED indicators are sometimes used to indicate the mode of operation such as buck, normal, boost etc.

Stepped voltage stabilizers are available with different types of electronic circuits with one to three relays to provide an output voltage of 200-240V. They are specified for maximum input voltage variation and for their output, KVA ratings say 170 to 270 volts 1 KVA or 135 to 260 volts 0.5 KVA.

Some of the stabilizers are provided with over-voltage and under-voltage cut off to protect the connected equipment.

Applications : Stepped voltage stabilizers are used along with refrigerators, air conditioners, TVs, VCRs etc. Colour TVs with self-contained switch mode power supplies do not require voltage stabilizer as they are designed to operate from 130 to 260 volts.

Servo - voltage stabilizer

The servo voltage stabilizer employs a toroidal auto-transformer and a servo motor driven by a sensing circuit which senses the voltage. The difference between the output and nominal voltage is sensed by a sensing circuit which drives the servo motor. Any variations in mains cause the motor to move clockwise or anticlockwise thus correcting the voltage.

A servo voltage stabilizer is provided with three transformers function along with control circuits and a servo motor as in Fig 6. T_1 is a continuously variable toroidal auto-transformer (variac) driven by a servo motor M.

SERVO VOLTAGE STABILIZER
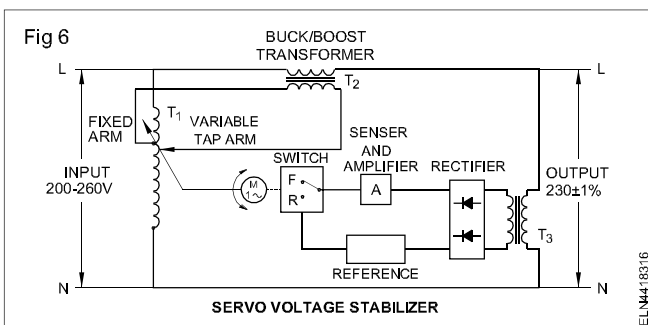
The output from the variac, drives a series buck/boost transformer T_2 so that boost takes place when the variable tap arm moves down and bucks the voltage when the arm moves up. The transformer T_3 provides the required reference voltage and sensing voltage for the electronic circuit which drives the motor.

When the output voltage is less than the reference voltage, the electronic circuit senses the difference, drives the motor in one direction which results in increase in the output voltage.

When the output voltage increases above the ratings, the motor is driven in the opposite direction so that the output voltage increases. When the voltage difference in output and the reference are equal, the servo motor is switched off by the circuit.

A servo stabilizer provides constant voltage to an accuracy around ±1% or ±0.5% and a correction range 10 to 30 volt/sec.

A servo stabilizer is more accurate and also costlier, and, therefore, used with costlier equipments such as computers, xerox machines, medical electrical equipments etc.

Constant voltage transformer

A constant voltage transformer works on ferro-resonant principle. The variation in the primary flux with an unsaturated iron core does not affect the secondary flux with saturated iron core. Thus, the secondary induced voltage remains relatively independent of the voltage impressed upon the primary winding.

In an ordinary transformer, the primary and secondary coils are closely coupled. Any change in primary voltage is directly transferred to the secondary in the ratio of the number of turns. In a CVT, the primary and secondary coils are loosely coupled. These are wound on separate sections of the transformer core as in Fig 7. In between the coils, a separate shunt path is provided for the flux to flow but an air gap is provided in the shunt path. A capacitor is provided in parallel with the secondary.

WINDINGS ARRANGEMENT IN CVT
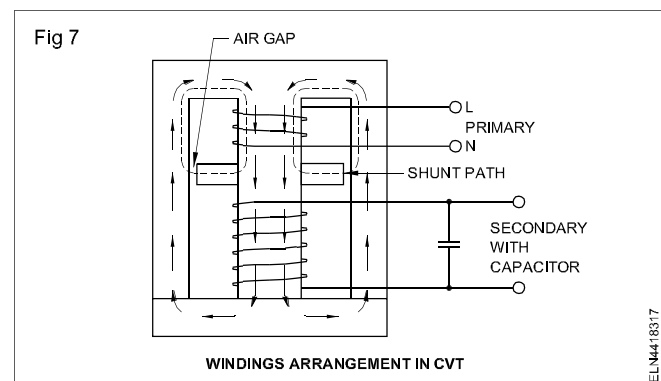
Now imagine what will happen when voltage is applied to the primary. Starting from zero, if the voltage increases slowly, initially, all the flux generated by the primary voltage will pass through the lower half of the transformer core because the air gap in the shunt path will prevent it from taking this path. This is shown by bold arrows in Fig 6. As a result, the rise in secondary voltage is proportional to the primary. But as voltage in the secondary coil rises, at a certain point the impedance of the coil will become equal to the impedance of the capacitor, i.e.

$$X_L = X_C \text{ or } 2\pi fL = \frac{1}{2\pi fC}$$

This is the condition of resonance, and at this point a high current will flow in the LC circuit. This high current will result in a sudden rise of voltage across the secondary (Fig 6), and the core in this section of the transformer will saturate.

Once the core gets saturated, it prevents the entry of further flux coming from the primary side. Therefore, any increase in flux due to increase in primary voltage has to take an alternate shunt path as in Fig 7. Hence, very little increase in the secondary voltage takes place. This little increase can also be nullified by a feedback-FB winding connected as in Fig 8. The output winding can be separated from the capacitor circuit if the voltage required is low or tappings can be taken out of the capacitor.

Fig 8

CVT WITH FEED BACK WINDING
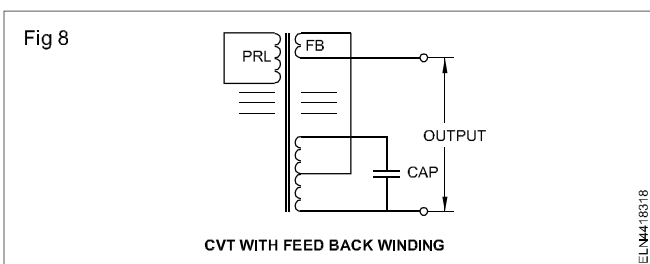
CVT may not be suitable for an instrument in which SCR power supply is used or an inductor or a capacitor is coming in the AC circuit or a motor drawing a heavy in-rush current is used inside the instrument. But it is suitable for electronic machines such as TVs, computers, FAX machines etc.

Testing a stabilizer : To test a stabilizer for its operating range, a variac and rated load along with voltmeters/ ammeters are necessary. A simplified circuit for testing the stabilizer is given in Fig 9.

Fig 9

TYPICAL CIRCUIT FOR TESTING THE STABILIZER
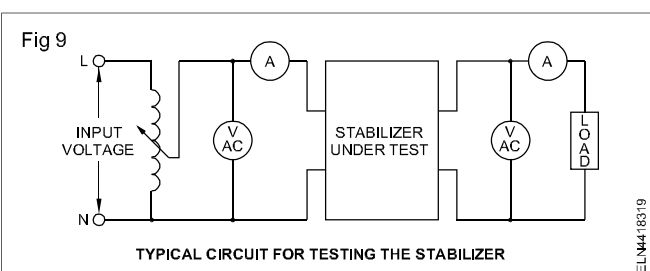
By connecting the stabilizer as shown in the figure above and varying the input voltage to the range specified in the name-plate detail such as 170 to 260V or 130 to 270V etc. The output voltage should be satisfied with the specified voltage such as 200 to 240V. There should not be any undue heating or failures with the rated load for a continuous working.

Basics of UPS systems

Most people take the mains AC supply for granted and use it almost casually without giving the slightest thought to its inherent defects and the danger posed to sophisticated and sensitive electronic instruments. For ordinary household appliances such as incandescent lamps, tubes, fans, TV and fridge, the mains AC supply does not make much of a difference, but when used for computers, medical equipments and telecommunication systems, a clean, stable, interruption-free power supply is of utmost importance.

As more and more personal computers, word processors and data terminals find their way into small business, UPS systems that meet the power requirements and price range needs for small business and offices are being manufactured.

The ever increasing importance of computers in industry and commerce will increase the need for quality, high stability and interruption-free power supplies.

Earlier Data Operating System (DOS) does not have any shut-down procedure. So in case power failure it does not affect the operating system. Latest operating system Windows 9x and application softwares require proper shuting down and exit procedures. This procedures requires time which is provided by UPS in case of mains power failure.

UPS (Uninterrupted Power Supply) is the only solution available to an individual customer faced with the problem of ensuring high quality of power for critical loads. All UPS designs contain a battery charger to keep the battery fully charged by the power from mains. Small UPS normally comes with a sealed maintenance free (SMF) batteries which can provide 10 to 15 minutes of power backup, the backup time increases with the capacity of the battery. Tubular batteries or automotive batteries are used in medium and large capacity UPSs.

UPS classification

There are two broad categories of UPS topologies - OFF line, and ON line . These topologies differ in the way they serve the load when the mains is present and is healthy. They vary in features & pricing.

OFF-Line and ON-Line

OFF-Line UPS filters the mains and feeds it directly to the load for most of the time. When the mains is unhealthy, perhaps due to a slight drop in voltage, the load is switched by a fast relay, in typically less than half a cycle, to an inverter deriving its power from a battery. The inverter generates a square or stepped waveform to emulate the mains-satisfactorily for most computers. This particular technique represents the lowest cost solution.

Online UPS converts AC mains into DC before inverting again to AC to power the load with a synthetic sine wave. A battery connected across the DC link acts as the backup power source.

This gives a supply for the computer that totally isolates the input mains from the load, removing all mains noise and with no break when the mains fails.

Standby/OFF Line block diagram (Fig 10)

In the off line UPS, the load is connected directly to the mains when the mains supply is available. When working over voltage/under voltage conditions are detected on the mains, the off line UPS transfers the load to the inverter. When the line is present, the battery charger charges the battery and the inverter may either be shut down or will be idling. Thus in an off line UPS, there is a load transfer involved every time, the mains is interrupted and restored. This transfer is effected by change- over relays or static transfer switches. In any case there will be a brief period during which the load is not provided with voltage. If the load is a computer and the transfer time is more than 5ms, then there is a chance that the computer will reboot.

Some modified designs incorporate a limited range of voltage regulation by transformer tapping and a certain degree of transient protection by using RF filters and MOV's (Metal Oxide Varistor). Off line UPS is an economical and simple design and hence it is preferred for small rating, low cost units aimed at individual PC user's market. When the load is really a critical one an off line UPS is not acceptable. Usually square wave output off line UPS are available in market with lower loading capacities.

Advantages of OFF line UPS: High efficiency, small size, low cost.

Disadvantages: There can be change over complaint in offline UPS. Off line very much depends on battery. If battery fails entire system fails. Sometimes during change-over computer re-boots which causes loss of files. Another disadvantage is that output voltage will be a varying one. Usually in the range of 200V-240V and hence not suitable to all electronic gadgets.

Fig 10
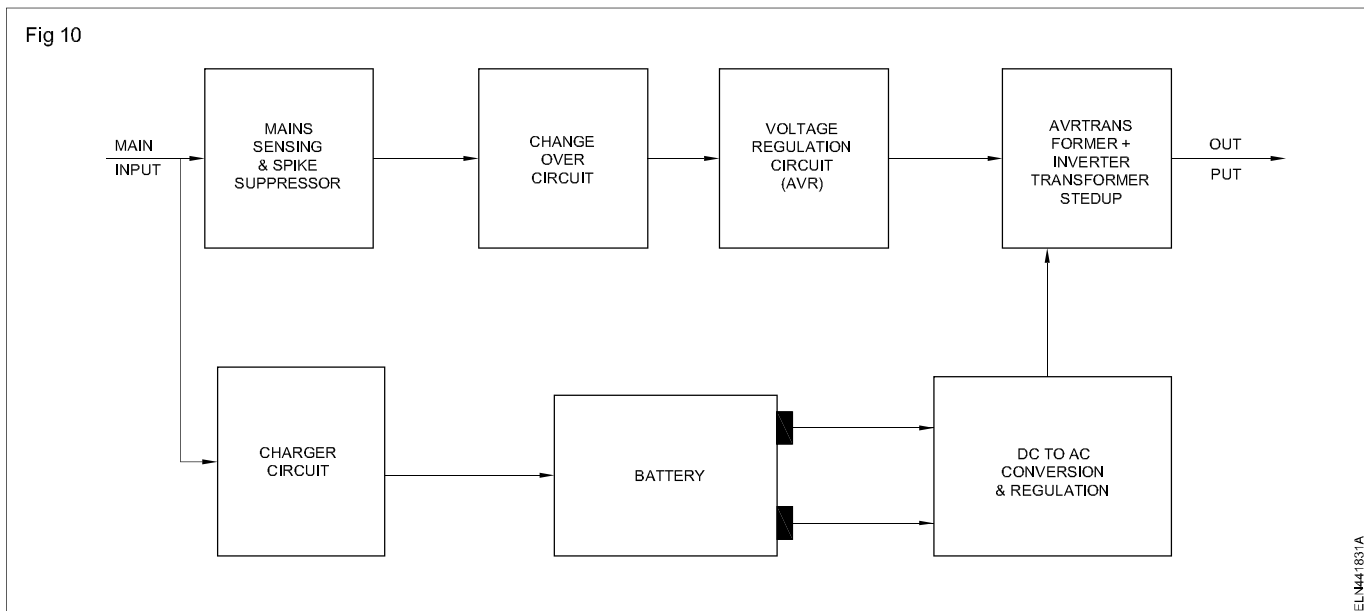
Front panel indications and rear panel sockets/switches used in UPS

All UPS systems have

- Fuse/Fuse holder
- Switches
- Sockets
- Panel indicator (LED and Neon lamp)
- Meters (Volt/Ampere)

Fig 11 and 12 shows the front and rear panel controls/sockets.

Switches: On/Off switch and reset switch are commonly used in UPS. Reset switch is used to cut off an overload circuit and restart the supply. This is a push to off switch. In normal position this switch keeps the circuit on and when pushed, it cuts off the circuit.

Fig 11

UPS FRONT PANEL

Fig 12

COMPUTER INTERFACE
(MODEL 425AP/525AP/625AP)

TELEPHONE/MODEM
SURGE PROTECTION

POWER OUTPUT
RECEPTACLE

FUSE

A/C INPUT POWER
RECEPTACLE

UPS REAR PANEL
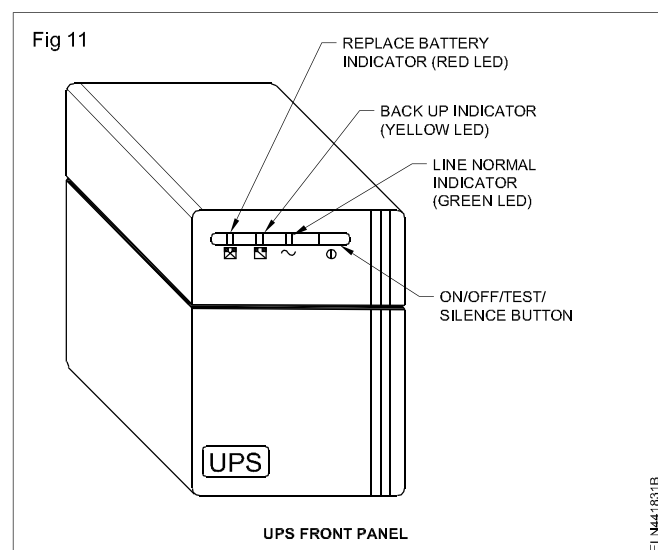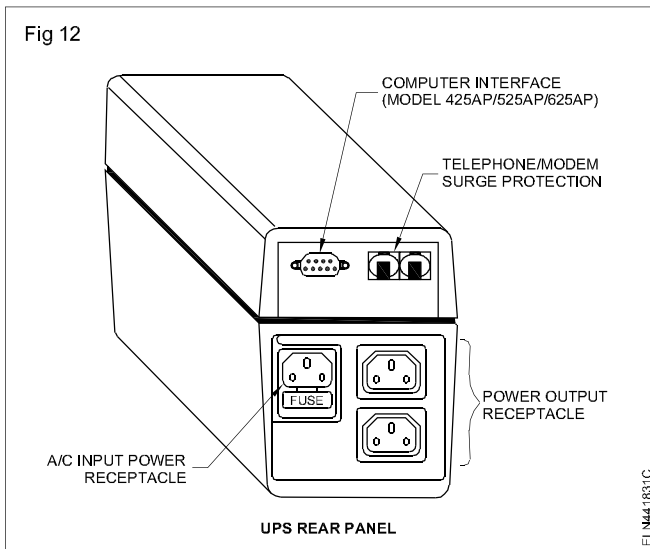
Socket: A common 5 Amp. or 15 Amps. three pin power output socket is used in UPS to provide UPS output to the various devices. One can connect an ordinary 5/15Amp. plug to the UPS output.

Different LED indications/buzzers that are used in UPS

Mains ON indication: It indicates mains input is present and UPS is working on mains.

Mains Low indication: It indicates that mains input is low and is below a rated value.

Mains high indication: It indicates mains input is high.

Inverter ON indication: It indicates that UPS is working in the battery mode and mains is absent.

To get the output from UPS switch ON the 'Inverter ON' switch.

UPS Trip indication: It indicates that UPS output is Off or tripped.

Overload indication: Which indicates that the load current is above a pre-determined value.

Overload buzzer: It beeps whenever overload occurs.

Low battery warning: It indicates battery voltage is below a pre-determined value along with a buzzer .

Battery charging indication: It indicates that battery is charging properly.

Output voltage low indication: It indicates that output voltage is below a pre-determined value.

General specifications & UPS protections

UPS are available from 500VA to 20KVA or above.VA is voltampere.

Power factor specification will be different for different manufactures. Suppose for 1 KVA UPS with a power factor 0.6 the load will be 1000 x0.6 = 600 watts.

Normally a single PC takes around 180 watts. There are sine wave, square wave and quasi square wave output UPS. Usually sine wave out UPS is better than square wave output UPS.

General specifications

Output capacity = Output capacity will be in volt amperes (VA)

Input voltage = 230V AC ±20%, 50 Hz single phase sine wave

Output voltage = 230V AC ±10%, 50 Hz square wave or sine wave

= 230V AC ±2%, 50 Hz (for ON-Line)

Battery = 7 AH, 12V Sealed Maintenance Free (SMF) for OFF-Line (depends on the capacity of the UPS)

= Tubular batteries from 40 AH to 160 AH (12V to 120V) for ON-Line (depends on the capacity of the UPS).

Availability of Automatic Voltage Regulation (AVR) feature.

Typical recharge time to charge 90% of the full capacity of the battery is 5 hours.

Different types of protection in UPS

Input fuse on mains: It protects the system from high voltage inputs, line disturbances and short circuiting etc.

MOV (Metal Oxide varistor) protection: MOV conducts when high input voltage appears thereby blowing the fuse

Polyester capacitor for lightening protection: This is connected across the transformer winding. It burns when lightening occurs and protects the transformer.

Fuses to protect the MOSFETS: MOSFETS are highly sensitive to rapid changing currents. These fuses are used to protect the MOSFET.

Charger fuse to protect the charger circuit: If any fault in charger circuit occurs, fuse blows to protect SCRs.

Output high voltage protection MOV: This MOV is connected across output sockets phase and neutral. If feedback circuit fails the output voltage will jump to more than 300 volts. In such situation the MOV conducts to protect the load.

Overload protection: It protects the UPS especially MOSFET/IGBT when output current exceeds a preset value (overloading the UPS). When this occurs, UPS output becomes OFF along with an indication.

Battery over charge/discharge protection: It protects the battery from charging to a high value (SMF batteries will charge upto 15.8V) and tubular batteries upto 14.1V. It also protects the battery from getting discharged below a level (low battery protection). If the battery voltage is discharged below 10.5V, then the UPS gets automatically switched OFF.

General tips for testing a UPS

- Connect the battery to the terminals using a fuse wire. If any fault occurs in testing the fuse will blow to protect the UPS.

- Do the testings on no load condition.

- Check the gate voltages of the two MOSFET banks it should be the same. If PWM gate pulses are not present gate voltage will be around 5.6V. If the PWM gate pulses are present then the gate voltage will be around 2-2.5 volts.

- Some frequency meters are designed to measure pure AC frequency only. If the UPS output is square wave, then the reading will not be correct. To mea- sure the correct frequency connect a 60/100W load at the output of the UPS. Then the frequency meter shows a near correct frequency.

- For overload setting in ON-Line UPS, the load current is calculated by dividing the maximum load with the output voltage. This can also be measured using a clamp meter on the output terminal. Overload is set at this value of load current.

- While using extension boxes either in the input or on the output of an UPS, ensure proper earth connection. Improper earthing may lead to poor line filtering and shock hazards.

- If number of MOSFETs are connected in parallel,care should be taken to see that all the MOSFETs are of the same Rds. For MOSFET Rds value (drain to source resistance) and current rating are important.

Changeover in OFF-Line UPS system

In this type of UPS, the relay controls the battery voltage which is applied for relay coils. If the battery voltage is too low then relay coil will not get sufficient supply to trigger the switch.This may lead to the absence of mains voltage, even if mains is present and is healthy. This type of OFF-Line systems are battery dependent.

Some OFF-Line systems are battery independent. The coil supply is provided by the mains itself. Mains supply is reduced and rectified. This rectified supply is given to the changeover relay coil . Battery low voltage does not affect the relay coil supply. This type of OFF-Line UPS provides mains output irrespective of the battery condition.

Isolation of inverter

Another important point is that the isolation of the inverter section during the presence of mains , this is done by the change over relay. For inverter side isolation a switching transistor is used . This switching transistor controls the shut down pin voltage of oscillator IC. This transistor makes this pin high when mains is present.

Once shut down pin becomes high, oscillator IC stops generating pulses to MOSFETs. MOSFEET becomes OFF and inverter section becomes inactive. When mains failure occurs this pin voltage is changed by the transistor to generate gate pulses.

The inverter section of OFF-Line and ON-Line UPS are almost same expect in the mains section.

OFF-Line UPS employs a mains delay capacitor. This is a prevention to fast varying mains input voltage. If mains condition is changing rapidly (Mains ON/OFF) then the UPS has to switch alternately to battery mode and mains mode. Since MOSFET cannot respond to these fast varying currents it will burn.To avoid this, a delay capacitor in mains mode (.1Mf) to delay the mains input. As soon as mains is sensed by the opto coupler, mains on indication glows. Changeover relay will respond after a few seconds to mains because of this capacitor. Removing this capaci- tor decreases changeover time. But this may cause damage of MOSFET.

ON line UPS

In an ON line UPS, the inverter always supplies the load irrespective of whether mains power is available or not. The load is always left connected to inverter and hence there is no transfer process involved. When the mains power is present, it is rectified and applied in parallel with the battery. Hence all the supply system transients are isolated at the battery and the inverter always delivers pure sine wave of constant amplitude to the load.

Fig 13 represents a basic block diagram of an ON Line UPS.

In the block diagram (Fig 13), the mains input is stepped down to a lower level and applied to a thyristor based phase controlled AC to DC converter, employing firing angle(α) control. The PWM inverter which usually employs pulse width modulation using triangular/square wave carrier runs in battery mode. The output is filtered and given to the load. The PWM inverter is switched in the frequency range (50Hz) depending on the power rating and hence the DC side current drawn by the inverter will contain switching frequency components.

Fig 13

BLOCK DIAGRAM OF ONLINE UPS
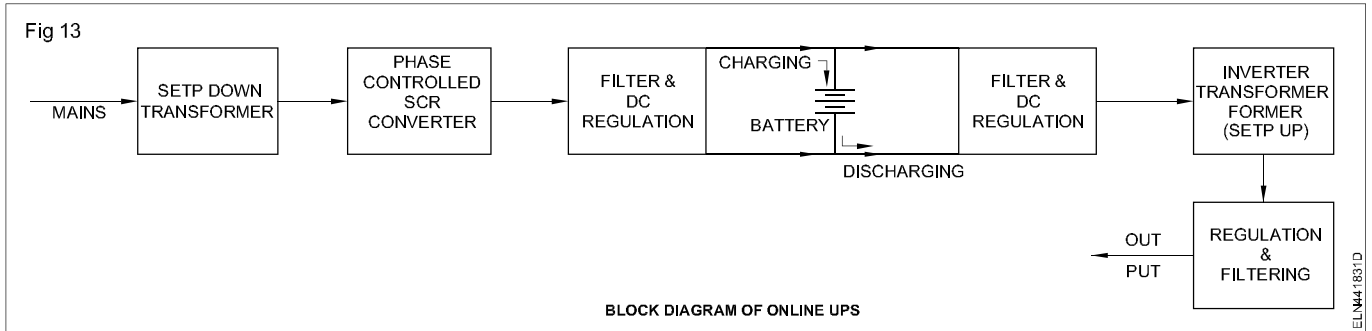
Along with the charging current the second harmonic component of DC side current of the inverter also flows into the battery. This second harmonic is quite large in value and this represents unnecessary strain on the battery. This is one of the major disadvantages of this design since it affects the battery life adversely.

When the mains is present the load power flows though the converter, reaches the battery node and from there flows into the inverter i.e there is double conversion of power. The converter, Inverter and the two level shifting transformers incur power losses in this process. Hence the efficiency of this design is lower than the OFF line design.

In a properly designed control system the battery voltage is measured and compared with a set float voltage. The error is processed in a proportional controller and the processed error decides the charging current that should flow into the battery. Charging current will be a constant one for ON line UPS.

Often it is found that the battery is in discharge mode even when mains is present i.e the battery shares the load current with the mains. This happens when the mains voltage is low and/or the output is loaded to above 75%. The efficiency of ON line UPS can be increased by using boost type power factor correction circuit.

Advantages

- Constant output voltage (No AVR card) free from changeover problem.

- Constant charging current.

Disadvantages

- complex in design, lower efficiency, higher cost, bigger in size and strain on the battery.

Presets of an ON-Line UPS

The presets of ON Line UPS are different from the OFF Line.

ON-Line UPS presets

Output high cut preset: Suppose there occurs a failure in PWM or feedback section. The output voltage will jump above 300V AC. This much output voltage causes harm to the output load. To prevent this output high cut preset is used. When the output voltage reaches set limit, this preset cuts the output. To set this limit, increase the output voltage using the PWM output voltage control preset till it reaches 265V and set the output high cut preset to shut off the output.

Emergengy light

Objectives: At the end of this lesson you shall be able to
• **explain the block diagram of emergengy light**
• **explain the emergency light circuit diagram and charging of battery.**

Emergency light

Emergency lighting system is commonly used in public building, work places, residences etc., The main function of the emergency lamp in the industry are

• to indicate ESCAPE routes

• to provide illumination to path ways and exit

• indicate the location of the fire fighting equipments.

The block diagram of an emergency light is in Fig 1. The circuit is discussed here are basic circuits without over charging protection for battery or trickle charging facility. Modern emergency lights have these facilities.

Fig 1

BLOCK DIAGRAM OF AN EMERGENCY LIGHT HAVING INCANDESCENT LAMP
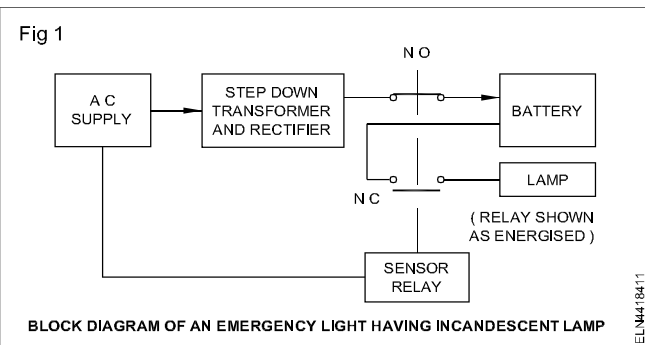
As shown in the block diagram AC main supply is fed to the step down transformer, then it is rectified to charge the battery through a sensor relay. A lamp is connected in the battery circuit through the relay. When AC supply fails the relay enables the battery to the connected lamp circuit through the normally closed contact and the lamp will glow.

When the AC supply is restored, the battery will be getting charged through the normally open contact of the relay. The charging current is regulated by the series resistances of 2.2 ohm, 5 watt. as in Fig 2. The two LEDs, one is red
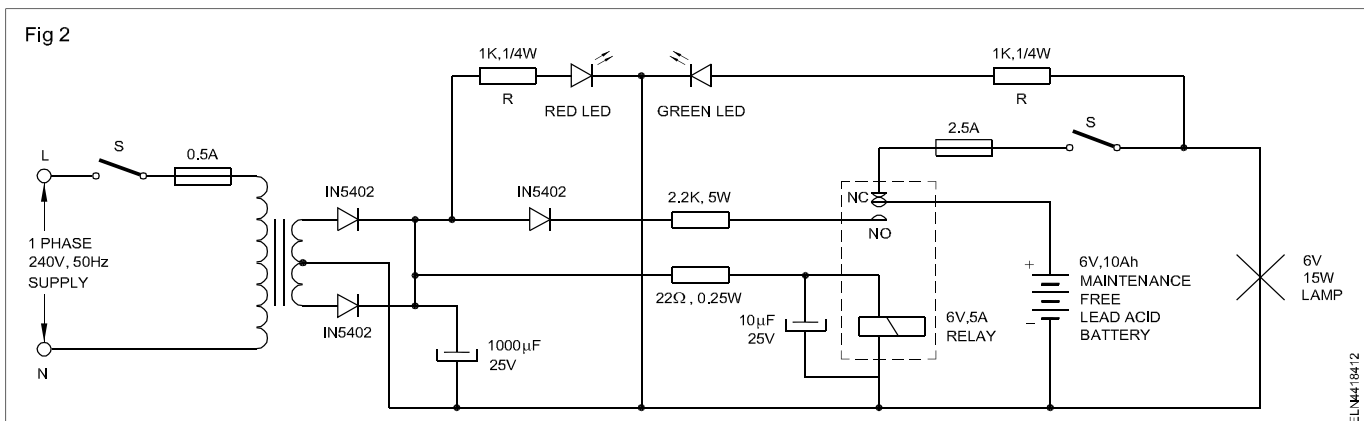
and the other is green are provided in the circuit to indicate the presence of AC and the lighting of the lamp through the battery supply respectively.

One 1000 microfarad capacitor is used in the rectifier circuit to smoothen the output D.C. supply and one 10 microfarad capacitor is used across the relay to increase the efficiency of relay operation.

Emergency tube light circuit: The emergency light which is connected to an ordinary incandescent lamp will give less light. If the fluorescent tube is used in emergency light it will give about 3 times more light consuming same wattage. Hence most of the emergency lights are incorporated with fluorescent tube lights.

The inverter circuit is incorporated with the ordinary incandescent lamp could be replaced by a tube light as shown in the block diagram, (Fig 3). The tube light requires a high voltage for its operation. The inverter is used to convert DC supply to AC and then it is stepped up to light the fluorescent tube. The inverter circuit is made operative by the sensor (relay). When AC supply is not available, during power failure battery voltage operates the inverter, in which DC is converted to AC and then stepped up to high voltage to enable the fluorescent tube to light up.

Fig 3

BLOCK DIAGRAM OF AN EMERGENCY LIGHT HAVING FLUORESCENT LAMP

Fig 2
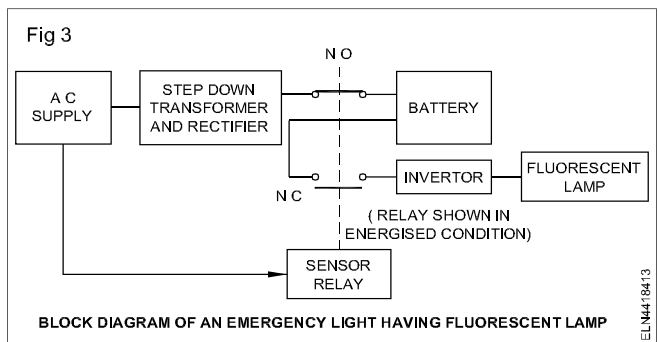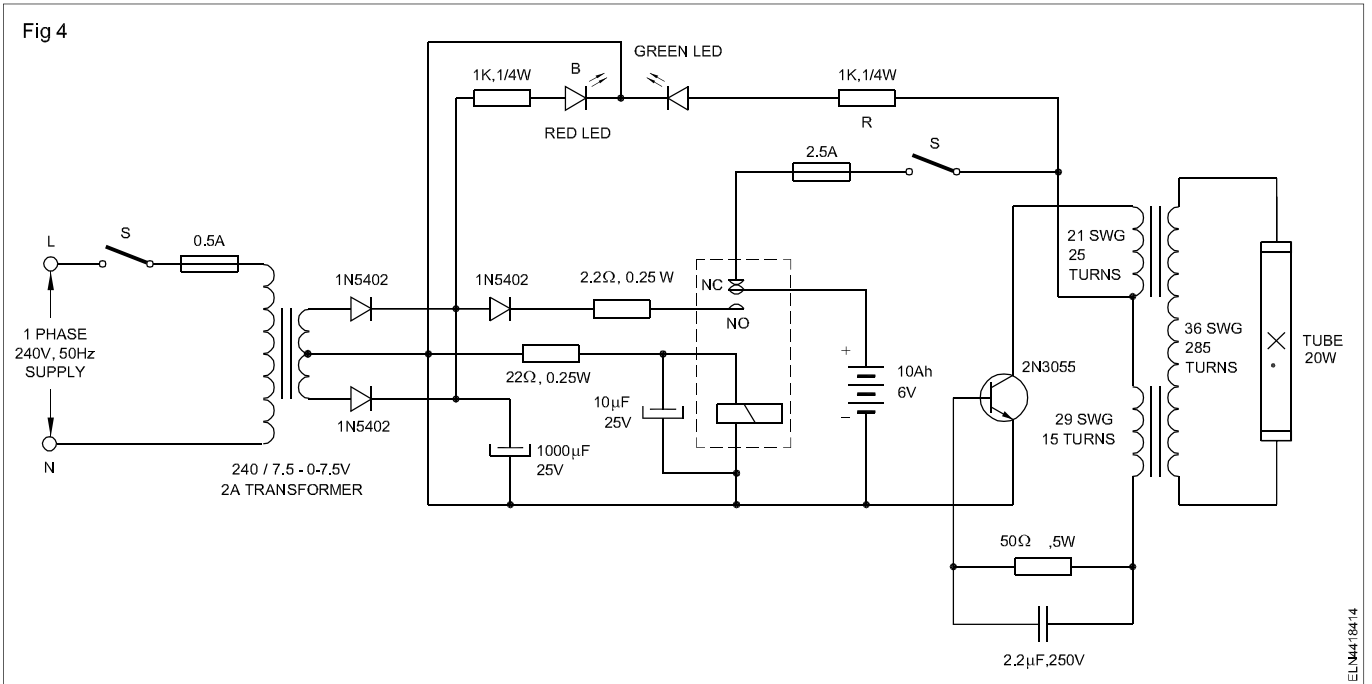
Fig 4

Inverters are basically transistorised oscillators as in Fig 4. They can be made to oscillate at the frequency of about 6.6 kHz. The frequency of the circuit can be changed by changing the value of resistor and capacitor in the circuit which is connected in the base of the transistor.

When the AC supply is resumed the sensor relay connects the battery terminals to the rectified DC circuit for charging

and the inverter circuit is disconnected from the circuit by the relay.

For keeping the temperature of the power transistor within its temperature range suitable heat sink should be mounted over the power transistor.

Battery charger and inverter

Objectives: At the end of this lesson you shall be able to
• **explain the working of battery charger with the help of block diagram**
• **describe various batteries and its maintenance, rating, methods of charging**
• **explain the battery charging circuit and its auto-cut-off**
• **state the principle of inverter with the help of block diagram**
• **explain power inverter and input output voltage, frequency, power relations.**

Battery charger

Proper selection and maintenance of the battery is very essential for the proper working of battery wherever is used: such as inverter,UPS etc

Many types of battery used for different purpose.Each have more advantages and disadvantages.

Commonly the following four types of batteries are used with the inverter systems, UPS etc.

•   Automobile batteries

•   Tubular/Industrial lead acid batteries

•   Sealed maintenance free (smf)batteries

•   Nickel cadmium batteries

Automobile batteries

This type of batteries are commonly used in automobile, cars, trucks etc. It is cheapest of the other batteries used. It has many draw backs one major draw back with these batteries are during stand by use.(i.e) In long duration under float charger they develops positive grid corrosion, which will reduce the back up time provided by it.

A good quality of automobile lead acid battery has a life an of only about 250-300 full charge /discharge cycle.

Tubular/Industrial lead acid battery

This type of batteries are designed for the heavy duty charge required .

The operating life is more than 1000 charge/discharge cycles. These type of battery requires regular maintenance. Because of the acid in these batteries irritating smell gases and It can not be kept in computer rooms and other AC rooms.

Sealed maintenance free (SMF)batteries

These batteries are completely sealed, so they do not require any kind of regular maintenance. In side of battery, do not contain any wet acid, (ie) lead paste batteries. It is small in size, and it can be kept in the ac room along with inverter.

It is more expensive when compared to the other batteries. It is more sensitive than other batteries. If the operating temperature is more than 40 degree centigrade half the capacity and life of batteries are reduced to half.

Nickel cadmium batteries

These are very expensive batteries and used in defence, space, nuclear science etc applications.It has extra any life operation .

Rating of battery

Commonly the batteries are available in 6V,12V,24V,48V, and 120V and so on. Normally 6 ,12 and 24 V rating are mostly available. The capacity of the battery is rated the Ampere/Hour(AH)

The back up time depends on the AH capacity of the battery. higher the AH capacity more the back up time.

Charging of battery

The life of battery is very much depends on the charging method used to charge the battery.

Three types of charging used to change the batteries.

•   Constant voltage

•   Constant current

•   Constant voltages- constant current

Constant voltage

This type of charging method using series regulators is suitable for the SMF batteries but not useful in automobile and tubular lead acid batteries.

Constant current

This charging method using shunt regulators, is useful for automobile and tubular /Industrial lead acid batteries, but it can damage the SMF batteries by overcharging them.

Fig 1

BLOCK DIAGRAM OF BATTERY CHARGER
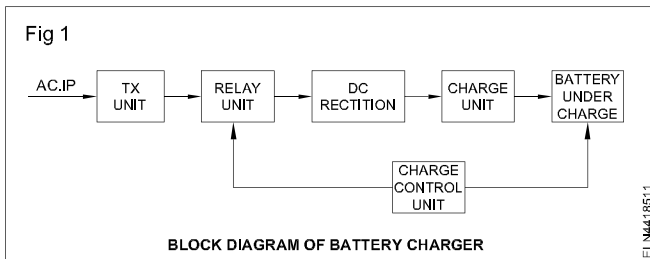
Transformer

The mains transformer primary is connected through auto transformer and the supply to auto transformer controlled through relays. The automatic charge control supply is always present at the primary of charge control unit transformer.

Relay unit

The relay unit supplies the DC rectifier input supply to the required DC input to the battery for charging. This relay unit also cut-off the rectifier input AC in case of the battery is fully charged.

DC rectifier

This rectifier unit always is a full wave bridge rectifier to handle heavy charging current. High current metal rectifiers are found mostly used in this circuit, but high current capacity semi conductor diode are in use.

Charging unit

This indicates the charging current taken by the battery and it is controlled by ON-OFF switches. A test switch is provided to test the charging condition of the battery.

Battery section

The battery under charger is always to kept in a well ventilated room and also open the vent plug for easy evaporation of exhausted gases from cells.

Charge control unit

Once the battery fully charged; then the DC supply to battery to be cut-off automatically. The voltage sensing circuit enables the control unit to trip the AC input to the rectifier unit thereby stop the charging voltage.

Constant voltage

This type of charging method using series regulators is suitable for the SMF batteries but not useful in automobile and tubular lead acid batteries.

Constant current

This charging method using shunt regulators, is useful for automobile and tubular /Industrial lead acid batteries, but it can damage the SMF batteries by overcharging them.

Constant voltage and constant current

This charging method contains more advantages .This method is suitable for automobile and tubular /Industrial lead acid batteries and also for SMF batteries.

This method provide regulated charging to improve the battery life.

Charging operation of battery

When the mains A.C is available, the mains supply is connected to 0-240V taping of auto transformer through a relay.

The transformer works on step down which has 0-240 V, taping at the primary and 12-0-12 V at the secondary.

The voltage at the secondary is used to charge the batteries connected.

Trickle charging

In an inverter, when the mains A.C is available the battery get charged. After the battery is fully charged the charger is cut-off. After the battery get fully charged if the charger is not cut off then the battery will get damaged.

Trickle charging is a special charging method used to keep the battery constantly in full charge position by keeping the battery charged constantly.

This method of charging is slightly different from the normal charging method.

For trickle charging 100th part of the normal charging current is provided to the battery.

A Simple battery charger

The charger can charge 6V,12Vand 24V battery at Suitable current rate. This circuit has many protection built in it to protect the battery from overcharge and reverse polarity etc.

The charger consist of an auto transformer X_2, (Fig 2) for supplying constant current and voltage.

A charger transformer 'X$_1$' is connected to the auto transformer and the secondary of the X_1 (Fig 2)is rectified through full wave bridge rectifier and supplied to the battery under charger through. Ammeter voltmeter and a potentiometer (Fig 2)

Fig 2

AUTOMATIC BATTERY CHARGER
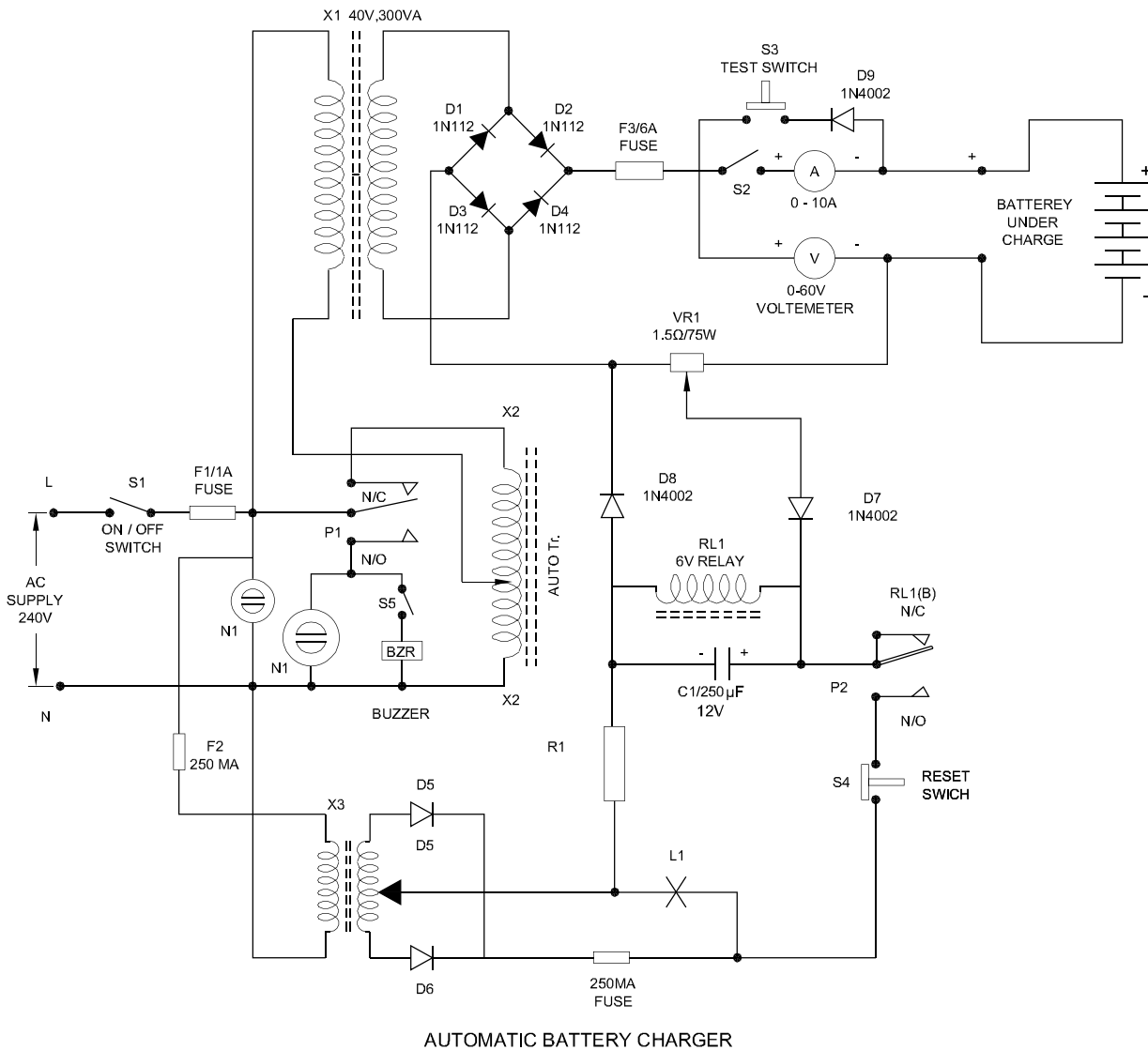
A step down transformer X_3 is used to keep cut off relay is energised condition when the mains AC supply is cut off to the charger circuit. Relay RL_1 used to cut off the AC mains supply to the charger circuit. Pole P_1 of relay RL_1 is connected to AC mains supply and pole P_2 is connected to cut off circuit.

Relay is energised by the centre tapping of potentiometer, which is set such that, the current in the charger circuit exceeds then it is energised and poles P_1 & P_2 are connected to normally opened (NO)pin, switching 'Off' A/C mains supply to the circuit.

The test switch S_3 is connected to check battery polarity, reset switch S_4 is used to reset the charger, when any fault occurs. Then the charger is cut off and the Switch 'S_1' is mains ON/OFF switch.

A fully charged lead acid battery must be 2.1 volt/cell during on charge.It will increase upto 2.7V/cell.The voltage of a battery is multiple of the number of cells.

In discharged condition the voltage is 1.8V/cell,it should not be further discharged in this condition as it may permanently damage the cell.

E.g A 100AH (ampere hour)battery requires (100 AH/10Hr=10 Amp) 10 Amp. Charging current for 10 hours for fully charged. To get complete discharge at the rate of 5Amps will require 20 Hrs.

The fully discharged battery requires about 11/2 times more to get charged .If the battery is in dead (or)not in use for long time even in normal changing current is passed. These dead batteries require higher charge voltage to start the charging current.

Checking of battery

Acid level and specific gravity of electrolyte, will indicate the condition of battery whether it requires charging or not.

The hydro meter is used for checking the acid level in a battery. The scale in marked in the hydrometer from 1100 to 1300. when it is inserted in the battery, the reading

i)   1100-1150 -indicates battery is down

ii)   1200-1250- indicates battery is o.k.

iii) 1250-1300 indicates excess acid

Voltage testing

By using high rate discharge tester, the voltage the each cell must be 2.1V, If it indicates below than 1.8V, then it shows the battery is in fully discharged. It is still below 1.8V. Then the battery becomes dead condition.

Never connect the high rate discharge tester for long duration while checking voltage, it will load the battery heavily and the cell, will discharge.

If the electrolytic level down in the container shell of the battery, top up with distilled water. Never add electrolyte prepared separately to the battery.

In a lead acid battery the electrolyte level of the battery should be checked and maintained every 15 days in summer season.

Inverter

It is an electronic device, which converts a D.C potential (voltages) normally derived from a lead-acid battery into a stepped-up AC potential (voltage) which is similar to the domestic AC voltage.

Locating the fault and troubleshooting of an inverters which provide sine wave outputs or the use of PWM (Pulse Width Modulation) technology is very difficult. (Fig 3)

BLOCK DIAGRAM OF A DRIVEN INVERTER
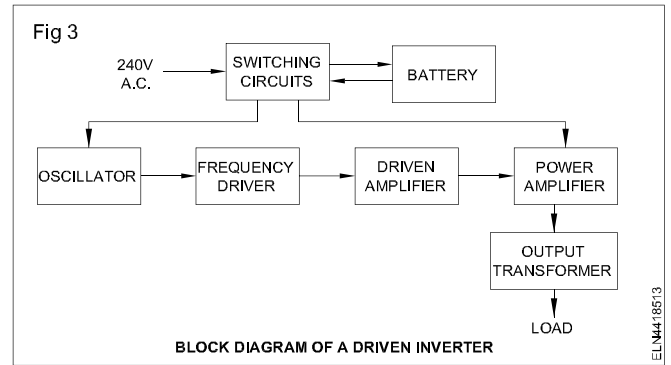
Switching circuits

It is the input stage of a inverter. This circuits supplying the power to further stages and connected to battery. The DC supply of battery in this supplies to the switching circuits for various needs.

Oscillator

It is an electronic circuit which generates the oscillating pulses either through an IC circuit or a transistorized circuit. This oscillations are the production of alternate pulse of positive and negative (ground) voltage peaks of a battery and at a specified frequency (No. of positive peaks per second). These are generally in the form of square waves and the inverters are called square wave inverters.

The complete circuit diagram of a static 50Hz static inverter is in Fig 4.

The oscillator section of the inverter used a IC circuit to produce control signal frequency to the control and driner section. The received oscillating frequency is amplified to a high current level using power transistor or MOSFET. IC 7473 (JK Flip type) used to power amplification and control the frequency to the driver transistors T1 and T2 driving the power transistor to the required level as in the Fig 4.

COMPELETE CIRCUIT DIAGRAM OF 50Hz STATIC INVERTER
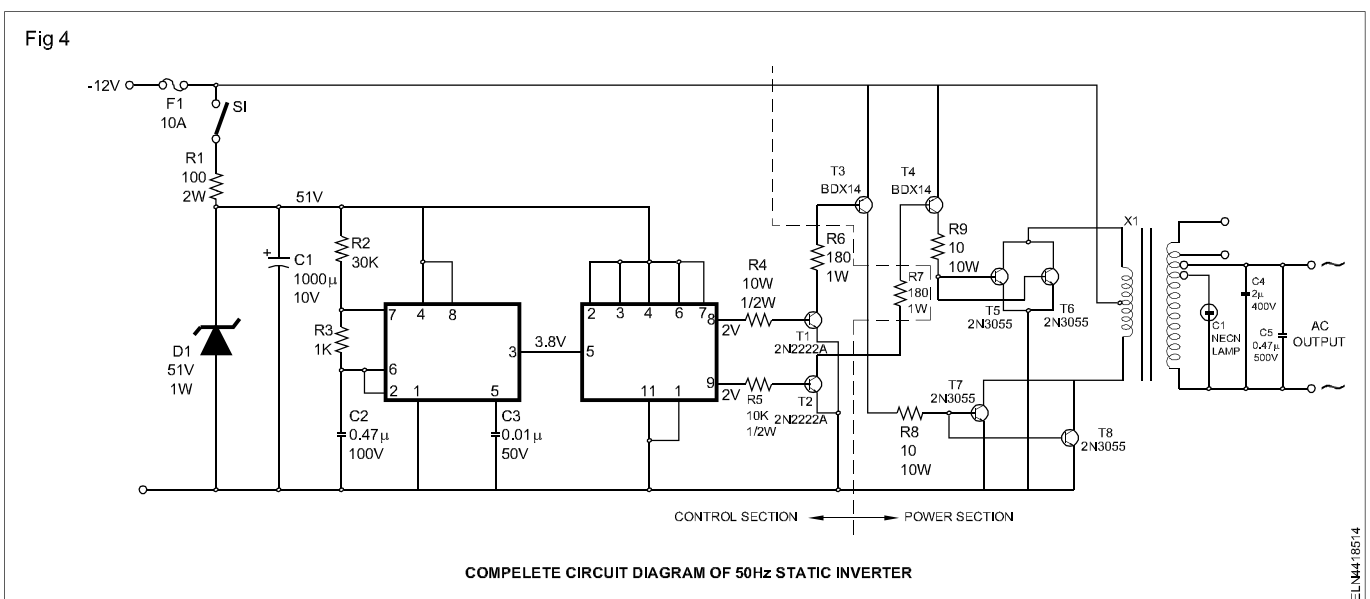
The two parallel connected power transistor T5, T6 and T7, T8 are connected to the output transformer which is used to step up the low level AC from the amplifies stage into the specified level.

The transformer secondary is supplied the required level of AC 240V. The generation of the oscillations due to which the process of voltage induction is able to take place across the windings of the transformer.

The inverter does not produce any power and the power produced by DC source. The inverter requires a relatively stable power source capable of supplying of enough current for the intended power demands of the system.

An inverter can produce square wave, modified sine wave, pulsed sine wave, pulse width modulated wave (PWM) or sine wave depending on circuit design.

The inverters more than three stages are more complex and expensive. Most of the electric devices are working with pure sine wave and AC motors directly operated on non-sinusoidal power may produce extra heat, and have different speed-torque characteristics.

Stabiliser, battery charger, emergency light, inverter and UPS

Objectives: At the end of this lesson you shall be able to
• **state the general precaution to carryout for preventive maintenance**
• **explain the steps to follow the break down maintenance**
• **service the voltage stabilizer, emergency light, battery charger, inverter and UPS**
• **analyse the trouble shooting chart and find the problem/ repair the equipment.**

Use of flow chart and troubleshooting charts for fault location : The circuit diagram is in Fig 1 is given for your reference. The working of the mains cord, fuse, relay contacts, windings of the auto-transformer etc. can easily be ascertained by using a test lamp and/or a series lamp or by a voltmeter for checking the electronic circuit and relay coil winding. A multimeter in appropriate range is a must to localise the fault. A series lamp or test lamp should not be used to test these as they are liable to spoil while testing.

Method of trouble shooting : Referring to Fig 1, we find that the absence of control voltage from S_1, S_2 or DC voltages will make both the relays inoperative, and, hence, will be in the off position resulting in higher output voltage than input voltage with boost indication. The same result also occurs when both transistors are open.

When both the transistors are short i.e. collector to emitter is short or both zener diodes are short the relays are energised and the output voltage will be lower than input voltage.

When one of the relay circuit is only not operating that particular function will be absent i.e. either back or boost function will be absent.

When a component mounted on PCB is suspected to be defective, first ascertain from all possible tests with in the circuit and then remove the component from PCB only when it is absolutely necessary. Even removing components for testing should be done as rarely as possible.

While removing the components from PCB, the component position with respect to the PCB, the terminal connections and hook up wire connections should be noted to enable the electrician to reconnect the component properly. When replacing the components procure the component of the same specification or equivalent so that the performance of the equipment is not affected after repair.

Troubleshooting chart given in Table 1 illustrates the problem, section to be suspected possible cause and action required for a stepped automatic voltage stabilizer.

TYPICAL CIRCUIT DIAGRAM OF A STABILZER
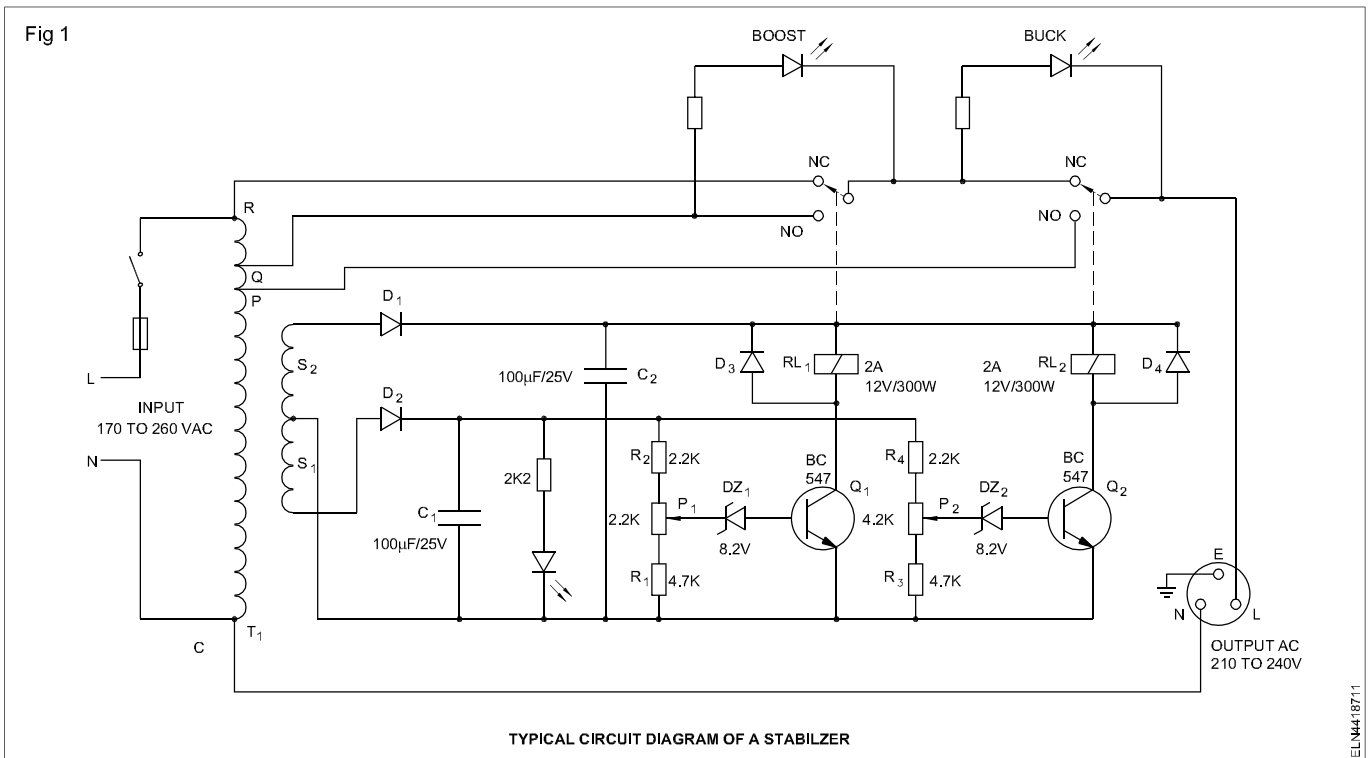
General precautions for preventive maintenance

Maintenance for any equipment needs a working knowledge of that machine is very much essential to the person concerned. For example the volt ampere rating of voltage stabilizer is very important to carryout the preventive maintenance. Low quality, substandard components or materials never be used or recommended for use. Necessary steps to taken for safe temperature controlling and over loading conditions. Proper operating sequence or working steps to follow of all the equipments under maintenance.

Steps to follow break down maintenance

Break down can happen anytime, anywhere. Adequate protection might have provided to all equipments, for its smooth working. However continuous running or usage, lack of maintenance, human error and some unexpected reasons break down is happening.

Once break down maintenance or repair is required a detailed study of that equipment is essential. Always involve more persons pertain to the repair work or maintenance work for achieving a good result. A collective and competitive effort only will produce good results. Give value for everyones suggestion, expertise and workmanship. There must be a clean idea and vision to finalise the maintenance and repair. Ensure the services of experts, availability of spares, details of past records, diagrams and past history of the equipment such as its installation date, service records, number of break downs and its frequency etc; Servicing of voltage stabilizer by trouble shooting method.

Table 1

Trouble shooting chart for stepped automatic stabilizer

Sl. No.	Problem	Section to be suspected	Possible cause for defective	Action
1	No output voltage at output socket.	Input buck/boost relays.	Mains cord, switch, fuse, transformer and relays	Locate and repair or replace
2	The output voltage is more, do not regulate.	Electronic circuit or relays.	Open/shorted rectifier / diodes, or open zener diodes	Locate the defective part and replace.
3	Output voltage is same as input. Do not regulate.	Transformer or Electronic circuit	Transistor or held up relay contacts or Partial open transformer / leads.	Test, repair or replace.
4	Output voltage is low. Do not regulate.	Electronic circuit	Shorted zener diode or transistor or open resistors	Test and replace.
5	Chattering in relays	Electronic circuit/relays	Leakage capacitors	Replace.

Trouble shooting of UPS

The trouble shooting and repair of UPS is difficult as this circuit is so complicated with so many functions. A step by step trouble shooting approach with a reasonable analysing is very important to carryout the troubleshooting in the UPS circuit.

A trouble shooting chart of UPS is given for your reference in table - 2.

Table 2

Troubleshooting chart of UPS

Sl.No.	Fault	Possible Reason	Troubleshooting
1	UPS works on 240V VAC mains but does not operate on battery	1 Battery fuse is blown out 2 Battery is discharged	1 Check the battery fuse. If fuse is blown, replace it, if it is loose, tighten 2 Recharge the battery, also check the polarity of battery
2	When UPS is switched on, charger does not turn on	1 Mains input fuse may be blown	1 Change mains fuse, if fuse blown

SI.No.	Fault	Possible reason	Troubleshooting
		2 Charger input fuse blown out	2 Check the battery polarity and conditions, correct it if wrong, replace the fuse
			3 Check the supply from mains, if OK, then check relay wiring, check relay coil.
3	240 VAC mains supply NOT available	1 Mains supply fails 2 Input AC mains is very low 3 Loose connection in input wiring	1 Check the supply of mains 2 Check the voltage 3 Tight the connection of wiring coming from distribution board
4	DC voltage is OK, but UPS shows DC under voltage and trips	1 Inverter fuse is blown 2 Rust/loose connection in battery	1 Replace fuse 2 Check the connection
5	When the UPS is switched ON with out load but DC under voltage indicator turns ON at load.	1 Load too high 2 Loose connection of battery terminal 3 Short or earth fault in load	1 Check the load, add loads gradually. 2 Tight the connections and check the polarity of battery 3 Check the load circuit wiring
6	Where there is no AC mains supply and the UPS is operating on battery, DC under voltage indicator turns ON	1 Battery is discharged 2 Battery terminal dust or loose	1 Recharge the battery, use proper current capacity cable in the battery circuit. 2 Check the connection
7	DC fuse blows OFF	1 Overload or short circuit	1 Change DC fuse 2 Reduce the overload. If power transistors are short or leaky, replace them.
8	UPS does not switch ON	1 Supply fails due to blown out fuse or some break in cable 2 No DC supply in the control card due to dry soldering or desoldering	1 Replace fuse, check the cables 2 Check and correct dry soldering and de-soldering 3 Check control card wiring
9	UPS trips when full load is connected	1 Overload setting is wrong	1 Adjust the overload setting, check the power consumption of the load. Gradually increase the load.
10	UPS output is high	1 Some connection is broken in the feedback loop 2 Control card is not functioning properly 3 Over voltage sensing is faulty	1 Check feedback transformer wiring and adjust feedback voltage preset. 2 Check /Replace control card 3 Check overload sensing circuit
11	UPS does not switch on in battery mode	1 Mains earthing is not proper 2 Problem in inverter circuit	1 Check the earth connection 2 Check battery, MOSFET, oscillator section, driver section, output section
12	Battery wire getting burned	1 The relay points are joined together	1 Check / Replace relays

SI.No.	Fault	Possible reason	Troubleshooting
13	Change over time high, computer connected to the UPS reboots during change over.	1 Check oscillator circuit	1 Check /replace IC and other components of oscillator section
14	Low backup time	1 Main filter capacitor problem 2 Battery get short circuit/discharge	1 Check and replace capacitor 2 Check battery, replace if required

Trouble shooting of battery charger and emergency light

As you have seen that the battery charger is a simple circuit compare to UPS. The main function of the charger circuit is to feed the DC voltage to battery at a prescribed level we discuss only the trouble shooting of charger circuit and its repair. Battery maintenance is not discussed in the trouble shooting chart.

Analyse the fault in battery charging circuit (Fig 1) with the help of trouble shooting chart given in Table 3 and 4.

Table 3

SI. No.	Problems	Section to be suspected	Possible cause for defects	Action
1	No DC voltage at charging terminal	1 Faulty Ammeter (open circuit)	Aged/over current	Replaced Ammeter
		2 Blown fuse	Over current	Replace fuse
		3 Faulty rectifies diode	Aging/over loading	Replace all diodes
		4 Defective transformer	Aging/over loading	Replace transformer
		5 Faulty Relay contacts	Repeated closed open	Replace contact
		6 Open Relay coil	Over voltage/current	Replace relay
		7 Main fuse blown	Over loading	Replace fuse
		8 No link between meter to battery	Loose connection	Tighten the connection
		9 Defective auto transformer	Over loading	Replace transformer
2	Low terminal voltage	Anyone pain diode open circuited	Ageing	Replace all four diodes
		Partial short in transformer	Over heat	Replace transformer
3	No automatic charging voltage cut off	Defective potentiometer	Long use	Replace new potentiometer
		Driver diode open	Ageing	Replaced 2 diodes(D7)
		Defective electrolytic capacitor	Ageing	Replace capacitor (C_1)
		Defective bleeder resistor	Over current	Replaced same value resistor(R_1)
		Control circuit rectifier diode open	Ageing Over current	Replace both diodes$(D_5$ & $D_6)$
		LT winding transformer open	Ageing / over current	Replace new transformer (x_3)
		LT fuse open	Over current	Replace fuses (F_2)
		Defective auxiliary relay terminal	Repeated operation	Replace contact RLI(B)

Table 3 contd...

SI. No.	Problems	Section to be suspected	Possible cause for defective	Action
4	Irregular over voltage cut off	Defective potentiometer	Loose contact in the disc (track)	replace new potentiometer (VP1)
		Shorted driver diode	ageing/over current	replace new diode (d7)
		Loose in relay contacts leaky electrolytic capacitor	Repeated contacts ageing	replace contacts replace electrolytic capacitor

Table 4

Trouble shooting chart for emergency light

SI No	Problems	Section to be suspected	Possible cause for defective	Action
1	Lamp dead in both condition lamp	Defective tube	Ageing	Replace tube lamp
		Defective inverter transformer	Over loading/ageing	Replace inverter transformer
		Defective driver	Over loading/ageing transistor	Replace transistor (213055)
2	Lamp out glowing if AC fails	Low/ dead battery	Ageing	Replace New battery

Servicing of equipment are discussed based on a sample circuits. When servicing of other equipments with different circuits may differ from the troubleshooting sequences. However the basic principle based on the block diagram may be taken for guidance to service/repair the equipment.

Trouble shooting of inverter

DC to AC inverter is quite complicated circuit, it consists of many functions. The switching circuit, oscillator circuit, control circuit power amplifier circuit, driver, finally the output circuit through the transformer. A feed back is also taken from the output transformer to regulate the output through the control circuits.

A constant DC source; either from a converter or battery is very much essential to keep the power output in a constant stage. DC to AC conversion with a specified frequency and a particular wave is difficult.

Analyse the fault in a inverter is explained (Fig 2) with the help of trouble shooting chart is given in Table 5. However the fault and problem are discussed while considering the 50Hz static inverter circuit is in Fig 2.

Fig 2

COMPELETE CIRCUIT DIAGRAM OF 50Hz STATIC INVERTER
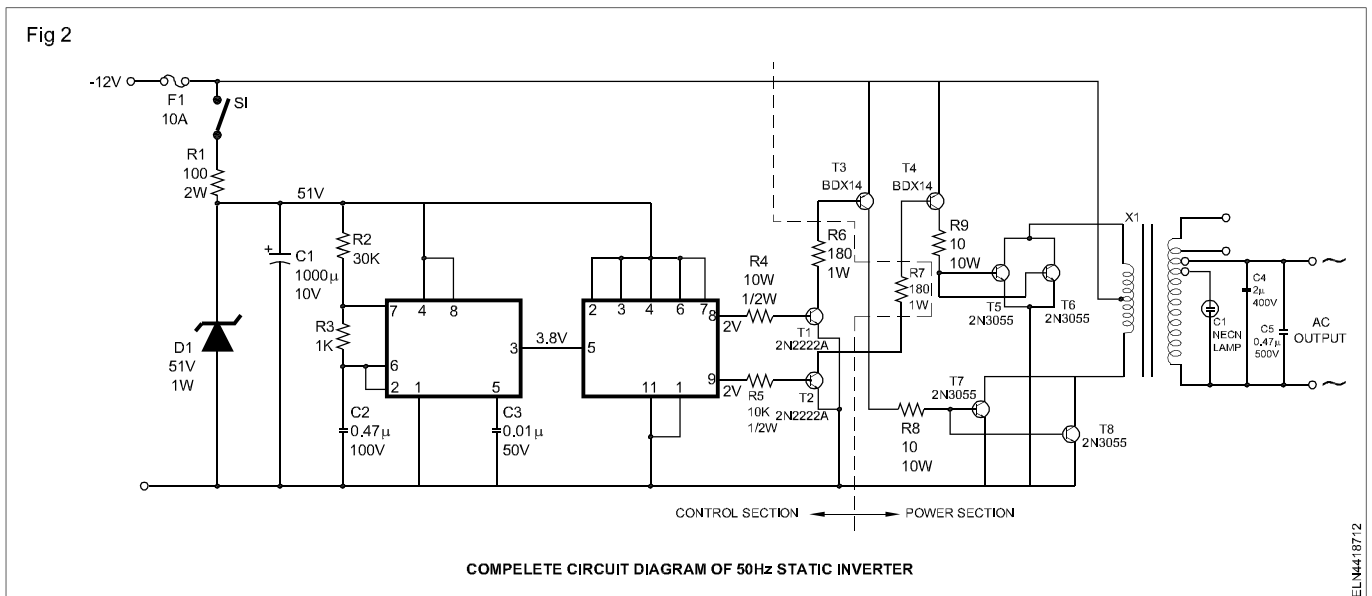
Table 5

SI No	Problems	Section to be suspected	Possible cause for defects	Action
1	Output - Dead	- Output transformer	- Transformer open or short	Rectify transformer
		- DC source	- CT & transformer open	Rectify the CT connection
			- No DC from battery	Replace battery
			- Battery dead	
2	Low or high frequency	- Oscillator IC (555)	- Faulty IC	Replace IC
		- Control IC JK Flip-Flop	- Faulty IC	Replace IC
			- No supply to IC (series resistor open)	Replace resistor
			- Capacitor connected to IC 555 shorted	Charge faulty capacitor
3	Low voltage frequency ok	- Driver transistor	Fault in driver transistor	Charge the transistor
		- Power transistor (output transistor)	Fault in power transistor	Replace the power transistor
			Fault in output transformer Partial short in winding / cave	Rectify the transformer fault or Replace the transformer
4	Frequent cut-off the output	- Battery	- Low A/H capacitor of battery	Replace Battery
		- Fault in IC	- Over heat in IC	Provide heat
		- Fault in power transistor	- Over heat in power transistor	Sink to IC Sink to transistor

Installation of inverter in domestic wiring

Objectives: At the end of this lesson you shall be able to
• **enumerate the important points to be kept in your mind to select the inverter to be installed**
• **state how to select the place to install the inverter and battery**
• **explain how to install the inverter with battery and load, and check for its performance**
• **state the rating of inverter and its sample calculation.**

Important points to be considered before installing an inverter

Many time when a new inverter is not giving proper service, the fault is due to improper installation only, not in inverter.

Another most important point is when connecting an inverter to the line is, the total load connected to the inverter should not exceed 80% of capacity of inverter.

Before providing points to connect the loads to the inverter, the total connected load must be considered.

If over load occur, then the overload protection will 'cut OFF' the output and reduce the load then the reset key must be pressed, and if the inverter is not provided with overload protection, it may get damaged at the time of over load than the capacity of the inverter.

Selection of place for installation of inverter

To connect inverter to the supply line, suitable place for the inverter is to be located. That place must be nearer to the service energy meter and ICDP switch and provide a 3 pin output socket from the mains supply line for the inverter and connect the inverter to the socket as in (Fig 1).

Installation of inverter

Collect the suitable inverter with sealed free maintenance battery to be installed, and check for their proper function

Place the inverter's battery to a suitable place near the inverter and connect the battery to the inverter.(Fig 1)

Fig 1

INVERTER INSTALLATION
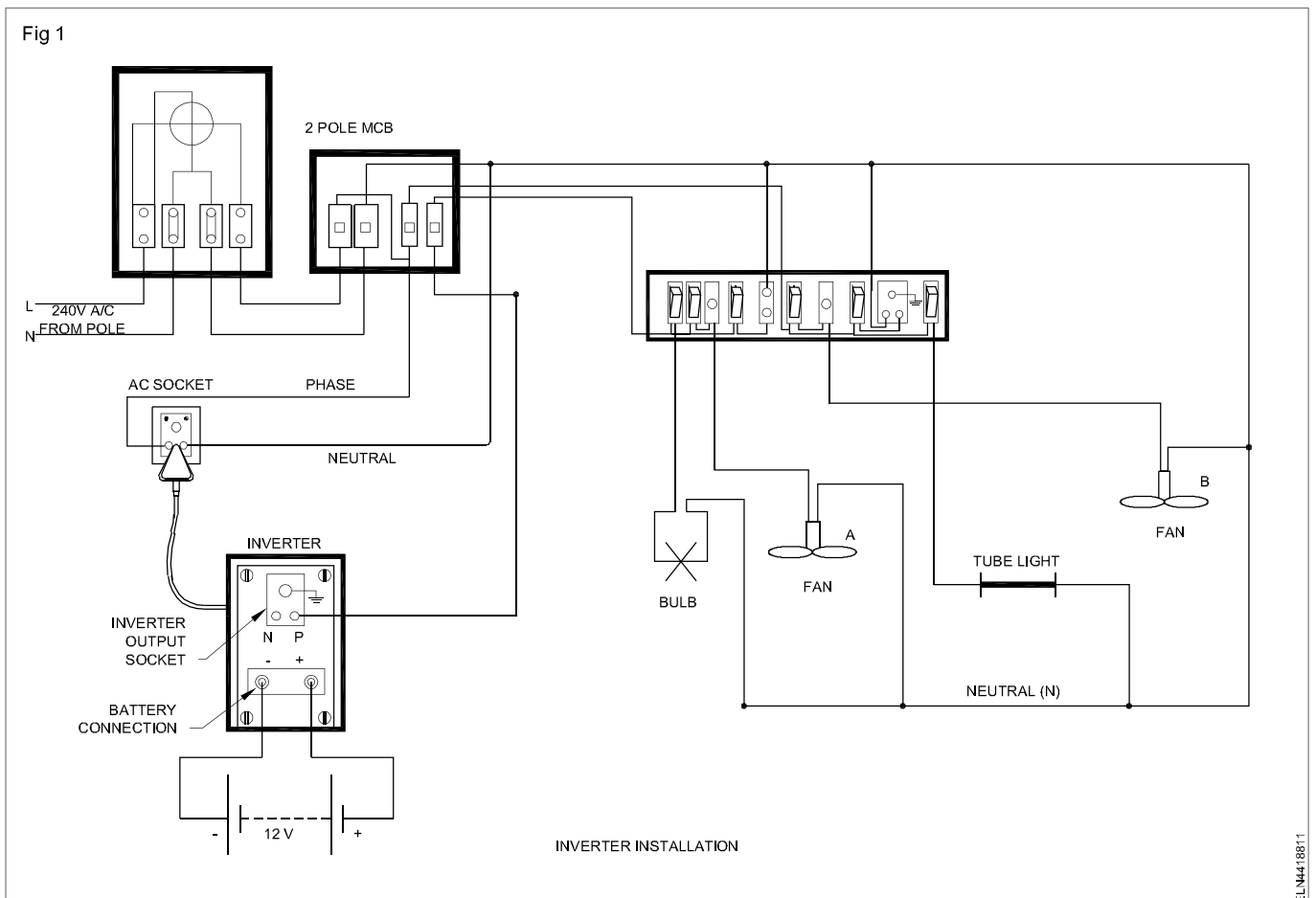
Keep the battery as close as possible to the inverter, so that the wire connecting the battery terminals to the inverter can be small and current loss is reduced. Make sure the battery is fully charged before installation.

The positive terminals of battery (red wire) is connected to the place provided for the positive terminal on the inverter and the negative terminal of the battery (blue or black wire), which is to be connected to the place provided for the negative terminal on the inverter.

When connecting battery terminals to the inverter, use special auto wires do not use common mains wiring with wires such as '3/20' and 7/20 etc.connecting battery using these wires will not provide proper connection between the battery and the inverter.

After connecting the battery, put some grease (or) vase-line on the battery terminals, which reducing the terminal corrosion.

All the connection is completed take the output from the inverters output socket and use it to power the load. Use 1/18 copper wire to the output of the load. Do not use 3/20, 3/22 or 7/20 wires, commonly used in house wiring.

The output is taken from the phase out 'pin of inverter' output socket, and is provided to the ON/OFF switches on the wall pause.(Fig 1)

The neutral line is common for both the inverter output and the mains A/C line. So, only one wire for the phase line can be drawn from the inverter output socket to the switches.

In Fig 1, one bulb, one fan and a 2 pin output socket are connected to the inverter output and the other devices in the room. (ie) the tube light, fan (2) and a 3 pin output socket are directly connected to the mains A/C line.

In the two pin socket, should not be connected with heavy load during power 'OFF' only small load like mosquito repeller can be connected.

As in (Fig 1) the load connected to the inverter will get the mains A.C supply. If the mains supply is 'On' at the same time, other devices will also work on the main supply, because they are connected directly to the mains A.C supply.

But at the time of power shut down, the devices directly are connected to the mains A.C will stop functioning and the devices, which are connected to the inverter output will keep on working on the inverter output.

Later, if the mains A.C supply returns, the inverter will once again connect the load, which are connected to its output to the main supply. This process is in Fig 2.

Inverter rating calculation

Generally, the inverters are available with ratings such as 200w,300w,400w,500w,600w,1000w,1200w,1500w and so on.

Fig 2

(a) BOTH THE BULBS & FANS CONNECTED TO THE INVERTER OUTPUT AND TO THE MAINS A/C SUPPLY WILL WORK

(b) WHEN MAINS A/C SUPPLY IS NOT AVAILABLE — ONLY THE BULB & FAN CONNECTED TO THE INVERTER OUTPUT WILL WORK
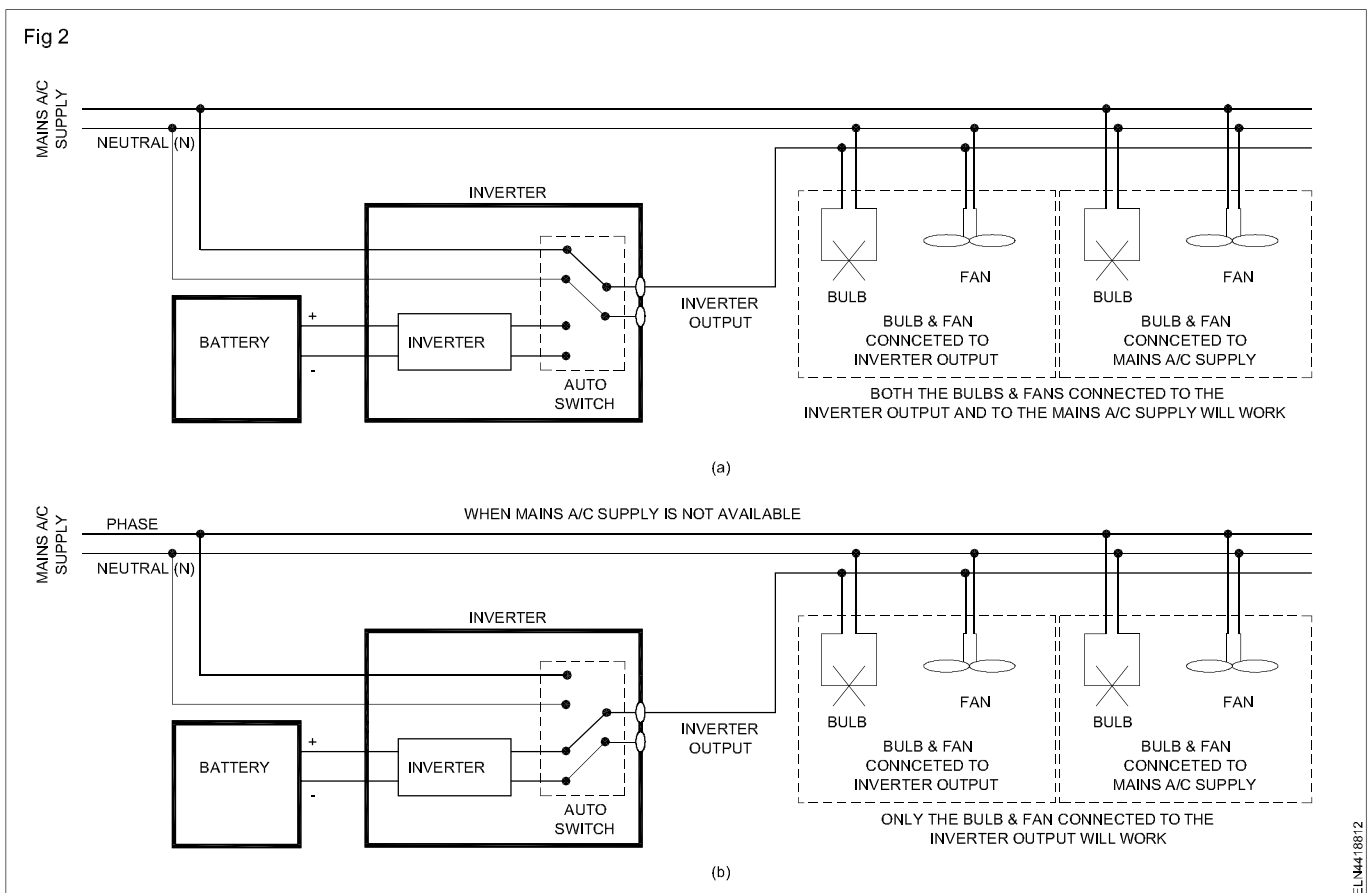
The cost of the inverter is proprotional to their capacity in wattage (or) VA. It must be considered before buying the Inverter.

Calculation of power consumption

True power = Apparent power x power factor
Let us assume,

The loads are	- 2 tube lights,(ie) 2x40W = 80W
	- 1 fan (ie) 1x60W = 60W
	- 1 bulb (ie) 1x40W = 40W
	Total load = 180 W

If the total load is 180W, the inverter capacity is to be selected for 300W, giving some safe margin.

Always, the inverter with high rating must be purchased by considering the future the household appliances may be added.

Power consumption Table

Device time	Approx Watts	P.f-0.8 (app) VA	Running for 1 unit of consumption (approx.) Hrs. - Min.
Incandecent bulbs (B.C bulbs)	25W	20	40-00
Incandecent bulbs	40W	32	25-00
Incandecent bulbs	60W	48	16-40
Incandecent bulbs	100W	80	10-00
Fluorescent tube 61 cms	20W	16	50-00
Fluroescent tube 122 cms	40W	32	25-00
4 feet night lamp	15W	12	66-40
Mosquito repellent	5W	4	200-00
Fans	60W	48	16-40
Air - coolers	170W	136	5-50
Air-conditioners (1 to 1.5 ton)	1500W	1200	0-40
Refrigerators (165 liters)	225W	180	4-30
Mixer/blender /juicer	450W	360	2-15
Toaster	800W	640	1-15

Device time	Approx Watts	P.f-0.8 (app) VA	Running for 1 unit of consumption (approx.) Hrs. - Min.
Hot plate	1000W	800	1-00
Oven	1000W	800	1-00
Electric kettle	1000W	800	1-00
Iron	450W	360	2-15
Water heater: (a)Instant geysers 1.5 - 2 liter)	3000W	2400	0-20
Water heater: (b)Storage type (10-12 liter)	2000W	1600	0-30
Water heater: (c) Immersion rod	1000W	800	1-00
Vacuum cleaner	700W	560	1-25
Washing machine	325W	260	3-00
Water pump	750W	600	1-20
TV	60W	48	16-00
Radio	15W	12	66-00
Video	40W	32	25-00
Tape recorder	20W	16	50-00
Stereo system	50W	40	20-00
PC Cop.	120W	150	8-20
PC/XT cop.	185W	230	5-25
PC/AT Cop.	255W	320	3-55
386& Higher Cop.	320W	400	3-08
Mono chrome monitor	44W	55	22-45
CGA monitor	64W	88	15-35
EGA monitor	80W	100	12-30
VGA monitor	120W	150	8-20
80-column dot-matrix printer	64W	80	15-40
160-240 cps printer	100W	125	10-00
132- column dot matrix printer	140W	175	7-08

Device time	Approx Watts	P.f-0.8 (app) VA	Running for 1 unit of consumption (approx.) Hrs. - Min.
Image writer II	80W	80	12-30
Laser write plus	880W	1100	1-08
HP Laser jet Printer	840W	1050	1-11
External Hard Disks	80W	100	12-30
Tape Back up	140W	175	7-08

Preventive and breakdown maintenance

Preventive maintenance : It improves the performance safety of a business instead of a large repairs being needed and major problems arising. Consistent maintenance is carried out to reduce these risks. This improves the performance of all equipment. It also helps to avoid unplanned repairs and unexpected maintenance needs.

Preventive maintenance further divided into two parts they are;

a Planned preventive maintenance and

b Unplanned preventive maintenance

a Planned preventive maintenance

A planned preventive maintenance cut-down maintenance cost and ensure the long life of equipment and a steady quality output. The following is the benefits of planned preventive maintenance.

a overtime costs reduced

b reduced risk of problems

c reduced no. of repairs

d small repairs can be carried out regularly

e ensures all equipment safe in good conditions

f If meets safety and environment standards

g Improves the safety and health of workers.

b Unplanned preventive maintenance

The unplanned preventive maintenance is nothing but a routine maintenance work. For example lubricating, cleaning, tightening of nuts and bolts etc, are same of the maintenance. This not involves any predetermined work associated. The following is the draw backs of unplanned preventive maintenance.

a Increases overall material cost

b Improper usage of manpower

c Not guaranteed of quality or quality or quantity in production

d No guarantee of machine condition

e Increased risk of problems

f Unexpected problems in production and quality.

Breakdown maintenance is a form of material or equipment remediation that is performed after the equipment or material has lost its functioning capabilities or properties.

Breakdown maintenance is maintenance performed an equipment that has broken down and is unusable. It is based on a breakdown maintenance trigger.

Demerits of breakdown maintenance

a Loss of production and business unexpected

b Huge expenses for restoration

c Non availability of spares and experts

d Accidents, environmental problems

e Leads to major accidents loss of life

f Wastage of raw material if time based supply

A well planned preventive maintenance can avoid breakdown of machines and keep maintain steady quality production and maintain company standards.

Sources of energy - Thermal power generation

Objectives: At the end of this lesson you shall be able to
• **explain conventional and non-conventional energy source**
• **state the various source of energy**
• **state the type of fuels used for power generation**
• **explain the working principle of thermal power station - cool and nuclear based**
• **explain schematic arrangement and constituents of thermal, diesel and gas turbine power plants.**

Introduction of power generation

Energy is the basic necessity for the economic development of a country and it exists in different forms in nature. But the most important form is the electrical energy . The modern society is fully depend on the electrical energy and it has close relationship with standard of living. The per capita consumption of energy is the measure of standard of living of people.

Sources of electrical energy

Since electrical energy is produced from energy available in various forms in nature, it is desirable to look into the various sources of energy. The natural sources of energy which are used to generate the electricity are :

i   Sun

ii   Wind

iii Water

iv Fuels

v   Nuclear energy

vi Tidal

Out of these sources, the energy due to Sun and wind has not been utilized on large scale due to a number of limitations. At present, the other three sources viz, water, fuels and nuclear energy are primarily used for the generation of electrical energy.

i   **Sun :** The Sun is the primary source of energy. .Solar cells are the one of the methods which uses the heat energy of the sun to generate the electrical energy in present days. this method came into large application of solar cells to produce electricity.however, than the limitations as:

a) It requires a large area for the generation of even a small amount of electric power.

b) It cannot be used in cloudy days or at night

c) It is an uneconomical method compared to conventional method

ii   **Wind:** This method can be used where wind flows for a considerable length of time. The wind energy is used to run the wind mill which drives a small generator.

In order to obtain the electrical energy from a wind mill continuously, the generator is arranged to charge the batteries which supply the energy even the wind stops. This method has the advantages that maintenance and generation costs are negligible. However, drawbacks of the method are that it is unreliable because of uncertainly about wind pressure and power generated is quite small.

iii **Water:** When water is stored at a suitable place, it possesses potential energy because of the head created. This water energy can be converted into mechanical energy with the help of water turbines. The water turbine drives the alternator which converts mechanical energy into electrical energy. This method of generation of electrical energy has become very popular because it has low production and maintenance costs.

iv **Fuels:** The main sources of energy are fuels viz. solid fuel as coal, liquid fuel as oil and gas fuel as natural gas. The heat energy of the fuels is converted into mechanical energy by suitable prime movers such as steam engines, steam turbines, internal combustion engines etc. The prime mover drives the alternator which coverts mechanical energy into electrical energy. Although fuels continue to enjoy the place of chief source for the generation of electrical energy, yet their reserves are diminishing day by day. Therefore, the present trend is to harness water power which is more or less a permanent source of power.

v   **Nuclear energy:** Towards the end of Second world War, it was discovered that large amount of heat energy is liberated by the fusion of uranium and other fissionable materials. It is estimated that heat produced by 1 Kg of nuclear fuel is equal to that produced by 27,50,000 kg of coal. The heat produced due to nuclear fission can be utilized to raise steam with suitable arrangements. The steam can run the steam turbine which in turn can drive the alternator to produce the electrical energy.

Comparison of energy sources

The main sources of energy used for the generation of electrical energy are water, fuels and nuclear energy. Below is given their comparison in a tabular form in Table 1.

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Table 1

Sl.No	Terms	Water Power	Fuels	Nuclear Energy
1	Initial cost	High	Low	Highest
2	Running cost	Less	High	Least
3	Reserves	Permanent	Exhaustible	Inexhaustible
4	Cleanliness	Cleanest	Dirtiest	Clean
5	Simplicity	Simplest	Complex	Most complex
6	Reliability	Most reliable	Less reliable	More reliable

Types of fuels used for power generations

Fuels are categorized into Three; They are

1 Solid fuels

2 Liquid fuels

3 Gaseous fuels

Solid Fuels

This can further be classified an

a Natural solid fuel

b Artificial soild fuel

The natural solid fuels are wood and different variation of coal, while the artificial solid fuels are charcoal, coke and pulverized fuel.

Liquid Fuels

This can replace coal for the production of steam. The major petroleum products, considered an liquid fuels are the following.

1 Gasoline (Petrol)

2 Kerosene

3 Gas oil

4 Diesel

Gaseous Fuels

This fuel can be divided in the following categories.

1 Natural Gas - It is obtained from soil by mean of dup wells and it is pumped out.

2 Producer Gas - This is a mixture of CO and H_2 with a little CO_2.

3 By product gases - This gas is obtained from blast furnace and coke ovens.

Advantages and disadvantages of liquid fuel

Advantages

i The design and layout of the plant where liquid fuel is used are quite simple and it occupies less space as the number and size of the auxiliaries are small.

ii Liquid fuel plant can be started quickly and can pick up the load in a short time.

iii There are no stand by losses.

iv The overall cost is much less than that of coal.

v The thermal efficiency is higher than that of a coal.

vi If requires less operating staff.

Disadvantages

i The plant where liquid fuel is used has high running cost as the fuel (i.e. diesel) used is costly.

ii The plant can generate only low power.

Advantage and disadvantage of solid fuel :-

Advantages

i The fuel (i.e coal) used in quite cheap.

ii The coal can be transported to the site of plant by rail or road.

Iii Solid fuel plant requires less space as compared to the hydro-electric power station.

v The cost is lesser than that of diesel.

Disadvantages

i It pollutes the atmosphere due to the production of large amount of smoke and fumes.

ii It's handling cost is high.

Types of electrical power generation

Basically power generation are of two types

a Conventional power generation

Power generations by using non- renewable sources of energy through various methods such as hydro, thermal and nuclear etc is called conventional power generation. It contributes to the major power requirement.

b Non conventional power generation

Power generation by using renewable energy sources such as wind, Tide and sun etc, is called non-conventional power generation. They are small scale power generation used for specific purpose.

Generating stations

Bulk electric power is produced by special plants known as generating station or power plants. A generating station employs a prime mover coupled with an alternator or generator for the production of electric power. The generated power is further transmitted and distributed to the customers.

Depending upon the form of energy converted into electrical energy the generating station are classified into,

1 Steam power stations /Thermal power stations

2 Hydro - electric power stations

3 Diesel power stations

4 Nuclear power stations

5 Gas - turbine power stations

1 Thermal /steam power station

A generating station which converts the heat energy of coal combustion into electrical energy is known as a steam power station.

The scheme of generation can be divided into two phases (i) Formation of steam in the boiler house (ii) Generation of electrical power in the generator room.

In the boiler the fuel is burnt and the water is converted into high pressure steam which is further super heated in a super - heater. The super - heated steam is passed in to the turbine to rotate the turbine blades, thus it converts the heat energy into electrical energy.

The turbine is the generation room acts as a prime mover of the alternator which generates electric energy. The alternator is connected through the circuit breaker to the bus bars.

This type of power station is suitable where coal and water are available in abundance and a large amount of electric power is to be generated.

2 Hydro - electric power station

A generating station which converts the energy posses by the water into the electrical energy is known as hydro-electric power station.

Water is a great source of energy. There are two types of energies which the water can posses. The flowing water in stream may have only kinetic energy. The flowing steam of water may have both kinetic as well as potential energy or simply potential energy at some elevation with respect to a lower datum level. The practical examples of which are water - falls or water stored at the back of a dam. The water stored in the reservoir is allowed to fall on the blades of a water turbine placed at the foot of the dam.

The initial cost of harnessing water and converting the potential energy into electrical energy is quite high but recurring expenses etc. are quite less. So, the overall system will be very economical.

3 Nuclear Power Station

A generating station which converts the nuclear energy into the electric energy is called as nuclear power station.

The nuclear power obtained by nuclear fission is fast entering into arena of energy sources. The heat produced by nuclear fission of atomic material is utilized in special heat exchangers to produce steam to run steam turbines. The atomic materials utilized for nuclear fission are thorium and uranium. Another reason of fast development of nuclear power is that the natural resources of coal and petroleum will exhaust early if the pace of industrial development remained so fast.

4 Non conventional energy

It is evident that all energy resources based on fossil fuels has limitations in availability and will soon exhaust. Hence the long term option for energy supply lies only with non-conventional energy sources. These resources are in-exhaustible/do not deplete for the next hundreds of thousands of years.

For example electrical energy from solar energy, Bio-energy, Wind energy, Geothermal energy, Wave, Tidal and Micro-hydro.

Choice of site for steam power stations

In order to achieve overall economy, the following points should be considered while selecting a site for a steam power station.

i **Supply of fuel :** The steam power station should be located near the coal mines so that transportation costs of fuel is minimum. However, if such a plant is to be installed at a place where coal is not available, then care should be taken that adequate facilities exists for the transportation of coal.

ii **Availability of water :** As huge amount of water is required for the condenser, therefore, such a plant should be located at the bank of a river or near a canal to ensure the continuous supply of water.

iii **Transportation facilities :** A modern steam power station often requires the transportation of materials and machinery. Therefore, adequate transportation facilities must exist. i.e., the plant should be well connected to other parts of the country by rail, road etc.

iv **Cost and type of land :** The steam power station should be located at a place where land is cheap and further extension, if necessary is possible. Moreover, the bearing capacity of the ground should be adequate so that heavy equipment could be installed.

v Nearness to load centers: In order to reduce the transmission cost, the plant should be located near the center of the load. This is particularly important if DC supply system is adopted. However, if AC supply system, is adopted, this factor becomes relatively less important. It is because AC power can be transmitted at high voltages with consequent reduced transmission cost. Therefore, it is possible to install the plant away from the load centers, provided other conditions are favourable.

vi Distance from populated area : As huge amount of coal is burnt in a steam power station, therefore, smoke and fumes pollute the surrounding areas. This necessitates that the plant should be located at a considerable distance from the populated areas.

Conclusion : It is clear that all the above factors cannot be favorable at one place. However, keeping in view the fact that now- a -days the supply system in AC and more importance is being given to generation than transmission, a site away from the towns may be selected. In particular, a site by river side where sufficient water is available and fuel can be transported economically, may perhaps be an ideal choice.

Schematic arrangement of steam power station

Although steam power station simply involves the conversion of heat of coal combustion into electrical energy, yet it embraces many arrangements for proper working and efficiency. The schematic arrangement of a modern steam power station is in Fig.1. The whole arrangement can be divided into the following stages for the sake of simplicity.

Fig 1

SCHEMATIC ARRANGEMENT OF STEAM POWER STATION
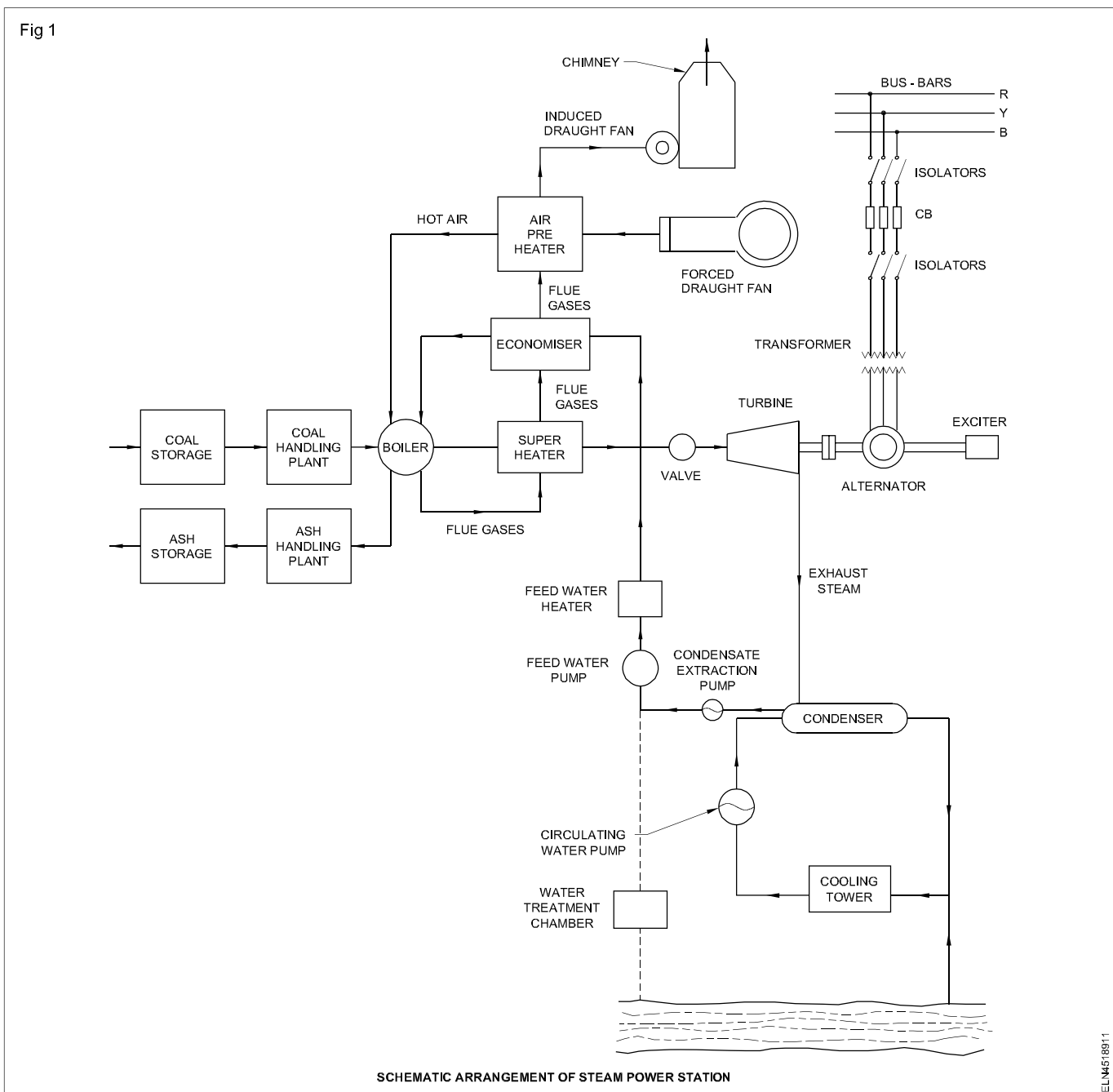
1 Coal and ash handling arrangement

2 Steam generating plant

3 Steam turbine

4 Alternator

5 Feed water

6 Cooling arrangement

Constituents in steam power station

A modern steam power station is highly complex and has numerous equipment and auxiliaries. However, the most important constituents of a steam power station are :

1 Steam generating equipment

2 Condenser

3 Prime mover

4 Water treatment plant

5 Electrical equipment

1 Steam generating equipment

This is an important part of steam power station. It is concerned with the generation of superheated steam and includes such items as boiler, boiler furnace, super heater, economizer, air pre-heater and other heat reclaiming devices.

i Boiler : A boiler is closed vessel in which water is converted into steam by utilizing the heat of coal combustion. Steam boilers are broadly classified into the following two types.

a Water tube boilers

b Fire tube boilers

In a water tube boiler, water flows through the tubes and the hot gases of combustion flow over these tubes. On the other hand, in a fire tube boiler, the hot products of combustion pass through the tubes surrounded by water. Water tube boilers have a number of advantages over fire tube boilers viz. require less space, smaller size of tubes and drum, high working pressure due to small drum, less liable to explosion etc. Therefore, the use of water tube boilers has become universal in large capacity steam power stations.

ii Boiler furnace : A boiler furnace is a chamber in which fuel is burnt to liberate the heat energy. In addition, it provides support and enclosure for the combustion equipment i.e burners. The boiler furnace walls are made of refractory materials such as fire clay, silica, kaolin etc. These materials have the property to resist change of shape, weight or physical properties at high temperatures.

The size of furnace has to be limited due to space, cost and other considerations. This means that furnace of a large plant should develop more kilo calories per square metre of furnace which implies high furnace temperature.

iii Super heater : A super heater is a device which super heats the steam (i.e) it further raises the temperature of steam. This increases the overall efficiency of the plant. A super heater consists of a group of tubes made of special alloy steels such as chromium-molybdenum. The steam produced in the boiler is led through the super heater where it is superheated by the heat of flue gases. Super heaters are mainly classified into two types according to the system of heat transfer from flue gases of steam viz.

a Radiant super heater

b Convection super heater

iv Economiser : It is a device which heats the feed water on its way to boiler by deriving heat from the flue gases. This results in raising boiler efficiency, saving in fuel and reduces stresses in the boiler due to high temperature of feed water. An economizer consists of a large number of closely spaced parallel steel tubes connected by headers of drums. The feed water flows through these tubes and the flue gases flow outside. A part of heat of flue gases is transferred to feed water, thus raising the temperature of the latter.

v Air Pre-heater : Super heaters and economizers generally cannot fully extract the heat from flue gases. Therefore, pre - heaters are employed which recover some of the heat in the escaping gases. The function of an air pre-heater is to extract heat from the flue gases and give it to the air being supplied to furnace for coal combustion. This raises the furnace temperature and increases the thermal efficiency of the plant. Depending upon the method of transfer of heat from flue gases to air, air pre-heaters are divided into the following classes.

a Recuperative type

b Regenerative type

2 Condensers

A condenser is a device which condenses the steam and the exhaust of turbine. It serves two important functions. Firstly, it creates a very low pressure at the exhaust of turbine, thus permitting expansion of the steam in the prime mover to a very low pressure. This helps in Converting heat energy of steam into mechanical energy in the prime mover. Secondly, the condensed steam can be used as feed water to the boiler. There are two types of condensers, namely

a Jet condenser

b Surface condenser

3 Prime movers

The prime mover converts steam energy into mechanical energy. There are two types of steam prime mover viz., steam engines and steam turbines. A steam turbine has several advantages over a steam engine as a prime mover

viz., high efficiency, simple construction, higher speed, less floor area requirement and low maintenance cost. Therefore, all modern steam power stations employ steam turbines as prime movers.

Steam turbines are generally classified into two types according to the action of steam on moving blades viz.

a   Impulse turbines

b   Reaction turbines

In an impulse turbine, the steam expands completely in the stationery nozzles (or fixed blades), the pressure over the moving blades remaining constant. In doing so, the steam attains a high velocity and the impulsive force on the moving blades which sets the rotor rotating.

In a reaction turbine, the steam is partially expanded in the stationery nozzles, the remaining expansion take place during its flow over the moving blades. The results is that the momentum of the steam causes a reaction force on the moving blades which sets the rotor in motion.

4   Water treatment plant

Boilers require clean and soft water for longer life and better efficiency. However, the source of boiler feed water is generally a river or lake which may contain suspended and dissolved impurities, dissolved gases etc. Therefore, it is very important that water is first purified and softened by chemical treatment and then delivered to the boiler

The water from the source of supply is stored in storage tanks. The suspended impurities are removed through sedimentation, coagulation and filtration. Dissolved gases etc, are removed by aeration and degasification. The water is then 'softened' by removing temporary and permanent hardness though different chemical processes. The pure and soft water thus available is fed to the boiler for steam generation.

Nuclear based thermal power stations

Composition of an atomic nucleus

A matter is said to be composed of small particles called atoms and the atom itself is composed protons, neutrons and electrons, arranged in a particular fashion. The centre of the atom consists of a very dense nucleus formed by protons and neutrons. Around the nucleus the electrons revolve in orbit. The system so formed is similar to that of planetary system as shown in Fig 2. The radius of the nucleus is about 10^{-12} cm. While that of electron orbit is about 10^{-5} cm.

The important properties of the atomic structure are:

The mass of proton and neutrons is almost same while the mass of each electron is 1/1840 times that of a proton or neutron which shows that the mass of an atom is only due to the nucleus. From avogadro's hypothesis, the number of atoms in a gram atom is 6.03×10^{23} (actually its mass is 1.008 gm)

REPRESENTATION OF SPINNING OF ELECTRONS
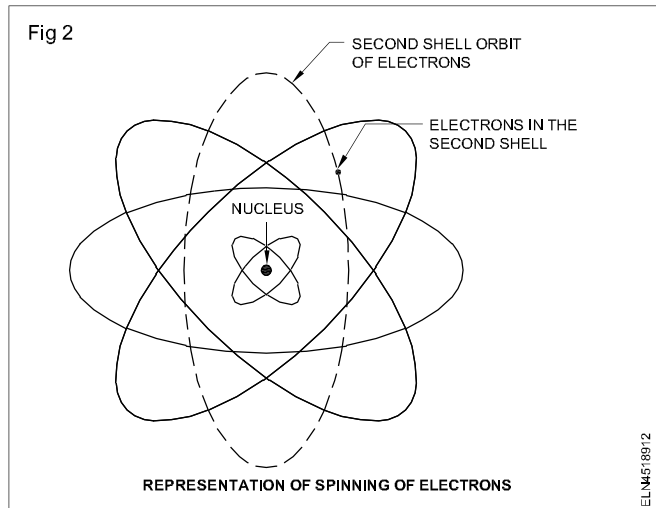
$$= \frac{1.008}{6.03 \times 10^{23}}$$

$= 1.67 \times 10^{-24}$ gm $= 1.67 \times 10^{-27}$ kg................ (1)

The mass of 1 electron

$$= \frac{1.67 \times 10^{-27}}{1840} = 9.10 \times 10^{-31} \text{ kg}.................(2)$$

It has been practically observed that, to deposit 1 molecule gram of hydrogen 96,493.7 coulombs of electricity are required.

So, charge on each electron

$$= \frac{96.493.7}{6.03 \times 10^{23}}$$

$= 1.602 \times 10^{-19}$ coulombs .... (3)

The charge of proton is the same as that of electron

$= 1.602 \times 10^{-19}$ coulombs .... (4)

The charge and mass of an electron, proton and neutron can be summarized as.

Name of atomic ingredient	Electric charge in coulomb	Mass in kilogram	Mass in atomic mass unit (a.m.u)*
1. Electron	-1.602×10^{-19}	9.10×10^{-21}	0.000, 548
2. Proton	$+1.602 \times 10^{-19}$	1.67×10^{-27}	1.00,758
3. Neutron	0	1.67×10^{-27}	1.00,898

*1 a.m.u = 1.6597×10^{-19} kg.

Atomic number and mass number: The chemical properties of an atom depend on the number of protons present in the nucleus.

The atomic number of an atom is defined as the number of protons present in the nucleus of an atom and is represented as Z.

Let, N be equal to number of neutrons in the nucleus. The mass number (A) is given as.

A= Z +N

The advantage of atomic number and mass number is that this represents an atom uniquely. Thus, for example sodium atom is represented as $_{12}Na^{23}$, where, the prefix represents the atomic number (Z) and suffix represents mass number (A), i .e 12 is atomic number and 23 is mass number.

The number of neutron (N) presents in the atom can be determined by

N = A - Z = 23-12

= 11

The atomic number, mass and number of neutrons for some elements are listed in Table 1.

Table 1

Element	Symbol	Atomic number = Z	Mass No =A	Neutrons A - Z
Hydrogen	$_1H_1$	1	1	0
Helium	$_2He_4$	2	4	2
Oxygen	$_8O_{16}$	8	16	8
Uranium	$_{92}U_{238}$	92	238	146

Nuclear power station

A generating station in which nuclear energy is converted into electrical energy is known as a Nuclear power station.

In nuclear power station, heavy elements such as Uranium (U^{235}) or Thorium (Th^{232}) are subjected to nuclear fission in a special apparatus known as a reactor. The heat energy thus released is utilized in raising steam at high temperature and pressure. The steam runs into the steam turbine which converts steam energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy.

The most important features of a nuclear power station is that huge amount of electrical energy can be produced from a relatively small amount of nuclear fuel as compared to other conventional types of power station. Although the extracting of the nuclear fuels (i.e Uranium and Thorium) is difficult and expensive, yet the total energy content are considerably higher than those of conventional fuel, viz. coal, and gas.

Advantages

i The amount of fuel required is quite small. Therefore, there is a considerable saving in the cost of fuel transportation.

ii A nuclear power plant requires less space as compared to any other type of the same size.

iii It has low running charges as a small amount of fuel is used for producing bulk electrical energy.

iv This type of plant is very economical for producing bulk electric power.

v It can be located near the load centers because it does not requires large quantities of water and need not be near coal mines. Therefore, the cost of primary distribution is reduced.

vi There are large deposits of nuclear fuels available all over the world. Therefore, such plants can ensure continued supply of electrical energy for thousands of years.

vii It ensures reliability of operation.

Disadvantages

i The fuel used is expensive and is difficult to extract.

ii The capital cost on a nuclear plant is very high as compared to other types of plants.

iii The erection and commissioning of the requires greater technical know - how.

iv The fission by products are generally radio - active and may cause a dangerous amount of radioactive pollution.

v Maintenance charges are high due to lack of standardization. Moreover, high salaries of specially trained personnel employed to handle the plant further raise the cost.

vi Nuclear power plants are not well suited for varying loads as the reactor does not respond to the load fluctuations efficiently.

vii The disposal of the waste, which are radioactive, is a big problem. They should either be disposed off in a deep trench or in the sea away from the sea- shore.

Schematic arrangement of nuclear power station

The schematic arrangement of a nuclear power station is in Fig 3. The whole arrangement can be divided into the following main stages.

i Nuclear reactor

ii Heat exchanger

iii Steam turbine

iv Alternator

i **Nuclear reactor :** It is an apparatus in which nuclear fuel (U^{235}) is subjected to nuclear fission. It controls the chain reaction that starts once the fission is done. If the chain reaction is not controlled, the result will be an

explosion due to the fast increase in the energy released.

A nuclear reactor is a cylindrical stout pressure vessel and houses fuel rods of Uranium, moderator and control rods (Fig 4).

The fuel rods constitute the fission material and release huge amount of energy when bombarded with slow moving neutrons. The moderator consists of graphite rods which enclose the fuel rods. The moderator slows down the neutrons before they bombard the fuel rods. The control rods are of cadmium and are inserted into the reactor. Cadmium is strong neutron absorber and thus regulates the supply of neutrons for fission.

When the control rods are pushed in deep enough, they absorb most of fission neutrons and hence few are available for chain reaction which, therefore, stops. However, as they are being withdrawn, more and more of these fission neutrons cause fission and hence the intensity of chain reaction (or heat produced) is increased. Therefore, by pulling out the control rods, power of the nuclear reactor is increased whereas by pushing them in, it is reduced.

In actual practice, the lowering or raising of central rods is accomplished automatically according to the requirement of rod. The heat produced in the reactor is removed by the coolant, generally in a sodium metal. The coolant carries the heat to the heat exchanger.

Fig 3

SCHEMATIC ARRANGEMENT OF NUCLEAR POWER PLANT
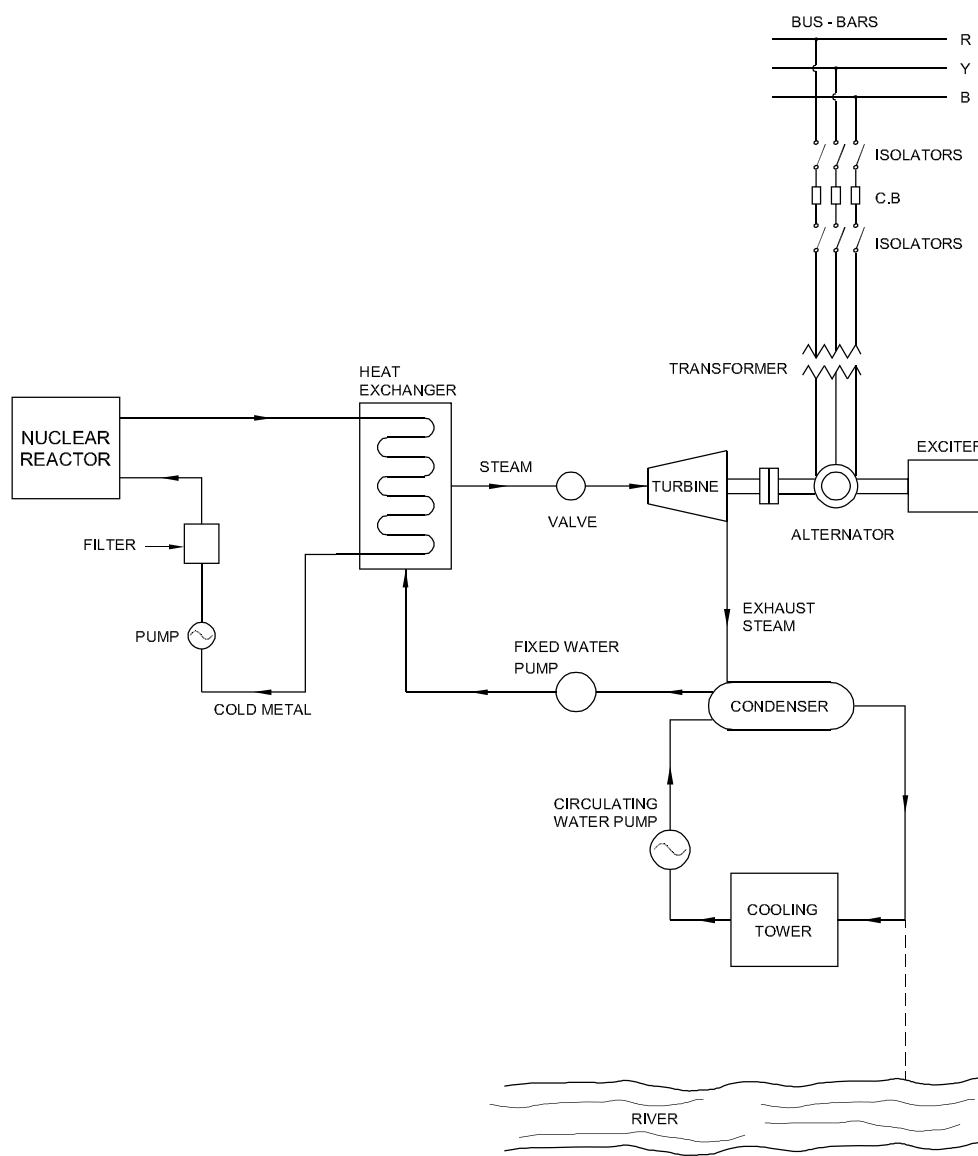
ii Heat exchanger : The coolant gives up heat to the heat exchanger which is utilized in raising the steam. After giving up heat, the coolant is again fed to the reactor.

iii Steam turbine : The steam produced in the heat exchanger is led to the steam turbine through a valve. After doing a useful work in the turbine, the steam is exhausted to condenser. The condenser condenses the steam which is fed to the heat exchanger through feed water pump.

Fig 4

CONTROL ROD

COOLANT

STEAM

WATER

URANIUM

COOLANT
CIRCULATING
PUMP

PRESSURE
VESSEL

MODERATOR(GRAPHITE)

NUCLEAR REACTOR
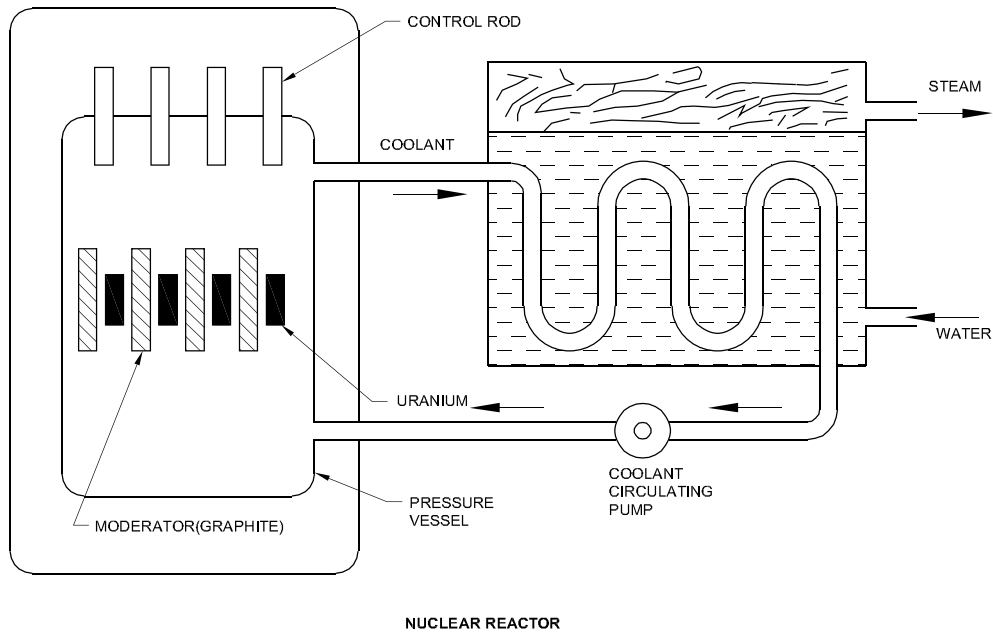
iv Alternator : The steam turbine drives the alternator which converts mechanical energy into electrical energy. The output from the alternator is delivered to the bus- bars through transformer, circuit breaker and isolators.

Selection of site for nuclear power station

The following points should be kept in view while selecting the site for a nuclear power station.

i   Availability of water : As sufficient water is required for cooling purposes, therefore, the plant site should be located where ample quantity of water is available e.g. across a river or by sea - side.

ii Disposal of waste : The waste produced by fission in a nuclear power station is generally radioactive which must be disposed off properly to avoid health hazards. The waste should either be buried in a deep trench or disposed off in the sea quite away from the sea shore. Therefore, the site selected for such a plant should have adequate arrangement for the disposal of radioactive waste.

iii Distance from populated areas : The site selected for a nuclear power station should be quite away from the populated areas as there is a danger of presence of radio - activity in the atmosphere near the plant.

However, as the precautionary measure, a dome is used in the plant which does not allow the radioactivity to spread by wind or underground waterways.

iv Transportation facilities : The site selected for a nuclear power should have adequate facilities in order to transport the heavy equipment during erection and to facilitate the movement of the workers employed in the plant.

From the above mentioned factors it becomes apparent that idel choice for a nuclear power station would be near

sea or river and away from thickly populated areas.

Nuclear reactors

Nuclear reactors may be classified on the following basis.

A) On the basis of neutron energy

1   Thermal reactors

2   Fast breeder reactors

B) On the basis of fuel used

1   Natural uranium

2   Enriched uranium

C) On the basis of moderator used

1   Graphite reactors

2   Beryllium reactors

D) On the basis of coolant used

1   Water cooled reactors (ordinary or heavy)

i   Boiling water reactor

ii Pressurized water reactor

iii Heavy water cooled and moderated reactor

2   Gas cooled reactors

3   Liquid metal cooled reactors

4   Organic liquid cooled reactors

E) On the basis of type of core used

1   Homogenous reactors

2   Heterogeneous reactors

Boiling water reactor (BWR)

In this reactor fuel used is enriched uranium. Water is used as both the moderator and coolant. As is clear from its name it utilizes light water as a coolant. In this case the

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steam is generated in the reactor itself. Feed water enters the reactor tank at the bottom and takes up the heat generated due to the fission of fuel and gets converted into steam.

Steam leaves the reactor at the top and flows into the turbine. Uranium fuel elements are arranged in a particular lattice form inside the pressure vessel containing water. Feed water passes through fuel elements in the core as coolant and also as moderator. Fig 5 shows a boiling water reactor.

Advantages

1 Heat exchanger circuit is eliminated and as a result there is reduction in cost and gain in thermal efficiency (30% to 20% for a pressure water reactor (PWR)).

2 As water is allowed to boil inside the reactor the pressure inside the reactor vessel is considerably lower than in the case of a PWR. As a result the reactor vessel can be made much lighter reducing its cost considerably.

3 The BWR cycle is more efficient than the PWR cycle since for a given containment pressure the outlet temperature of steam is appreciably higher in a BWR.

4 The metal surface temperature is lower than in the case of a PWR since boiling of water is inside the reactor.

5 A BWR is more suitable than a PWR, (In fact BWR is commonly known as a self - controlled reactor)

Disadvantages

1 There is a possibility of radio - active contamination in the turbine mechanism should there occur any failure of fuel elements. Therefore more elaborate safety measures are needed. This increases the cost.

Fig 5

BOILING WATER REACTOR (BWR)
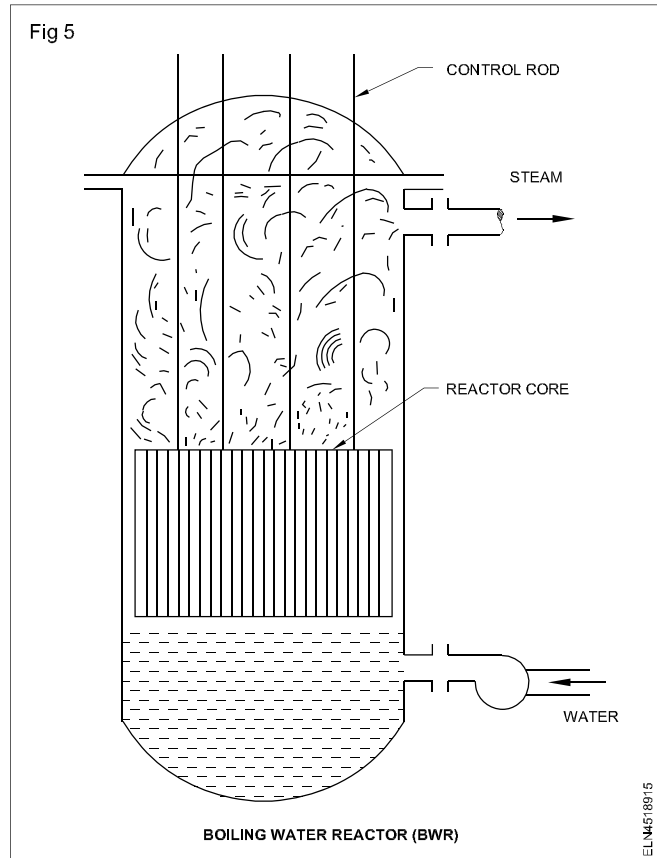
2 There is wastage of steam resulting in lowering of thermal efficiency on part load operation.

Pressurized Water Reactor (PWR)

A pressurized water reactor is in Fig 6. The line arrangement of such a reactor with heat exchanger in circuit is in Fig 7.

Fig 6

A PRESSURISED WATER REACTOR (PWR)

Fig 7

LINE ARRANGEMENT OF A PRESSURISED WATER REACTOR
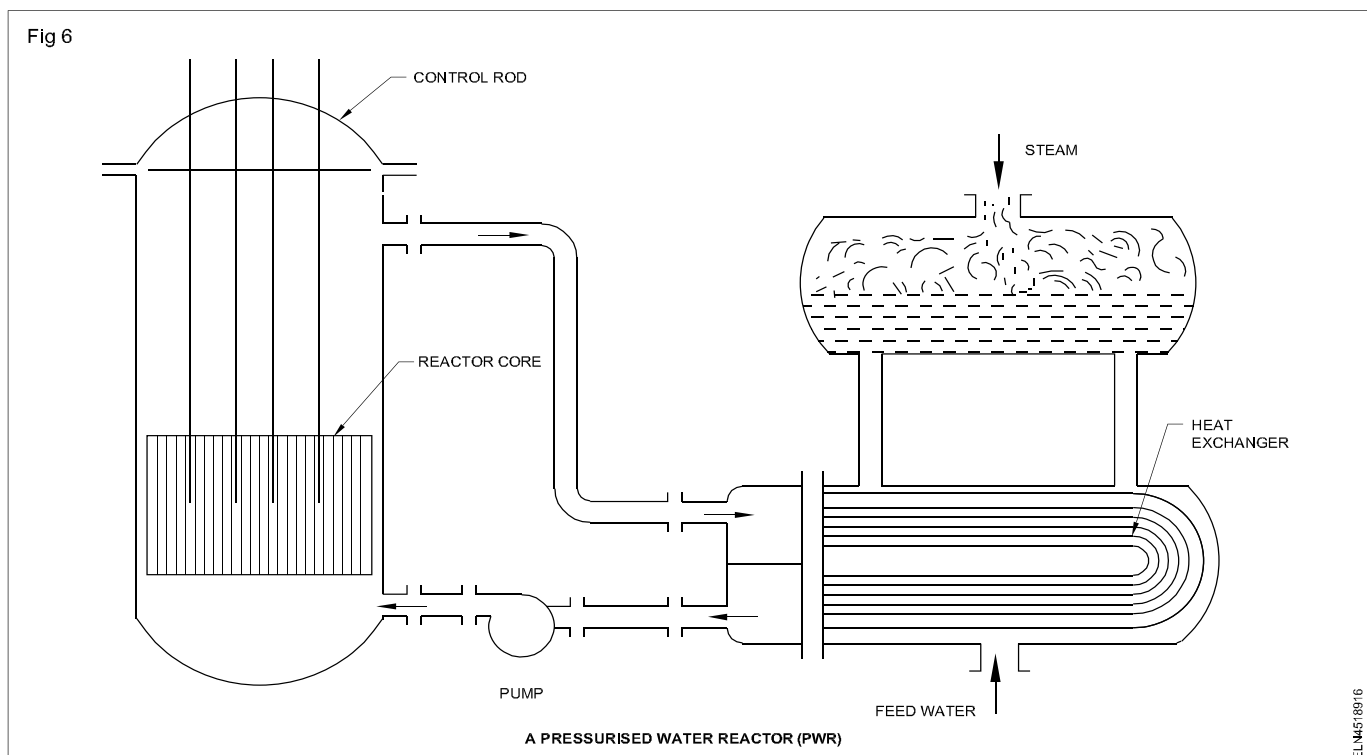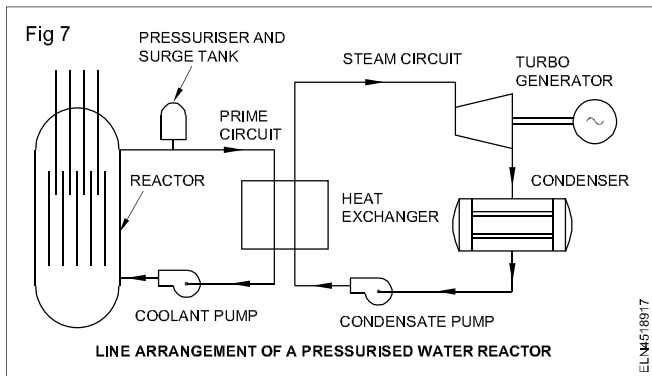
The fuel used is enriched uranium clad with stainless steel or zirconium alloy and water under pressure is used as both moderator and coolant. This type of reactor is designed to prevent the boiling of the water coolant in the uranium core. A pump circulates water at high pressure (as high as 140 Kg/cm^2) round the core so that water in liquid state absorbs heat from the uranium and transfer it to the secondary loop-the boiler. The boiler has a heat exchanger and a steam drum.

A pressuriser and surge tank tapped into the pipe loop maintains constant pressure in the water system throughout the load range. An electric heating coil in the pressuriser boils the water to form steam which is collected in the dome; this steam pressurizes the entire coolant circuit. Water spray is used to condense the steam when pressure is desired to be reduced.

Since water is passing through the reactor becomes radio - active the entire primary circuit including heat exchanger has to be shielded.

Advantages

1   A PWR is relatively compact in size compared with other types.

2   There is a possibility of breeding plutonium by providing a blanket of U-238.

3   The reactor has a high power density.

4   Due to use of heat exchanger containment of fission products is possible.

5   An inexpensive substance (light water) can be used as moderator - cum-coolant-cum-refractor.

6   The reactor responds to supply more power when the load increases. (The positive power demand co-efficient makes this almost automatic)

Disadvantages

1   The moderator remains under high pressure; a strong pressure vessel is required.

2   Expensive cladding material is required to prevent corrosion.

3   There is heat loss due to use of heat exchanger.

4   In comparison to other types more elaborate safety devices are required.

5   The reactor lacks flexibility; this requires the reactor to be shut down before recharging and there is difficulty in fuel element design and fabrication.

6   The thermal efficiency of a PWR is as low as 20%

Less compared with that required for PWRs and BWRs. Amongst disadvantages are : the extremely high cost of heavy water, problem of leakage and very high standard of design etc.

Nuclear fission and fusion

Nuclear fission : When an uranium nucleus is bombarded with a slow moving neutron, it exploded into two nearly equal fragments of Barium and Krypton.

The process of breaking up of the nucleus of a heavy atom into two fragments with the release of large amount of energy is known as fission. The fission is accompanied by the release of three neutrons and energy in the form of γ-rays.

Fig 8 shows that the compound nucleus undergoes distortion due to the excitation energy to attain the shape of a dumb-bell and finally splits up into fission products Ba^{141} and Kr^{92} with the release of three neutrons.

Fig 8
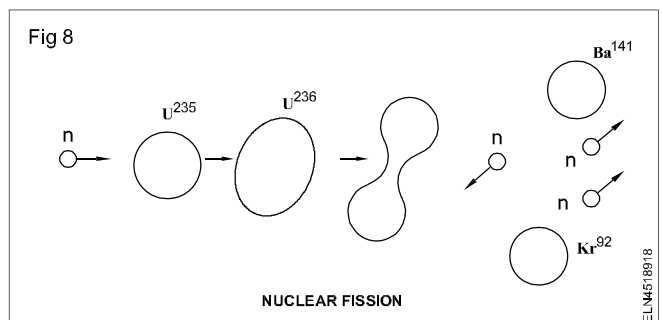
NUCLEAR FISSION

It was observed that Barium and krypton were not the only products of fission, the isotopes of different elements in the atomic number range from 34 to 58 were also obtained as the fission products.

Chain reaction

The process of nuclear fission usually results in the emission of two or three free neutrons per fission besides the other fission fragments.

When $_{92}U^{235}$ nucleus splits up, it generally release three neutrons. One of the neutrons may escape without hitting any other uranium nucleus and thus get lost. The other two may strike against other fissionable nuclei to produce further fission, accompanied by the release of still more neutrons and so on. Thus more than one neutron per fission is produced on the average.

The number of fissions taking place at each successive stage goes on increasing at a rapid rate, giving rise to what is called chain reaction. A chain reaction can be set up only if the mass of the fissionable material is greater than a critical mass.

Hydel power plants

Objectives: At the end of this lesson you shall be able to
• **state the types of hydro- electric power station**
• **state the advantage & disadvantage of hydro electric power station over thermal power station**
• **list out the reason for selecting the site of a hydro electric power station**
• **explain the schematic arrangement of hydro electric power station**
• **state the turbines used in hydro electric power station with suitable reasons**
• **state the classification of hydro electric power station.**

Hydro - electric power stations

A generating station which utilizes the potential energy of water at a high level for the generation of electrical energy is known as "Hydro-electric power station".

A basic model of a H.E.P generation is illustrated in Fig 1 is known as hydro - electric power station.
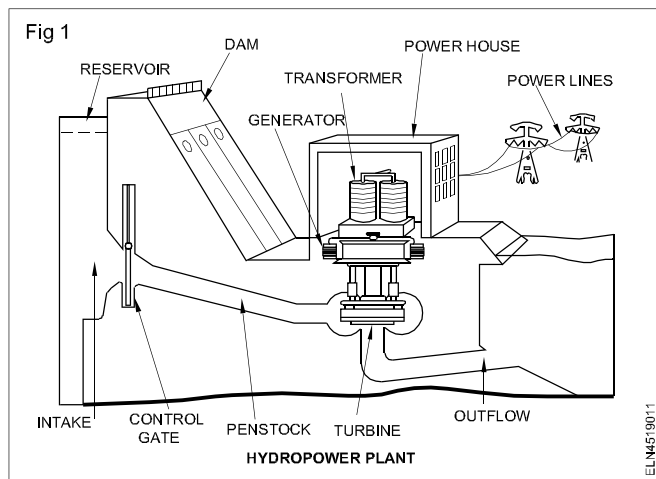
Hydro - electric power stations are generally located in hilly areas where dams can be built conveniently and large water reservoirs can be obtained. From the dam, water is led to a water turbine. The water turbine captures the energy in the falling water and changes the hydraulic energy (i.e product of head and flow of water) into mechanical energy at the turbine shaft.

The turbine drives the alternator which converts mechanical energy into electrical energy. Hydro electric power stations are becoming very popular because the reserves of fuels (i.e coal and oil) are depleting day by day.

Advantages

i   It requires no fuel as water is used for the generation of electrical energy

ii   It is quite neat and clean as no smoke or ash is produced

iii It requires very small running charges because water is the source of energy which is available free cost.

iv   It is comparatively simple in construction and requires less maintenance.

v   It does not requires a long starting time like a steam power station. In fact, such plants can be put into service instantly.

vi   It is robust and has a longer life.

vii Such plants serve many purposes. In addition to the generation of electrical energy, they also help in irrigation and controlling floods.

viii Although such plants require the attention of highly skilled persons at the time of construction, yet for operation, a few experienced persons may do the job well.

Disadvantages

i   It involves high capital cost due to construction of dam

ii   There is uncertainly about the availability of huge amount of water due to dependence on weather conditions.

iii Skilled and experienced hands are required to build the plant

iv   It requires high cost of transmission lines as the plant is located in hilly areas which are away from the consumers.

Choice of site for hydro - electric power stations

The following points should be taken into account while selecting the site for a hydro - electric power station

i   **Availability of water :** Since the primary requirement of a hydro - electric power stations is the availability of huge quantity of water, such plants should be built at a place (e.g. river, canal) where adequate water is available at the good head.

ii   **Storage of water :** There are wide variations in water supply from a river or canal during the year. This makes it necessary to store water by constructing a dam in order to ensure the generation of power throughout the year.

iii **Cost and type of land :** The land for the construction of the plant should be available at a reasonable price. Further, the bearing capacity of the ground should be adequate to withstands the weight of heavy equipment to be installed.

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vi Transportation facilities : The site selected for hydro - electric plant should be accessible by rail and road so that necessary equipment and machinery could be easily transported

Schematic arrangement of hydro - electric power station : (Fig 2)

SCHEMATIC ARRANGEMENT OF A HYDRO - ELECTRIC PLANT
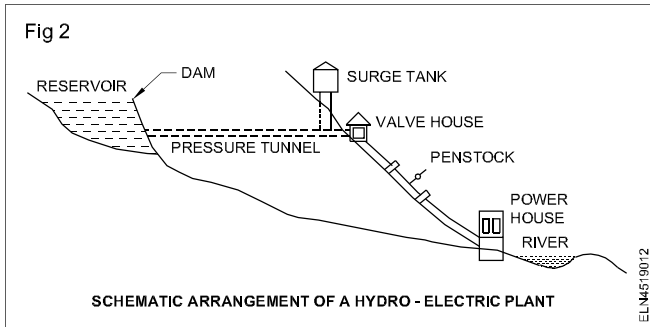
The schematic arrangement of a modern hydro - electric plant is shown in Fig. 2. The dam is constructed across a river or lake and water from the catchment area collects at the back of the dam to form a reservoir. A pressure tunnel is taken off from the reservoir and water brought to the valve house at the start of the Penstock.

The valve house contains main sluice valves and automatic isolating valves. The former controls the water flow to the power house and the latter cuts of supply of water flow to the power house when the penstock bursts. From the valve house, water is taken to water turbine through a huge steel pipe known as penstock . The water turbine converts hydraulic energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy.

Constituents of Hydro - Electric Plant

The constituents of hydro - electric plant are (1) hydraulic structures (2) water turbines and (3) electrical equipment.

1 Hydraulic Structures

Hydraulic structures in a hydro electric power station include dam, spillways, headworks, surge tank, penstock and accessory works.

i Dam : A dam is a higher barrier which stores water and creates water head. Dams are built of concrete or stone masonry, earth or rock fill. The type and arrangement depends upon the topography of the site. The type of dam also depends upon the foundation conditions, local materials and transportation available, occurrence of earthquakes and other hazards.

ii Spillways : There are times when the river flow exceeds the storage capacity of the reservoir. Such a situation arises during heavy rainfall in the catchment area. In order to discharge the surplus water from the storage reservoir into the river on the down - stream side of the dam, spillways are used.

iii Headworks : The headworks consists of the diversion structures at the head of an intake. They generally include booms and racks for diverting floating debris, sluices for by - passing the debris and sediments and valves for controlling the flow of water to the turbine. The flow of water into and through head works should be as smooth as possible to avoid the head loss and cavitation. For this purpose, it is necessary to avoid sharp corners and abrupt contractions or enlargements.

iv Surge tank : Open conduits which leading the water to the turbine require no protection. However, when closed conduits are used, protection becomes necessary to limit the abnormal pressure in the conduit. For this reason, closed conduits are always provided with a surge tank. a surge tank is a small reservoir or tank (open at the top) in which water level rises or fails to reduce the pressures swings in the conduit.

A surge tank is located near the beginning of the conduit. When the turbine is running at a steady load, there are no surges in the flow of water through the conduit is just sufficient to meet the turbine requirements. However, when the load on the turbine decreases, the governor closes the gates of turbine, reducing water supply to the turbine.

The excess water at the lower end of the conduit rushes back to the surge tank and increases its water level. Thus the conduit is prevented from bursting. On the other hand, when load on the turbine increases, additional water is drawn from the surge tank to meet the increased load requirement. Hence, a surge tank overcomes the abnormal pressure in the conduit when load on the turbine falls and acts a reservoir during increase of load on the turbine.

(v) Penstocks : Penstocks are open or closed conduits which carry water to the turbines. They are generally made of reinforced concrete or steel. The thickness of the Penstock increases with the head or working pressure

Various devices such as automatic butterfly valve, air valve and surge tank are provided for the protection of penstocks. Automatic butterfly valve shuts off water flow through the penstocks promptly of its ruptures. Air valve maintains the air pressure inside the penstock equal to outside atmospheric pressure.

When water run out of a penstock faster than it enters, a vacuum is created which may cause the penstocks to collapse. Under such situations, air valve opens and admits air in the penstock to maintain inside air pressure equal to the outside air pressure. A typical penstock protective device is in Fig 3.

(vi) Tail race : The tail race is the channel which carries water (known as tail water) away from the power house after it has passed through the turbine. It may be the natural stream channel or a specially excavated channel entering the natural stream at some point down stream from the power house. The water surface in the tail race is known as tail race level or simply the tail race.

Fig 3

VARIOUS PENSTOCK PROTECTION DEVICE
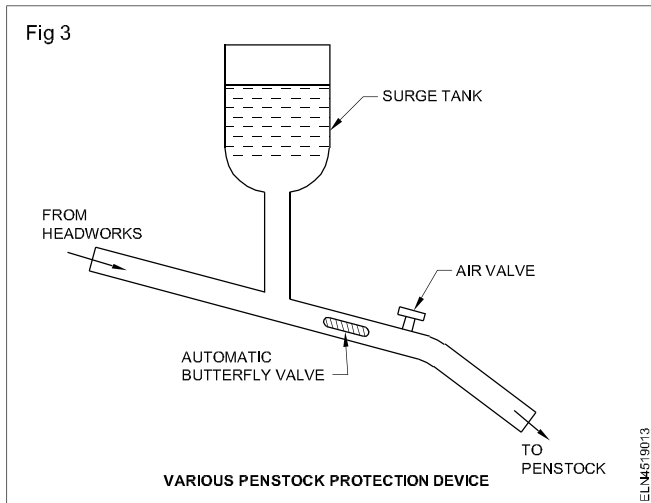
(vii) Draft tube : In the case of a reaction turbine there is a pressure difference existing between water in the turbine and atmosphere. Therefore this type turbine must be completely enclosed. Accordingly it is necessary to connect the turbine outlet by means of a pipe or a passage of gradually increasing cross sectional area up to tail - race level.

A draft tube has two important purposes to serve.

1   It permits a negative or suction head to be established at the runner exit thus making it possible to install the turbine above the tail race level without loss of head.

2   It converts a large proportion of the velocity energy rejected from the runner into useful pressure head i.e it acts as a recuperator of pressure energy.

2   Water turbine

Water turbines are used to convert the energy of falling water into mechanical energy. The principal types of water turbines are :

i   Impulse turbines

ii   Reaction turbines

i   Impulse turbines : Such turbines are used for high heads. In an impulse turbines, the entire pressure of water is converted into kinetic energy in a nozzle and the velocity of the jet drives the wheel i.e, pelton wheel as in Fig 4. It consists of a wheel fitted with elliptical buckets along it periphery. The force of water jet striking the bucket on the wheel drives the turbine. The quantity of water jet falling on the turbine is controlled by means of needle or spear (not shown in the figure) placed in the tip of the nozzle.

The movement of the needle is controlled by the governor. If the load on the turbine decreases the governor pushes the needle into the nozzle, there reducing the quantity of water striking the bucket. Reverse action takes place if the load on the turbine increases.

ii   Reaction turbines : Reaction turbines are used for low and medium heads. In a reaction turbine water enters the runner partly with pressure energy and

partly with velocity head. The important types of reaction turbine are.

Fig 4

PELTON WHEEL
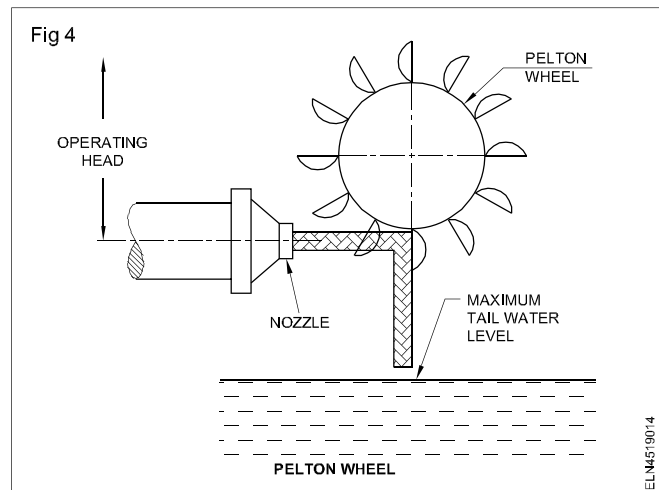
a.   Francis turbines

b.   Kaplan turbines

A fancies turbine is used for low to medium heads. It consists of an outer ring of stationary guide blades for to the turbine casing and an inner ring of rotating blade forming the runner. The guide blades control the flow water to the turbine. Water flows radically inwards and changes to a downward direction while passing there the runner. As the water passes over the rotating blade of the runner, both pressures and velocity of water reduced. This causes a reaction force which drive turbine.

A Kaplan turbine is used for low heads and large quantities of water. It is similar to Francis turbine except that the runner of Kaplan turbine receives water axially. Water radially inwards through regulating gates all round sides, changing direction in the runner to axial flow causes a reaction force which drives the turbine.

3   Electrical equipment

The electrical equipment of a hydro - electric power includes alternators, transformers, circuit breaker and switching and protective devices.

Types of hydro - electric plants

There are three different methods of classifying the electric plants. The classification may be based on,

a   Quantity of water available

b   Available head

c   Nature of load

Classification of Hydro - electric plants according to quantity of water available.

According to this classification, the plants may be divided into.

i   Run - off river plants without pondage

ii   Run - off river plants with pondage

iii Reservoir plants

i   Run off river plants without pondage

As the name indicates this type of plant does not store water. The plant uses water as it comes. The plant can use water only as and when available.

ii   Run- off river plants with pondage

Usefulness of a run - off river plant is increased by pondage. Pondage permits storage of water during the off - peak periods and use of this water during the peak periods.

iii Reservoir plants

Water is stored behind the dam and is available to the plant with control as required. Such a plant has better capacity and can be used efficiently throughout the year.

Classification of hydro - electric plants according to available head

Hydro - electric plants may be classified into high - head, medium - head and low head plants. A plant may be classified as high - head if operating on a head above 300 meters. Low - head plants work under heads below 30 metres. Medium - head plants are those lying between the above two classes.

In the case of high - head plants water in due to rains or melting of snow is stored at high elevation. A low - head plant stores water by the construction of a dam across a river and the power plant is installed near the base of the dam of the down - stream side. The medium - head plant is similar to the low - head plant but works on a head of about 30 to 300 m.

Classification of Hydro- electric plants according to nature of load

Hydro - electric plants may be classified in to base load peak load and pumped storage plants for peak load.

Visiting of electrical substation

Objectives: At the end of this lesson you shall be able to
- **state the initial preparatory work before commencing the visit**
- **explain the individual trainees main areas and its importance for preparation**
- **list out the supporting materials to carry for visit**
- **prepare a list of do's and dont's during visit.**

Introduction

A industrial visit is a very important step to tap actual working environments. During practical exercises practicing in the lab or workshop never provides actual working condition because it is a part of structure training planned to complete within a stipulated time and a assessment at later stage.

Initial preparatory work

The trainees should be in a position to interact well at the actual site. Every industry technical experts execute the work on a team and produce better results. The technician or operator concerned will be able to give a clear idea of working or procedure of a particular work and you have to extract it fully

To understand the whole process from the concerned technician or operator, you must have a sound knowledge of that particular abject or process. You should prepare well to meet the challenge whenever you go industrial visit in a factory or work place.

Preparation areas and its importance

If the process is complicated or multi level procedure involved; in that case trainees should be made small batches to interact or involve the whole process. In such cases each batch should be formed in advance and decided the section or part to be interacted. Finally all the batches together to make the end result.

Supporting materials

When the visit is at generating stations, have must collect the following:

1 Installed capacity of the plant.

2 Maximum load demand **.**

3 Load factor .

4 Distance of the nearest sub station.

5   Total number of alternators installed and its working conditions.

6   Details of the fuel used (Coal- Nuclear - Its availability, quality etc) and the daily expenditure for fuel.

7 Solutions to meet extra fuel in case of environmental emergency.

8 Location Map of the plant and its surroundings.

9 Gather maximum information regarding generation and distribution techniques other than guided or studied.

10 Maximum hazardous Area - PPE facility Emergency root in case of emergency.

Do's & Dont's

Do's

1 Wear uniform with name badge.

2 Ensure the protective gadgets are available otherwise carry them.

3 Follow the safety norms imposed in the particular areas, listen the instruction carefully.

4 Carry materials to record your findings and assessments to make then and their.

5 Follow strict discipline and punctuality .

6 Obey all the instructions and rules.

7 Walk in the prescribed areas only.

Dont's

1 Avoid wearing loose clothes and ornaments.

2 Not to carry any bag or attachments.

3 Do not cross-over any prohibited areas .

4 Do not operate, touch or play with any part or machine you pass over.

5 Do not sit or learn over any machine or place you come accross.

6 Do not shout or make any unusual noices when the visit is in progress or inside the factory.

7 Do not involve any kind of horse play at the time of visiting various sections, areas.

8 Do not avoid or neglect any instruction passed on you at any time.

9 Do not indulge any horse play or encourage others to do. The person responsible for leading the visit has to arrange the programme well in advance and informs all concerned. Taking permission to visit and arrange transportation to reach in time. Arrangement may also be done to carry or provide hospitality is also the responsibility of the person concerned.

Fig 1 shows a typical single line layout diagram of a transmission and distribution substation.

Fig 1

SINGLE LINE DIAGRAM
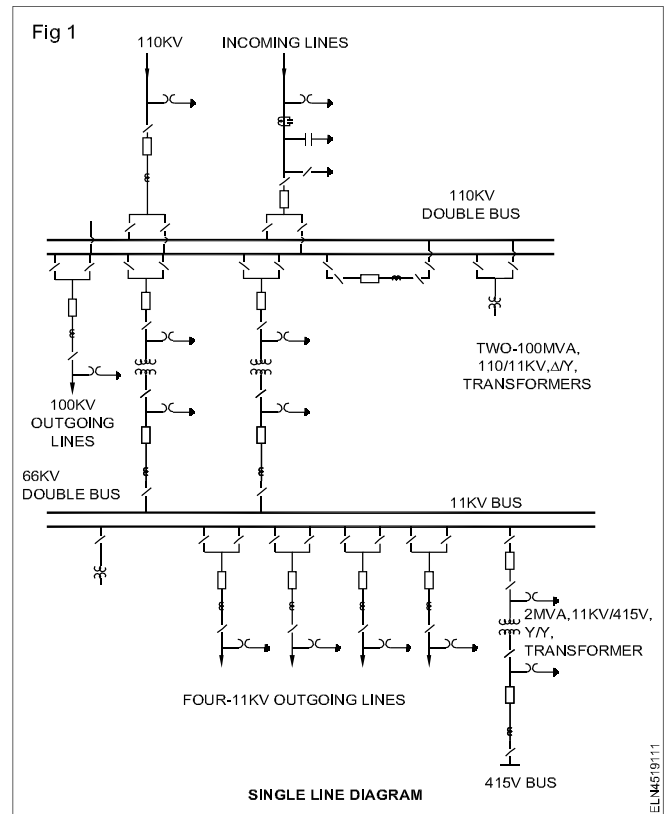
Electrical substations

Objectives: At the end of this lesson you shall be able to
• **state the functions and purpose of electrical substations**
• **classify the different types of substation**
• **list out the equipment and components used in substation**
• **state the single line diagram of electrical substation with symbols.**

Substations

Electric power is produced at the power generating stations, which are generally located far away from the load centers. Between the power generating station and consumers a number of transformations and switching stations are required. These are generally known as substations.

Substations are important part of power system and form a link between generating stations, transmission systems and distribution systems. It is an assembly of electrical components such as bus-bars, switch gear apparatus, power transformers etc.

Function

Their main functions are to receive power transmitted at high voltage from the generating stations and reduce voltage for switching operations of transmission lines. Substations are provided with safety devices to disconnect equipment or circuit at the time of faults.

Substations are the convenient place for installing synchronous condensers for the purpose of improving power factor and it provides facilities for making measurements to monitor the operation of the various parts of the power system.

Classification of substation

The substations may be classified in according to service requirements and constructional features. According to service requirements they are classified in to transformer substations, switching substations and converting substations.

1 **Transformer substations :** Majority of the substations in the power system are in this type. They are used to transform the power from one voltage level to another voltage level. Transformer is the main component in such substations. Transformer substations are further classified into step-up substations, primary grid substations, secondary substations and distribution substations.

a **Step - up substations :** These substations are usually located at the generating stations. Generating voltage of the order of 11KV needs to be stepped up to a primary transmission voltage level of the order of 220KV or 400KV.

b **Primary grid substations :** These substations are located at the end of primary transmission lines and the primary voltage is stepped down to suitable secondary voltages of the order of 66KV or 33KV.

c **Secondary substations :** The voltage is further stepped down to 11KV. Large consumers ar supplied with power at 11KV.

d **Distribution substations :** These substations are located near the consumer localities to supply power at 415V three phase or 240V single phase to the consumers.

2 **Switching substations :** These substations are meant for switching operations of power lines without transforming the voltage. Different connections are made between the various transmission lines.

3 **Converting substation :** Such substations are meant for either converting AC to DC or vice versa. Some are used to change the frequency from higher to lower or vice versa for industry utilizations.

According to constructional features substations are classified into indoor substations, outdoor substations, under ground substations and pole mounted substations.

1 **Indoor substations :** All equipment of the substation are installed within the station buildings.

2 **Outdoor substations :** All equipments such as transformers, circuit breakers, isolators, etc, are installed outdoors.

3 **Underground substations :** In thickly populated areas where the space is the major constraint, and cost of land is higher, under such situation the substations are laid underground.

4 **Pole mounted substations :** This is an outdoor substation with equipment installed overhead of a H pole or 4 pole structure.

The substations can also be classified in several ways including the following.

1 **Classification based on voltage levels :** eg. AC substation : EHV, HV, MV, LV : HVDC substation.

2 **Classification based on outdoor or indoor :** Outdoor substation is in open air. Indoor substation is inside a building.

3 **Classification based on configuration**

• Conventional air insulated outdoor substation or

• SF_6 Gas insulated substation (GIS)

• Composite substations having combination of the above two.

4 **Classification based on application**

• **Step up substation :** Associated with generating station as the generating voltage is low.

• **Primary Grid substation :** Created at suitable load centre along primary transmission lines. It receive the power from EHV lines at 400KV, 220 KV, 132KV and transform the voltage to 66KV, 33KV or 22KV (22KV is uncommon) to suit the local requirements in respect of both load and distance of ultimate consumers.

These are also referred to EHV substations.

• **Secondary substation :** Along secondary transmission line. It receive the power at 66/33KV which is stepped down usually to 11KV.

• **Distribution substation:** Created where the transmission line voltage is stepped down to supply voltage.

• **Bulk supply and industrial substation :** Similar to distribution substation but created separately for each consumer.

• **Mining substation :** Needs special design consideration because of extra precaution for safety needed in the operation of electric supply.

• **Mobile substation :** For emergency replacement of transformer etc.

• **Distribution substations :** It receive power at 11KV, 6.6 KV and step down to a volt suitable for LV distribution purposes, normally at 415 volts.

The parts, equipment and components installed in substation

Each substation has the following parts and equipment.

1 **Outdoor switchyard**

• Incoming lines

• Outgoing lines

• Busbar

• Transformers

• Bus post insulator & string insulators

• Substation equipment such as circuit-breakers, isolators, earthing switches, surge arresters, CTs, PTs neutral grounding equipment

• Station earthing system comprising ground mat, risers, auxiliary mat, earthing strips, earthing spikes & earth electrodes.

• Overhead earthwise shielding against lightning strokes.

• Galvanized steel structures for lower equipment supports.

• PLCC equipment including line trap, tuning unit, coupling capacitor, etc.

• Power cables

• Control cables for protection and control

• Road, cable trenches

• Station illumination system

2 **Main office building**

• Administrative building

• Conference room etc.

3 **6.6/11/22/33/66/132 KV switch gear LV**

• Indoor switch gear

4 Switchgear and control panel building

- Low voltage AC switchgear
- Control panels, protection panels

5 Battery room and DC distribution system

- DC battery system and charging equipment
- DC distribution system

6 Mechanical, electrical and other auxiliaries

- Fire fighting system
- D.G (Diesel Generator) set
- Oil purification system

An important function performed by a substation is switching, which is the connecting and disconnecting of transmission lines or other components to and from the system. A transmission line or other component may need to be de-energized for maintenance or for new construction, for adding or removing a transmission line or a transformer. All work to be performed, from routine testing to adding new substations, must be done while keeping the whole system running.

A fault may develop in a transmission line or any other component. Some examples of this a line is hit by lightning and develops an arc, or a tower is down by a high wind. The function of the substation is to isolate the faulty portion of the system within the shorted possible time.

Substation layout and their components

Fig 1 shows the typical substation layout. It consists of the following components and explained below.

Power transformer : Power transformers are used for generation and transmission network for stepping-up the voltage at generating station and stepping down the voltage for distribution. Auxiliary transformers supply power to auxiliary equipment at the substations. (Fig 2).

Current transformers (CT) : The lines in substations carry currents in the order of thousands of amperes. The measuring instruments are designed for low value of currents. Current transformers are connected in lines to supply measuring instruments and protective relays. For example a 100/1A CT is connected in a line carrying 100A, and then the secondary current of CT is 1A. (Fig 3).

Fig 1

| A | B |

A:PRIMARY POWER LINES' SIDE	4.POTENTIAL TRANSFORMER	7.CURRENT TRANSFORMER	B:SECONDARY POWER LINES' SIDE	9.MAIN TRANSFORMER
1.PRIMARY POWER LINES	5.DISCONNECT SWITCH	8.LIGHTNING ARRESTER	7.CURRENT TRANSFORMER	10.CONTROL BUILDING
2.GROUND WIRE	6.CIRCUIT BREAKER		8.LIGHTNING ARRESTER	11.SECURITY FENCE
3.OVERHEAD LINES				

SUB STATION LAYOUT

Fig 2

- OIL LEVEL INDICATOR
- DEHYDRATING BREATHER
- OIL FILTER PLUG
- CONSERVATOR
- CONTANCT THERMOMETER
- BUCHHOLZ RELAY
- RATING PLATE
- TERMINAL BOX
- CORRUGATED TANK
- WHEEL

Fig 3

HV TERMINAL

PORCELAIN INSULATOR

TANK

SECONDARY TERMINAL BOX

ELN4519123

Potential transformers (PT) : The lines in substations operate at high voltages. The measuring instruments are designed for low value of voltages. Potential transformers are connected in lines to supply measuring instruments and protective relays.

These transformers make the low voltage instruments suitable for the measurement of high voltages. For example a 11KV/110V PT is connected to a power line and the line voltage is 11KV then the secondary voltage will be 110V. (Fig 4).

Fig 4

ELN4519124

Circuit breaker (CB) : Circuit breakers are used for opening or closing a circuit under normal as well as abnormal (faulty) conditions. Different types of CBs which are generally used are oil circuit breaker, air - blast circuit breaker, vacuum circuit breaker and SF$_6$ circuit breaker.

Isolators for isolating switches : Isolators are employed in substations to isolate a part of the system for general maintenance. Isolator switches are operated only under load condition. They are provided on each side of every circuit breaker.

Lightning arresters (LA) : Ligtning arresters are the protective devices used for protection of equipment from lightning strokes. They are located at the starting of the substation and also provided near the transformer terminals.

Earth switch : It is a switch normally kept open and connected between earth and conductor. If the switch is closed it discharges the electric charge to ground, available on the uncharged line.

Wave trap : This equipment is installed in the substation for trapping the high frequency communication signals sent on the line from remote substation and diverting them to the telecom panel in the substation control room.

Coupling capacitor : A coupling capacitor is used in substations where communication is done by AC power line. It offers very low impedance to high frequency carrier signal and allows them to enter the line matching unit and blocks the low frequency signals.

Bus - bar : When number of lines operating at the same voltage levels needs to be connected electrically, bus - bars are used. Bus - bars are conductors made of copper or aluminium, with very low impedance and high current carrying capacity. Different types of bus - bar arrangements are single bus bar arrangements, single bus - bar with sectionalization, double bus- bar arrangements, sectionalized double bus - bar arrangement, double main and auxiliary bus - bar arrangement, breaker and a half scheme /1.5 Breaker scheme, and ring bus - bar scheme.

Single bus-bar arrangement : It consists of single bus - bar. Both incoming and outgoing lines are connected to the single bus - bar (Fig 5). The advantages of this arrangement are low maintenance, low initial cost and simple operation. The drawback of this arrangement is if any repair work is to be done on bus-bar, complete system get interrupted.

Fig 5

INCOMING LINES

BUS-BAR

OUTGOING LINES

SINGLE BUS-BAR ARRANGEMENT

ELN4519125
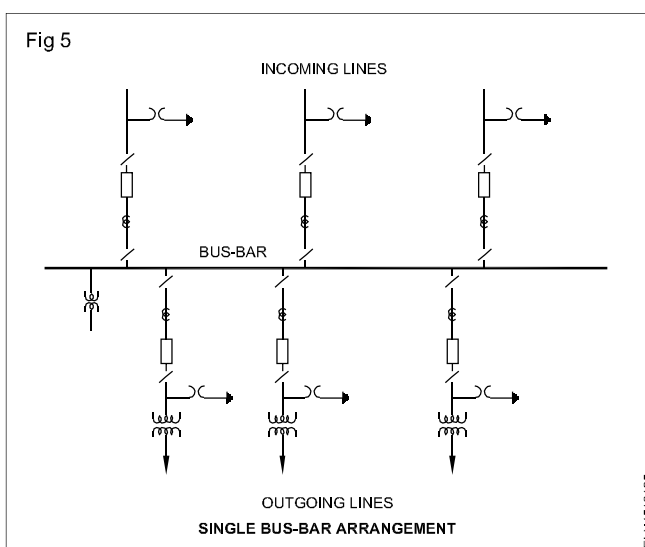
Single bus-bar with sectionalization: Single bus-bar is divided into sections. Any two sections are connected by circuit breaker and isolators. During fault or maintenance particular section can be de-energized. This eliminates complete shutdown of the system. Fig 6 shows that two incoming and two outgoing lines are connected bus section I and other two incoming and two outgoing lines are connected bus section. 2 by using bus coupler.

Double bus - bar arrangements : This arrangement is also known as duplicate bus-bar system. It consists of two bus -bars 'main' and a 'spare' of same capacity. Incoming line and outgoing lines can be connected to either bus by means of bus coupler breaker and isolators. Continuity of supply of the circuit can be maintained during maintenance of main bus-bar or fault occurring on it.

Single line diagram for substation

Any complex power system even though they are three phase circuits, can be represented by a single line diagram, showing various electrical components of power system and their interconnection. In single line representation of substation the electrical components such as power transformers, incoming and outgoing lines, bus- bars, switching and protecting equipments, are represented by **standard symbols** and their interconnections between them are shown by line. Single line diagrams are useful in planning a substation layout.

Fig 6

SINGLE BUS-BAR WITH BUS COUPLER SUBSTATION
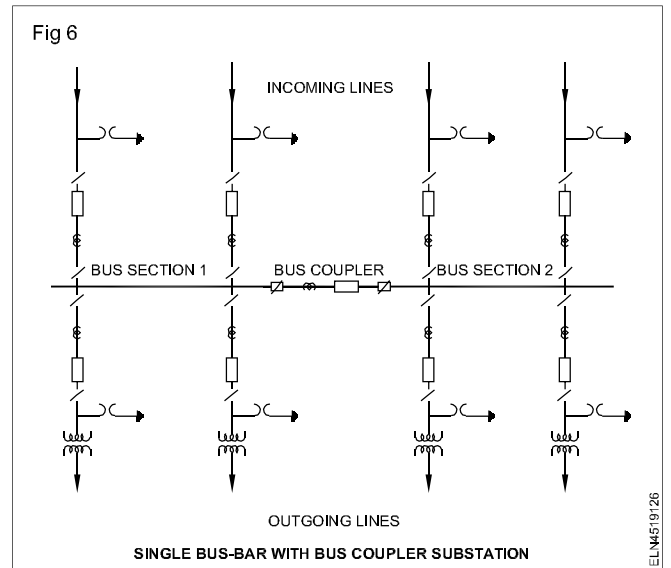
Standard symbols used for single line diagram of substation

Sl. No.	Electrical components	Symbosl
1	AC Generator	
2	Bus bar	
3	Power transformer - Two winding	
4	Three winding transformer	
5	Current transformer (CT)	
6	Voltage transformer or Potential transformer (PT)	
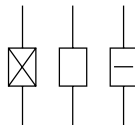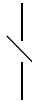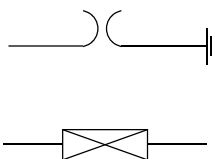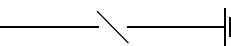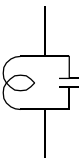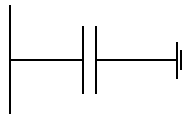
Sl. No.	Electrical components	Symbosl
7	Circuit Breaker (CB)	
8	Circuit breaker with isolator	
9	Isolator or Group Operating Switch (GOS)	
10	Lightning Arrester (LA)	
11	Earth Switch (ES)	
12	Wave or Line trap	
13	Coupling Capacitor (CC)	

Fig 7 & 8 show the examples (1 & 2) of substation layout drawings with all equipments represented by symbols.

Example 1

Draw the single line diagram of substation having the following equipment.

i Incoming lines : Two, 110KV

ii Outgoing lines : (a) One, 110KV (b) Four, 11KV

iii Transformers : (a) Two, 100MVA, 110/11KV, Δ/Y (b) one, 2MVA, 11KV/ 415V, Y/Y

iv) Bus-bars : 110KV- Duplicate bus - bar, 11KV single bus - bar shows the positions of CTs, PTs isolators, lightning and arresters, circuit breakers.

Fig 7 shows the single line diagram of the substation.

Example - 2

Draw the single line diagram of a pole mounted substation.

Fig 8 shows the typical single line diagram of pole mounted substation.

Fig 7

110KV   INCOMING LINES

110KV
DOUBLE BUS

100KV
OUTGOING
LINES

TWO-100MVA,
110/11KV,Δ/Y,
TRANSFORMERS

66KV
DOUBLE BUS

11KV BUS

2MVA,11KV/415V,
Y/Y,
TRANSFORMER

FOUR-11KV OUTGOING LINES

415V BUS

SINGLE LINE DIAGRAM

ELN4519127

Fig 8

11KV LINE

LA

ISOLATING
SWITCH

FUSE

11KV/415V

LT CB

DISTRIBUTION BOX

TO CONSUMERS

POLE MOUNTED SUBSTATION

ELN4620218

Electrical : Electrician (NSQF LEVEL - 5) - Related Theory for Exercise 4.5.191 & 4.5.192   183

Electrical power generation by non conventional methods

Objectives: At the end of this lesson you shall be able to
- **state the non - conventional energy**
- **explain the methods of generators power from, bio-gas, micro-hydel, tidal, magnetic hydro dynamic power generation**
- **list out the merits and demerits of non-conventional power generation.**

Non - conventional energy

Energy generated by using wind, tides, solar, geothermal heat and biomass including farm and animal waste is known as non-conventional energy. All these sources are renewable or inexhaustible and do not cause environmental pollution.

Mertis of non - conevential over conventional sources of energy

1 Provide more energy

2 Reduce security risk associated with the use of nuclear energy.

3 Reduce pollutants

4 Less running and maintenance cost

5 Never destroyed

6 Despite the high initial investment and several limitations, use of solar energy to meet our ever increasing energy demand seems to be the only answer.

7 Green house effect and global warming is avoided

8 Less environment problems.

Demerits of non conventional over conventional sources of energy

1 Many non- conventional sources are still in their infant stages and required a lot of development efforts. The use of solar energy is a completely a very gentle / minutes operation. Cadmium is used in fabricating thin film solar cells, which is both poisonous and radio active.

   But it is very small quantity of cadmium is released from discarded PV panels, Carbondioxide produced while forming silicon from silica increases atmospheric temperature.

2 High initial cost

3 Less reliable and efficiency

4 Can not be used for base load demand.

Bio-gas power generation

The method of generating the electrical energy by using bio-gas is termed as bio-gas power generation.

Bio-gas

Biogas is a good fuel. Bio mass like animal excreta, vegetable wastes and seeds undergo decomposition in the absence of oxygen in a biogas plant and form a mixture of gases. This mixture is the **biogas**. Its main constituent is methane. This is used as a fuel for cooking and lighting.

Aerobic and anaerobic bio- conversion process

There are mainly three aerobic and anaerobic bio conversion process for the biomass energy applications. There are;

Bio products : Converting biomass into chemicals for making products that typically are made from petroleum.

Bio fuels : Converting biomass into liquid fuels for transportation.

Bio power : Burning biomass directly, or converting it into a gaseous fuel or oil, to generate electricity.

Properties of biogas

Main properties of biogas are :

1 Comparatively simple and can be produced easily.

2 Burns without smoke and does not leave any ash as residues.

3 Household wastes and bio-wastes can be disposed off, usefully and in a healthy manner.

4 Reduces the use of wood and to a certain extent prevents deforestation.

5 The slurry from the biogas plant is excellent manure.

Biogas plant technology & status

The important parts of biogas plant are :

1 The tank where biomass undergoes decomposition (digester)

2 The tank where biomass is mixed with water (mixing tank)

3 The tank where slurry of biomass is collected (out flow tank)

4 Arrangement to store gas.

Due to the action of bacteria in the absence of oxygen, biogas is produced in the plant. This is collected in the tank. In the gasholder type plant, the cylinder rises up as the gas fills the tank and the storage capacity increases. The gas storage capacity of dome type will be less than that of gasholder type. Residue of biomass (slurry) can be used as good manure.

Biogas plants are built in several sizes, small ($0.5\,m^3$/day) to very large ($2500\,m^3$/day). Accordingly, the configurations are simple to complex.

Biogas plants are mainly classified into following two types.

- Continuous type and batch type
- Drum type and dome type

Continuous type

Continuous type biogas plant delivers the biogas continuously and is fed with the biomass regularly. Continuous type biogas plant is of two types.

(A) Single stage continuous type biogas plant

In such a plant phase - I (Acid formation) and phase -II (methanation) are carried out in the same chamber without barrier. Such plants are simple, economical, easy to operate and control. These plants are generally preferred for small and medium size biogas plants. Single stage plants have lesser rate of gas production than the two stage plant.

(B) Two stage continuous type biogas plant

In such a plant phase - I (Acid formation) and phase -II (methane formation) take place in separate chambers. The plant produces more biogas in the given time than the single stage plant. However, the process is complex and the plant is costlier, difficult to operate and maintain. Two stage plant is preferred for larger biogas plant systems.

Batch type biogas plant

The infeed biomass is fed in batches with large time interval between two consecutive batches. One batch of biomass infeed is given sufficient retention time in the digester (30 to 50 days). After completion of the digestion, the residue is emptied and the fresh charge is fed. The fresh biomass charge may be subjected - to aeration or nitrogenation after feeding and then the digester covers are closed for the digestion process. Thereafter, the biogas is derived from the digester after 10 to 15 days. Fermentation continues for 30 to 50 days.

Salient features

1 Batch type biogas plant delivers gas intermittently and not continuously.

2 Batch type biogas plant may have several digesters (reactors) which are fed in a sequential manner and discharged in a sequential manner to obtain the output biogas continuously.

3 Batch type biogas plants have longer digestion time and are therefore more suitable for materials which are difficult for anaerobic digestion (e.g. harder, fibrous biomass).

4 Batch type biogas plant needs initial seeding to start the anaerobic fermentation.

5 Batch type biogas plant needs larger volume of the digester to accommodate larger volume of the batch. Hence initial cost is higher.

6 Operation and maintenance is relatively more complex. Batch type biomass plants need well organized and planned feeding. Such plants are preferred by European farmers. Such plants are not yet popular in India.

Fixed dome type digester (Fig 1)
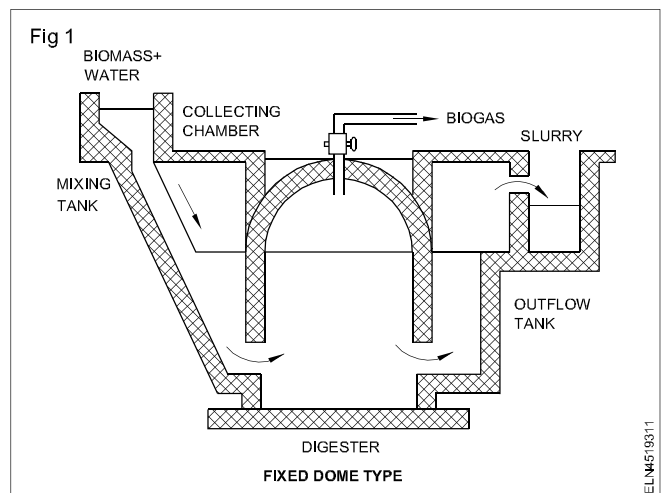
In the fixed dome type digester biogas plant, the digester and gas collector (gas dome) are enclosed in the same chamber. This type of construction is suitable for batch type biogas plant. The digester is conveniently built at or below ground level in comparatively cooler zone. The construction of the digester is with locally available materials like, bricks, terracotta.

The pressure inside the digester increases as the biogas is liberated. The biogas gets collected in the upper portion of the digester in a dome shaped cavity. The outlet pipe is provided at the top of the fixed dome. Alternatively, the gas collector (gas holder) is a separately installed chamber. The digester tank and gas collector chamber are separated by a water seal tank.

The arrangement of a separate gas collector is preferred as the tapping of gas from the gas holder does not affect the pressure and the digestion process in the main digester. The water seal tank prevents the return of the gas from the gas collector to the digester chamber.

An additional displacement chamber may be provided for providing space to the displacement slurry in the digester, due to gas pressure in the upper dome of the fixed type digester. The fixed dome type digester can be fed on daily

basis with small quantities of the slurry. The excess slurry in the digester gets accommodated in the displacement chamber.

The level of the slurry in the main digester and the displacement collector can vary in accordance with the pressure and volume of the biogas in the fixed type of dome. The pressure in the fixed dome and the displacement gas collector are almost the same as they are connected by the outlet from the main digester.

Floating gas holder type (Fig 2)

FLOATING GAS HOLDER TYPE
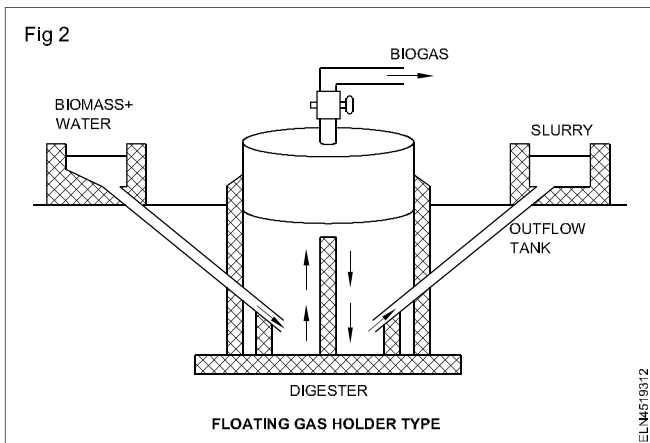
In this design a dome made floats above the slurry in the disaster. In the Fig 2 the digester tank is of cylindrical masonry construction. The floating dome is of fabricated steel construction. The dome guide shaft provides the axial guide to the floating dome.

As the gas is collected in it, the sliding bearing provides smooth sliding surface and guide to the floating dome. The gas generated in the slurry gets collected in the dome and the dome arises. The water seal tank provides separation between the gas in the dome and the outlet gas.

Electricity generating plant

Generating plant fuelled by biomass uses conventional steam turbine as used in thermal power stations with modifications to the combustion chamber and fuel handling systems to handle the bulkier fuel. The schematic arrangement is in Fig 3.

ELECTRICITY GENERATION POWERED BY BIOMASS
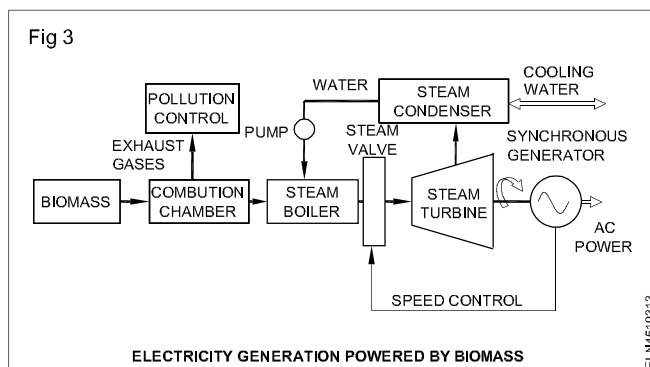
Co - generation

Because of the poor energy conversion efficiencies of biomass fuels, practical generating systems often employ a co-coal generation to achieve reasonable utilization of the generating plant.

Environmental issues

While biomass crops provide an environment friendly fuel source for generating electrical energy. The land used for disposing the slurry (waste) may be better employed for cultivation.

Micro hydel power generation

Micro-Hydel Power (MHP)

The method of generating electrical power by using low head or small flow rate of water is termed as micro hydel power generation.

Small -scale micro hydro power is both an efficient and reliable form of energy, most of time. However, there are certain disadvantages that should be considered before construction a small hydro power system. With the right research and skills, micro hydro can be excellent method of harnessing renewable energy from small streams.

Advantages

a Efficient energy source

It only takes a small flow rate of water (as little as two gallons per minute) or a head as low as two feet to generate the electricity with micro hydro.

b Reliable electricity source

Hydro produces a continuous supply of electrical energy in comparison to other small - scale renewable technologies. The peak energy season is during the winter months when the large quantities of electricity are required.

c No reservoir required

Microhydro is considered to function as a 'run- of-river' system, meaning that the water passing through the generator is directed back into the stream with relatively little impact on the surrounding ecology.

d Cost effective energy solution

Building a small -scale hydro - power system can cost less amount depending on site electricity requirements and location. Maintenance cost are relatively small in comparison to other technologies.

e Power for developing countries

Because of the low-cost versatility micro hydro, the developing countries can adopt and implement the technology to help supply much needed electricity to small communities and villages.

f Integrate with the local power grid

If your site produces a large amount of excess energy, some power companies will buy back your electricity overflow.

g Suitable site characteristic required

In order to take full advantage of the electrical potential of small streams, a suitable site is needed. Factors to consider are; distance from the power source to the location where energy is required, stream size (including flow rate, output and head), inverter, batteries, controller, transmission line and pipelines.

Disadvantages

a Energy expansion not possible

The size and flow of small streams may restrict the future site expansion as the power demand increases.

b Low - power in the summer months

In many locations stream size will fluctuate seasonally. During the summer months there will likely be less flow and therefore less power output. Advanced planning and research will be needed to ensure adequate energy requirements are met.

c Environmental impact

The ecological impact of small - scale hydro should be minimal. Stream water will be diverted away from a portion of the stream, and proper caution must be exercised to ensure there will be no damaging impact on the local ecology or civil infrastructure.

Micro-hydel electric system basic components

Here are some brief descriptions of the common equipment used in grid- intertied and off- grid micro hydro electric systems. The basic components of the systems may vary, where all the following equipment is not necessary for every system.

- Intake
- Pipe line
- Turbine
- Controls
- Dump load
- Battery bank

- Metering
- Main DC disconnect
- Inverter
- AC breaker panel

Intake

Intakes can be as simple as a screened box submerged in the water course, or they can involve a complete damming of the stream. The goal is to divert derbis and air-free water into a pipe line. Effectively getting the water into the system's pipe line is a critical issue that often does not get enough attention. Poorly designed intake often become the focus of maintenance and repair effort for hydro-electric systems.

Pipe line

Most hydro turbines require at least a short run of pipe to bring the water to the machine, and some turbines require piping to move water away from it. The length can vary widely depending on the distance between source and the turbine. The pipeline's diameter may range from 1 inch to 1 foot or more, and must be large enough to handle the design flow. Losses due to friction need to be minimized to maximize the energy available for conversion into electricity.

Turbine

The turbine converts the energy in the water into electricity. Many types of turbines are available, so it is important to match the machine to the site's conditions of head and flow.

Controls

The function of a charge controller in a hydro system is equivalent to turning on a load to absorb excess energy. Battery-based micro hydro systems require charges controllers to prevent the overcharging of the batteries. Controllers generally send excess energy to a secondary (dump) load, such as an air or water heater. Unlike a solar - electric controller, a micro hydro system controller does not disconnect the turbine from the batteries. This could create voltages that are higher than some components can withstand, or cause the turbine to over speed, which could result in dangerous and damaging over voltages.

Dump load

A dump load is an electrical resistance heater that must be sized to handle the full generating capacity of the micro hydro turbine. Dump loads can be air or water heaters, and are activated by the charge controller whenever the batteries or the grid cannot accept the energy being produced, to prevent damage to the system. Excess energy is "shunted" to the dump load when necessary.

Battery Bank

By using reversible chemical reactions, a battery bank provides a way to store the surplus energy when more is being produced than consumed. When demand increases beyond what is generated, the batteries can be called on to release the energy to keep your household loads operating.

Metering

System meters measure and display several different aspects of microhydro - electric system's performance and status - tracking the condition of battery, amount of electricity produced and used / consumed.

Main DC disconnect

In battery-based systems, a disconnect between the batteries and inverter is required. This disconnect is a DC-rated breaker mounted in a sheet-metal enclosures. It allows the inverter to be disconnected from the batteries for services and protects the inverter to battery wiring against the electrical faults.

Inverter

Inverter transform the DC electricity stored in battery into AC electricity for powering household appliance. Grid tied inverters synchronize the system's output with the utility's AC electricity, allowing the system to feed hydro electricity to the utility grid. Battery- based inverters for off -grid or grid - tied systems often include a battery charger, which is capable of charging a battery bank from either the grid or a backup generator.

Micro hydel power working principle

Hydro power is based on simple concepts. Moving water turns a turbine, the turbine spins a generator, and electricity is produced. Many other component's may be in a system, but it all begins with the energy already within the moving water.

Water power is the combination of head and flow. Both must be present to produce electricity. Consider a typical hydro system. Water is diverted from a stream into a pipeline, where it is directed downhill and flow through the turbine. The vertical drop (head) creates pressure at the bottom end of the pipeline. The pressurized water drives the turbine. More flow or more head produces more electricity. Electrical power output will always be slightly less than water power input due to the turbine and system efficiencies.

Flow is water quantity, and is expressed as "volume per time". such as gallons per minute (gpm), cubic feet per second (cfs) or litres per minute (lpm). Design flow is the maximum flow for which your hydro system is designed. It will likely be less than the maximum flow of your stream (especially during the rainy season), more than your minimum flow, and a compromise between potential electrical output and system cost.

Tidal power generation

Objectives: At the end of this lesson you shall be able to
• **explain the features of tidal power generation**
• **state the system on which the tidal power generation works**
• **state the advantages and disadvantages of tidal power generation.**

The generation of electricity using tidal power is termed as tidal power generation. It is basically the transformation of tidal power found in tidal motion of water in seas and oceans into electrical energy.

Tidal power

Tidal power is the power inherent in tides at sea or oceans, that is power of motion of water actuated by tides. Tides are defined as the increase and decrease in water levels due to the motion of water from one place to the other. Thus there is a renewable source of energy in the tidal motion of water at seas and oceans. This source of energy could be used to generate other types of energy that could be useful in industrial applications.

This is done using a very basic idea involving the use of a barrage or small dam built at the entrance of a bay where tides are known to reach very high levels of variation. This barrage will trap tidal water behind it creating a difference in water level, which will in turn create potential energy.

This potential energy will then be used in creating kinetic energy as doors in the barrage are opened and the water rush from the high level to the lower level. This kinetic energy will be converted into rotational kinetic energy that will rotate turbines giving electrical energy. Fig 1 shows the process in very simple terms.

Fig 1

A DIAGRAM SHOWING TRANSFORMATION OF TIDAL ENERGY TO ELETRICAL ENERGY
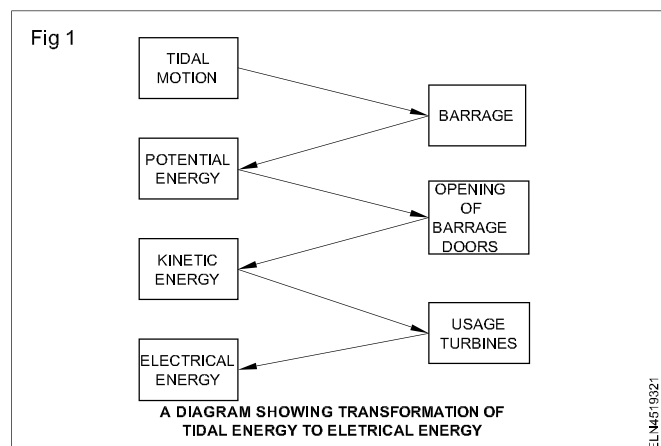
Physical concepts of the tidal phenomena

Tidal movements in seas are due to the increase of water levels at certain areas in the globe and the decrease of water levels at other areas. This is basically due to two factors.

1 The gravitational forces between the Sun, Moon and Earth.

2 The rotation of the moon and earth.

As there are gravitational forces between the moon and the earth, seas or oceans water is pulled away from earth toward the moon at the area where the moon and the earth are in front of each other. At the opposite side of the earth the water is being pushed away from the earth due to centrifugal forces. Thus there are two areas where the water levels are high and other areas where the water level is low. Thus, the tidal motion of water is created. This is called the **lunar tide**.

Working of tidal power generation system

In very simple terms a barrage is built at the entrance of a gulf and the water levels vary on both sides of the small dam. Passages are made inside the dam and water flows through these passage and turbines rotate due to this flow of water under head of water. Thus, electricity is created using the turbines. A general diagram of the system is in Fig.2.

GENERAL SCHEME OF THE TIDEL POWER STATION
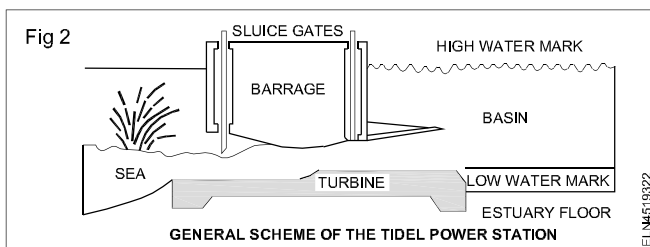
The components of a tidal power station are :

1 **A barrage :** a barrage is a small wall built at the entrance of a gulf in order to trap water behind it. It will either trap it by keeping it from going into the gulf when water levels at the sea are high or it will keep water from going into the sea when water level at the sea is low.

2 **Turbines :** They are the components responsible for converting potential energy into kinetic energy. They are located in the passage ways that the water flows through when gates of barrage are opened.

3 **Sluices :** Sluice gates are the ones responsible for the flow of water through the barrage they could be seen Fig 2.

4 **Embankments :** They are caissons made out of concrete to prevent water from flowing at certain parts of the dam and to help maintenance work and electrical wiring to be connected or used to move equipment or cars over it.

The following is a list of different methods of obtaining power from tidal power stations.

1 Ebb method

1st - Water starts to ebb or go toward the sea

2nd - The gates are left closed keeping the water trapped in basin to increase its level.

3rd - Then water is released out toward the sea rotating turbines creating electrical energy.

2 Flood method

1st - Water is let into the basin when it is empty

2nd - As the turbines are rotated and the electrical energy is created.

3 Ebb plus pumping method

1st- The turbines are operated as pumps and pumping the water into the basin at the flood period.

2nd - The water level in the basin is increased and creating greater head.

3rd - At the ebb phase the water is let out of the basin, creating energy for longer time than usual due to be increased head.

4 Two way power generation

1st - Starting with the basin full, the gates are opened, letting water flow out and generating energy.

2nd - The turbines are reversed as the flow will be reversed

3rd - The gates are closed when the flood period or cycle starts.

4th - Water starts to build up behind the dam.

5th - When a sufficient head is achieved, the gates are opened to start the flood generation cycle as the water flows into the basin.

5 Two basin generation method

1st - Two basins are built one called a high - level basin and the other is the low - level basin .

2nd - The turbines are placed in the wall dividing the two basins.

3rd - The high level basin is filled at high tide or flood period.

4th - Then the low - level basin is filled through the turbines from the high level basin.

5th - The low level basin is emptied at low tide ebb period.

Advantages of tidal power generation

There are many advantages of generating power from the tide; some of them are listed below.

- Tidal power is a renewable and sustainable energy resource.

- It reduces dependence upon fossil fuels.

- It produces no liquid or solid pollution.

- It has little visual impact.

- Tidal power exists on a world wide scale from deep ocean waters.

- It offers short time scale between investing in the modular construction and benefiting from the revenue.

- Tidally driven coastal currents provide an energy density four times greater than air, meaning that a 15-m diameter turbine will generate as much energy as a 60m - diameter windmill.

- Tidal currents are both predictable and reliable, a feature which gives them an advantage over both wind and solar systems. Power outputs can be accurately calculated far in advance, allowing for easy integration with existing electricity grids.

- The tidal turbine offers significant environment advantages over wind and solar systems; the majority of the assembly is hidden below the water line and all cabling is along the sea bed.

- Sea water is 832 times as dense as air; therefore the kinetic energy available from a 5-knot ocean current is equivalent to a wind velocity of 270 km/h.

Disadvantages and constraint to tidal power generation

Unfortunately, there are also disadvantages and limitations to generating tidal power. Some of these are;

- At the present time both tide and wave energy are suffering from orientation problems, in the sense that neither method is strictly economical (except in few locations throughout the world) on a large scale in comparison with conventional power sources.

- Tidal power systems do not generate electricity at a steady rate and thus not necessarily at times of peak demand, so unless a way can be found of storing energy efficiently - and any storage devices currently available incur a considerable loss - they would not help in reducing the overall need for fossil power stations, but only allow them to run at a lower rating for a certain amount of the time.

- Tidal fences could present some difficulty to migrating fish.

Magneto hydro dynamic (MHD) power generation

Objectives: At the end of this lesson you shall be able to
- **explain the features of magneto hydro dynamic power generation (MHD)**
- **state and explain the system components of MHD power generation**
- **state the advantages of MHD power generation.**

Magneto hydro dynamic power generation

The way of generating electricity directly from a fast moving stream of ionised gases without the need for any moving mechanical parts - no rotating turbines and generators is termed as magneto hydrodynamic power generation.

MHD power generation has also been studied as a method for extracting electrical power from nuclear reactors and also from more conventional fuel combustion systems.

Working principle

Fig 1 explains the principle of operations of MHD. The MHD generator can be considered to be a fluid dynamo. This is similar to a mechanical dynamo in which the motion of a metal conductor through a magnetic field creates a current in the conductor where as in the MHD generator the metal conductor is replaced by a conducting gas plasma.

The flow (motion) of the conducting plasma through a magnetic field causes a voltage to be generated (and an associated current to flow) across the plasma, perpendicular to both the plasma flow and the magnetic field according to Fleming's Right Hand Rule.

MAGNETO HYDRO DYNAMIC POWER GENERATION
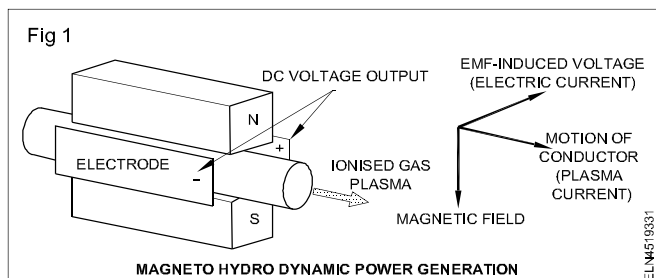
The MHD system

The MHD generator needs a high temperature gas source, which could be the coolant from a nuclear reactor or more likely high temperature combustion gases generated by burning fossil fuels, including coal, in a combustion chamber. The Fig 2 shows the components of this system.

OPEN CYCLE USING CONVENTIONAL FUEL
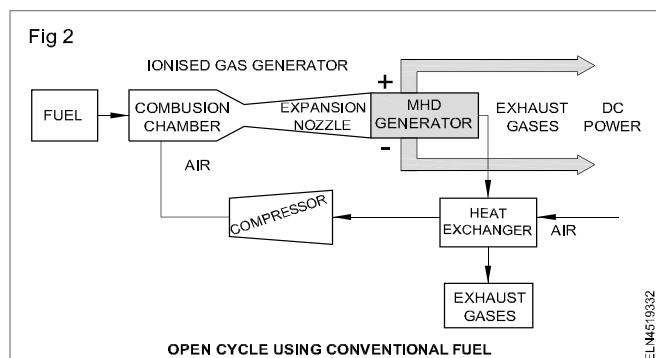
Expansion nozzle

It reduces the gas pressure and consequently increases the plasma speed (Bernoulli's Law) through the generator duct to increase the power output. At the same time, the pressure drop causes the plasma temperature to fall (Gay-Lussac's Law) which also increases the plasma resistance, so a compromise between Bernoulli and Gay-Lussac must be found. The exhaust heat from the working fluid is used to drive a compressor to increase the fuel combustion rate but much of the heat will be wasted unless it can be used in another process.

The plasma

The prime MHD system requirement is creating and managing the conducting gas plasma since the system depends on the plasma having a high electrical conductivity. The plasma can be the fourth state of matter after the solid, liquid and gaseous states, in which the atoms or molecules are stripped of their electrons leaving positively charged ions. Suitable working fluids are gases which derived from combustion, noble gases and alkali metal vapours.

The gas plasma

To achieve high conductivity, the gas must be ionised by detaching the electrons from the atoms or molecules leaving the positively charged plasma. The plasma flows through the magnetic field at high speed, in some designs, more than the speed of sound, the flow of the positively charged particles providing the moving electrical conductor necessary for inducing a current in the external electrical circuit.

Methods of Ionising the gas

Various methods for ionising the gas are available, all of which depend on imparting sufficient energy to the gas. It may be accomplished by heating or radiating the gas with X rays or Gamma rays. It has also been proposed to use the coolant gases such as helium and carbon dioxide employed is some nuclear reactors as the plasma fuel for direct MHD electricity generation rather than extracting the heat energy of the gas through heat exchangers to raise steam to drive turbine generators.

Seed materials such as Potassium carbonate or Cesium are often added in small amounts, typically about 1% of the total mass flow, to increase the ionisation and improve the conductivity, particularly of combustion gas plasmas.

Containment

Since the plasma temperature is typically over 1000°C, the duct containing the plasma must be constructed from non conducting materials capable of withstanding these high temperatures. The electrodes must be conducting as well as heat resistant.

The faraday current

A powerful electromagnet provides the magnetic field through which the plasma flows and perpendicular to this field, two electrodes are installed on opposite sides of the plasma across which the electrical output voltage is generated. The current flowing across the plasma between these electrodes is called the Faraday's current. This provides the main electrical output of the MHD generator.

Power output

The output power is proportional to the cross sectional area and the flow rate of the ionised plasma. The conductive substance is also cooled and slowed in this process. MHD generators typically reduce the temperature of the conductive substance from plasma temperatures to just over 1000°C.

An MHD generator produces a direct current output which needs an expensive high power inverter to convert the output into alternating current for connection to the grid.

Efficiency

Typical efficiencies of MHD generators are around 10 to 20 percent mainly due to the heat lost through the high temperature exhaust.

This limits the MHD's potential applications as a stand alone device but they were originally designed to be used in combination with other energy converters in hybrid applications where the output gases (flames) are used as the energy source to raise steam in a steam turbine plant. Total plant efficiencies of 65% could be possible in such arrangements.

Experience

Demonstration plants with capacities of 50 MW or more have been built in several countries but MHD generators are expensive. Typical use could be in peak shaving applications but they are less efficient than combined - cycle gas turbines which means there are very few installations and MHD is currently not considered for mainstream commercial power generation.

Advantages of MHD generation

1   Here only working fluid is circulated, and there are no moving mechanical parts. This reduces the mechanical losses to nil and makes the operation more efficiency.

2   The temperature of working fluid is maintained the walls of MHD.

3   It has the ability to reach full power level almost directly.

4   MHD has very high efficiency

5   The price of MHD is very low.

Power generation by solar and wind energy

Objectives: At the end of this lesson you shall be able to
• **state the necessity of tapping natural resources for energy**
• **explain the basic principle and construction of the solar cell**
• **explain the characteristic and general specification of a solar cell**
• **explain the features of solar power generation system**
• **explain the features of wind power generation system**
• **calculate the required series parallel group of solar cells for a given power requirement.**

Solar cells: Heat energy is the most sought energy for human being to cook the food as well as to keep warm in cold climate. However the use of wood as the fuel for fire, has ended up in deforestation and resulted in drought. Search of fuel lead the man to use coal and then oil. However these commodities are fast dwindling and after few hundred years both may completely vanish from earth. As such it is essential that human race should find alternative source of energy from nature.

Hence the use of natural resources like heat from sun thought by several scientists and one of the solutions to the energy crisis is the invention of solar cells.

The solar cells is essentially a large photo diode designed to operate solely as photo voltaic device and to give as much output power as possible. When these cells are under the influence of light rays from sun, they give out about 100 mw/cm^2 power.

The construction and cross section of a typical power solar cell is in Fig 1. The top surface consist of a extremely thin layer of P-type material through which light can penetrate to the junction.

Fig 1
a) SYMBOL AND CONSTRUCTION

LIGHT ENERGY

SOLDER (+VE CONTACT)
NICKEL PLATING
p-TYPE SILICON
pn-JUNCTION
n-TYPE SILICON
NICKEL PLATING
SOLDER (–VE CONTACT)

LOAD

⊕ DIRECTION OF HOLE FLOW
⊖ DIRECTION OF ELECTRON FLOW

b) CROSS SECTION

CONSTRUCTION AND CROSS SECTION OF A SOLAR CELL.
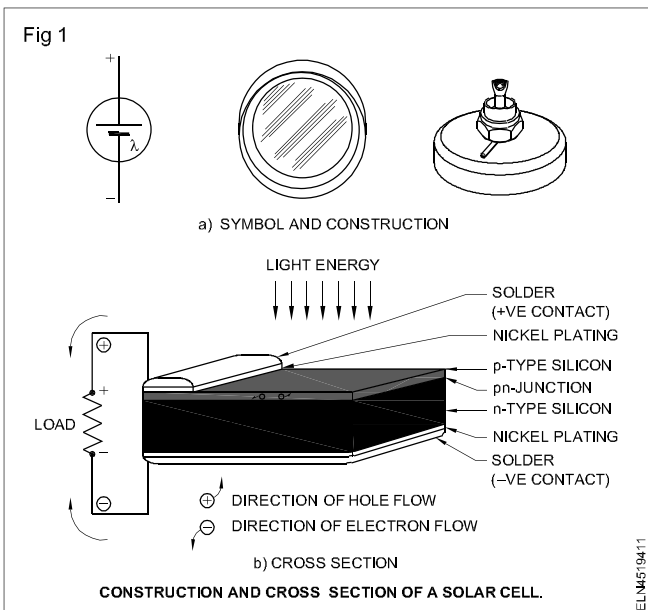
The nickel plated ring around the P-type material is the positive output terminal, and the button plating is the

negative output terminal. commercially produced solar cells will be available in flat strip form for efficient coverage of available surface areas. The circuit symbol of solar cell is shown in Fig 1.

According to different manufacturing standards, the output power varies from 50mw/cm^2 to 125mw/cm^2 as shown in Fig 2. The graph (Fig 2) shows the characteristic of a solar cell which gives 100mw/cm^2. Considering the characteristic curve it is apparent that the cell will deliver an output current of 50mA when the output terminals are short circuited the output voltage will be zero. On the other hand open circuited voltage of the cell will be 0.55mv but the output current is zero. Therefore again the output power is zero. For maximum output power the device must be operated at the knee of the characteristic. In solar cells the output power decreases at high temperature.

Typical output characteristics of power photocell for use as a solar energy converter. (Fig 2)

Fig 2

MAXIMUM POWER POINT

125mW/cm^2
100mW/cm^2
50mW/cm^2

OUTPUT CURRENT

OUTPUT VOLTAGE

OUTPUT CHARACTERISTICS OF POWER PHOTOCELL FOR USE AS A SOLAR ENERGY CONVERTER
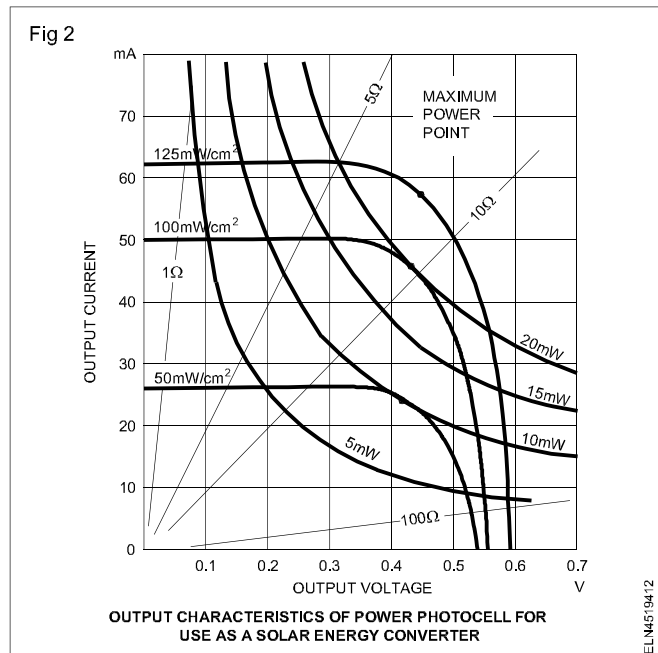
Array of solar cells connected as a battery charger. (Fig 3)

Fig 3 shows a group of series-parallel connected solar cells operating as a battery charger. Several cells must

be series connected to produce the required output voltage, and number of parallel groups to be provided as per the required output current.

Fig 3

18 PARALLEL GROUPS

13 SERIES CONNECTED CELLS

13 V

BATTERY

12 V

ARRAY OF SOLAR CELLS CONNECTED AS A BATTERY CHARGER
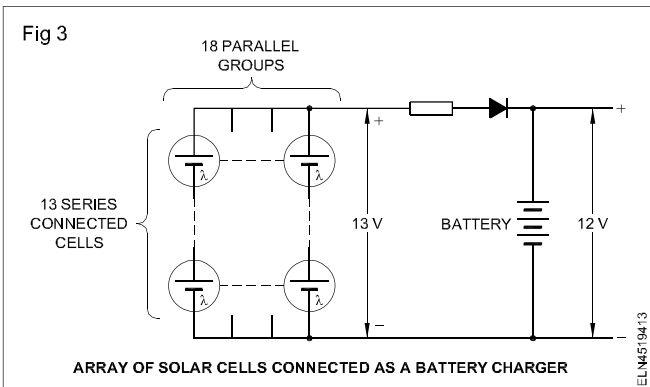
Example

A village welfare club is having a black and white TV which operates at 24V taking a current of 3amp for four hours.

Normally an array of solar cells are used for charging the 24V batteries and the light source from sun available to energise the cells for about 10hours a day. Calculate the total number of solar cells of 125mw/cm^2 required and the series parallel grouping of cells.

Solution

Refer Fig 2. As per the graph the solar cells (energy converters) should be operated at approximately 0.45V and 57mA. Assuming the charging voltage should be higher than the battery voltage of 24V the solar cells should supply 26.4volt for charging the battery circuit.

Number of series connected cells

$$= \frac{\text{Output voltage}}{\text{Cell voltage}} = \frac{26.4V}{0.45V}$$

= 58.5 = say 59 cells

The charge taken by the batteries after every day of TV programme will be 3amp x 4hours = 12 ampere hours. This should be supplied by the solar cells in 10 hours. Hence the ampere (current) requirement

$$\text{Current} = \frac{\text{Ampere hours}}{\text{hours}} = \frac{12}{10}$$

= 1.2 amp

Total number of groups of cells in parallel

$$= \frac{\text{Output current}}{\text{cell current}} = \frac{1.2amp}{57mA}$$

= say 21 cells

The total number of cells required

= Number of cells in series x number of groups in parallel

= 59 x 21

= 1239 cells.

Solar energy generation

Solar energy is very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8 x 1011 MW, which is many thousands of time large than the present consumption rate on the earth of all commercial energy sources. Thus, in principle, solar energy could supply all the present and future energy needs of the world on a continuous basis. This makes it one of the most promising of the non conventional energy sources.

In addition to its size the solar energy has two other factors in its favour. Firstly, unlike fossil fuels and nuclear power, it is an environmentally clean source of energy. Secondly, it is free and available in adequate quantities in almost all parts of the world where the people live.

However, there are many problems associated with it use. The main problem is that it is a dilute source of energy. Even in the hottest regions of earth, the solar radiation flux available rarely exceeds. 1 KW/m^2, which is a low value for technological utilization. Consequently, large collecting areas are required in many applications and these result in excessive costs.

Solar electricity

When sunlight strikes on photovoltaic (PV) solar panel, the electricity is produced. The method of generating the electrical energy from the solar panel (cells) is termed as solar energy generation.

Generation of electricity by using solar energy depends up on the photovoltaic effect in some specific materials. There are certain materials that produce electric current when these are exposed to direct sun light. This effect is seen in combination of two thin layers of semiconductor materials. One layer of this combination will have a depleted number of electrons.

When sunlight strikes on this layer, it absorbs the photons of sun light ray and consequently the electrons are excited and jump to the other layer. This phenomenon creates a charge difference between the layer and resulting to a tiny potential difference between them.

The unit of such combination of two layers of semi conductor materials, for producing electric potential difference in sunlight is called solar cell. Silicon is normally used as solar cell. For building cell, silicon material is cut into very thin wafers. Some of these wafers are doped with impurities. Then both doped and undoped wafers are sandwiched together to build solar cell. A metallic strip is attached to two extreme layers to collect current.

A desired number of solar cell are connected together in both parallel and series to form a solar module for producing desired electricity.

The solar cell can also work in cloudy weather as well as is moon light but the rate of production of electricity low as and it depends up on intensity of incident light ray.

Fig 4 describes the typical system of solar panels, controller, energy storage, inverter for converting DC into AC and how the system is connected to power grid.

Fig 4

SOLAR POWER PLANT
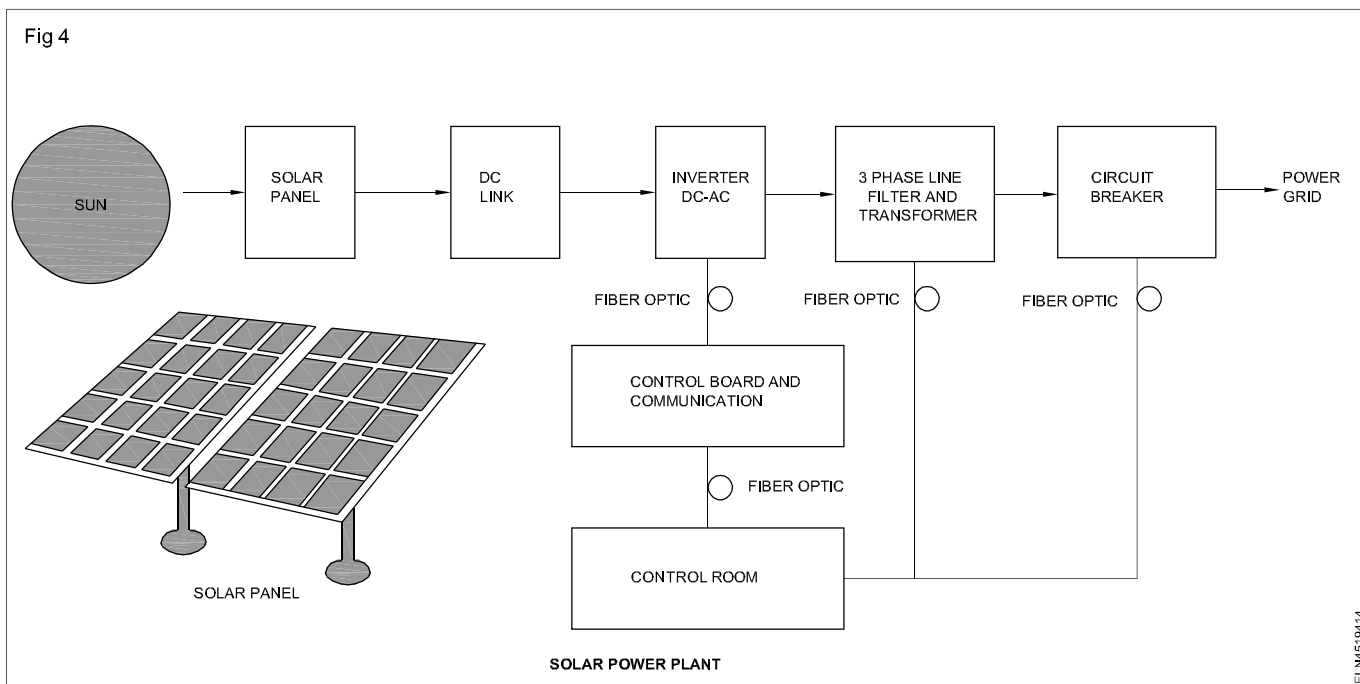
Solar panel installation norms

Solar modules must have some industry standards known as the standard test condition (STC).

It is a set of conditions to test a module, mainly includes these factors.

Irradiance (sunlight intensity)

It is the amount of sunlight falling on a plain surface. Its unit is watt per square metre. The measurement standard is unit $1000Kw/m^2$.

Air mass

It is the thickness and clarity of air through which the sunlight passes to reach the modules its standard is 1.5.

Cell temperature : It is the testing temperature as $250°C$.

Module efficiency : It is the ratio of output power to the input power is called module efficiency. Module uses the photons in the sunlight to produce DC electricity.

• Normally $1000W/M^2$ of sunlight strikes 1 square metre area of a module. If 100W of power is produced from that square metre, then the module efficiency is 10% If it is 50W power is produced from that square metre it a has an efficiency of 5%.

• **For efficient cell, if must have the following key factors.**

• It must have a high short circuit current.

• The open circuit voltage is also must be high for obtaining the above possible character with possible condition must be fulfilled.

• By choosing low band gap materials to get high value of short circuit current and high open circuit voltage.

Assembling and installation of solar panels

A solar panel is a able to function using the solar energy which is derived from the sun. The solar panel installed on the roof top absorb sun's light (photons) from the sun.

Silicon and the conductors in use for solar panel converts the sunlight into direct current (DC) electricity flows into the inverter. It is an renewable energy. The process of converting sunlight to electrical energy and more efficient than other process.

Solar panel contains many different silicon cells (or) solar cells. The energy derived from the sun is connected into electricity with help of solar panels.

1   The solar panels installed on the roof top absorb sun's light from the sun.

2   The silicon and the conductor in the panel convert the sunlight into DC flows into inverter.

3   The inverter then converts DC to AC which can be used at home.

4   Excess electricity that is not used, can be feedback to the grid.

5   When the solar panels produce less power than required at home.

Process of connecting solar panel to electricity

Solar panels is used a special process of connecting photons to electrons to generate a current by making use of a special type of cell known as photovoltaic cell. These cells are commonly found on the front of calculation and small gadgets are connected together, called as solar panels (photovoltaic cells) are made up of semiconductor materials such as silicon, which absorb the light from the sun. The photons in the sunlight current the electron within the sunlight.

Basic idea of a solar module, array and balance of system (BOS)

Module

Solar cells are made in various shapes and sizes. The smallest of the cells can be seen in devices like an ordinary calculator, these type of devices are very little amount of power used in home lighting system needs more power to run on. The number of cells are put together to produce more power. The group of cells is packaged together in an enclosed space is called as a **module**.

It helps to give higher voltage, high power and protects the panel from rain, snow and wind etc. voltage and power output of module depend on the size and number of cells used. So, more number of modules are to be connected in a simple assembly of modules is known as **array.** (Fig 5)

Fig 5

CELL   MODULE

ARRAYS   PANELS

CELL MODULE PANEL AND ARRAY SYSTEM
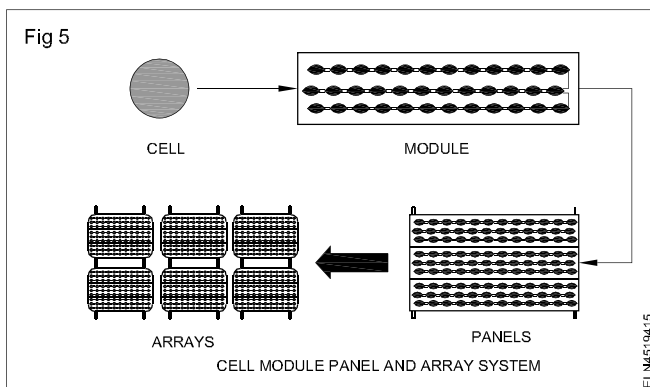
Balance of system (BOS)

The cells modules and arrays are the power producing part, a small devices like radio, needs a small amount of power, can be directly connected to a small module. But most of the devices appliances need more power at night. The assembly of module, battery and an appliance is simple form a P.V system.

A module cannot be connected directly to a battery, so, a charge controller ON charge regulator is used in between module and battery and inverter are required to operate AC appliances. So, the whole system excepts the module is known as balance of system (BOS). (Fig 6)

Fig 6
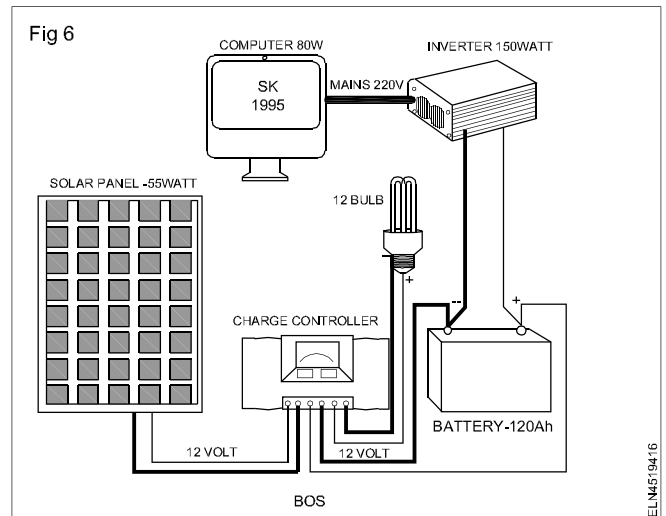
The main components is BOS assembly are:

•   Storage battery

•   Charge controller

•   Inverter

•   Support structure

•   Junction boxes

•   Wire, cables and fuses

•   Connections and switches

The functions of the above components are explained briefly below:

Storage battery

The most small systems used for lightening needs only 12V battery for longer system like refrigerator, 24V is used. If helps to keep the wire size small and system losses to a minimum. It needs to be handled carefully. If must not be over charged or fully discharged to prevent from damage.

Charge controller

If the battery is not able to control charge on its own. This work is done by a simple automatic device known as a charge controller in the following way.

•   It senses the battery charge and switches 'OFF' the charging current and avoid from damage.

•   It disconnects the appliances when the battery charge goes below a set limit.

•   Prevents reverse current and protects from short circuit.

Inverter

A solar system produces only DC power. But home appliances need AC power. The device (example CFL) is required for this purpose to convert DC into AC is called as inverter.

Support structure

The solar module cannot be simply placed either on ground or roof. It needs to collect the sunshine at an angle. To keep the module safe from any strong winds support structure is used for solar PV system.

Junction boxes

It is meeting point for many wires. These may be from a raw of modules are from modules to a battery bank. A junction box is made of an unbreakable material (ie) polycarbonate. It makes use of copper connectors for a high current flow. It protects the system from moisture.

Wires and fuses

This solar systems carry a low voltage but high current. So, the large diameter wire is needed. Fuses keep the solar equipment safe against the short circuit.

CFL(Compact Fluorescent Lamp)

It is not only energy saving lamp but also having long life (8000hrs) and less heat output common available CFL are:

• 5W - 235 Lumens

• 7W - 370 Lumens

• 9W - 600 Lumens

• 11W - 900 Lumens

The solar panels are installed for some applications like:

- Solar power plant

- Solar lantern

- Solar lighting system

- Solar water pumping system

- Solar battery charging system

- Solar Hybrid system

- Solar grid connected power plants

- Solar home system

- Solar water heater etc.,

For example the procedure for installing of a solar home system is explained below:

Fig 7 shows the block diagram of solar panel installation.

- Collect the system from the packing

Fig 7

BLOCK DIAGRAM OF SOLAR POWER SYSTEM
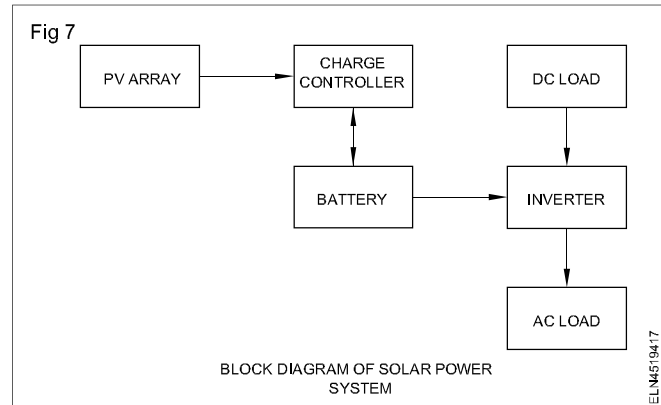
- Check for the any damage from outride on the different parts of system.

- Connect the load to junction box controller

- Connect all lighting loads charge controller to load junction box with interconnecting cables.

- Place the charge controller on batter box, keep the battery inside.

- Fire module on the support structure.

- Wore the system appear box layout.

Mounting of charge controller

- Mount the controller to the wall into screws that fit to the wall material.

- Connect the battery cable assembly with fuse supplied along with the controller.

- Connect first controller and then battery and two modules

- Connect the wires to the load and only then to controller.

Electrical connection

• Connect the battery to the system only after getting fully charged.

• Do not switch 'ON' charged the loads for 2 - 3 days (when battery is 'ON' a full charged)

• Connect the array cable to charge controller with correct polarity.

• Keep the switch in 'OFF' position and connect the load cables and battery cables to charge controller.

• Switch 'ON' the load (ie) lamps for the normal operation.

• Test the solar panel installation for it's functioning.

(Fig 8a & b) shows the installed solar panel with mid clamp and with frame mounted installation are illustrated.

Functionality of solar panel

Sunlight is the basic fuel for a solar panel. Sunshine is the cause to keep the panel for normal functioning. But the environment around the modules will affect it's working.

Fig 8(a)

MID CLAMP ILLUSTRATELL

Fig 8(b)

INSTALLED SOLAR PANEL WITH FRAME ILLUSTRATELL
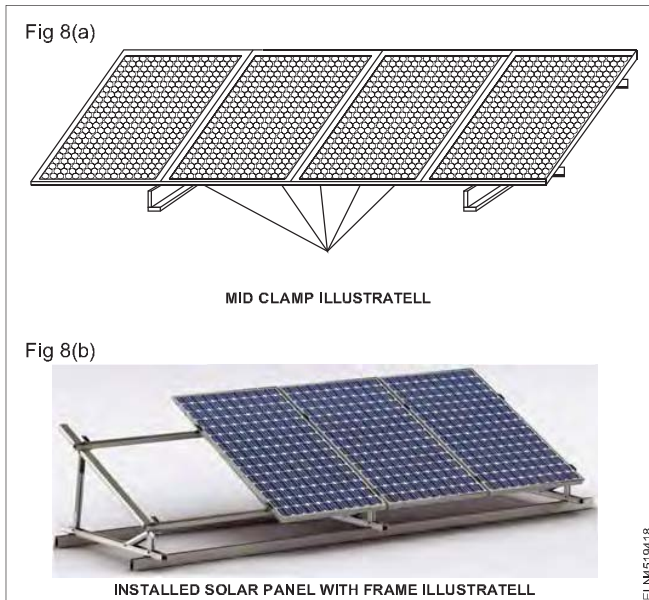
The following few factors will affect it's normal working cause for power loss.

- Tilt angle

- Dust

- Shading

- Light intensity

- Temperature

- Charge controller

- Semiconductor energy loss

- Cabling losses

- Improper connections

Tilt angle

The solar module must be installed in the proper path of sun and it is tilted properly at an angle, equal to the latitude of the place. If any error in the tilt angle will lead to same amount of power loss.

Dust

If the modules is not cleaned properly, dust will form on the modules surface in the dry season, and it may cause for high energy loss 5-10%.

Shading

Solar module faces the sun all day. Their shade should

not be present on it. In such a place only it must be put up. But due to extended free transformer, T.V antennas etc, may cause to present shades.

A solar modules are made of a string of individual solar cells and connected in series with one another. Suppose as an example one cell from 36 cells in a module is fully shaded, the power output from the module will become zero due to high resistance. But if one cell is 50% shaded then the power output is reduced to 50% only offers high resistance.

Light intensity

More power is produced from the panel in bright sunlight. For $1000W/M^2$ of sunlight, the rated output power will be full. But, if it is $500W/M^2$ only the rated power output will be half. The output power is directly proportional with the increasing of solar in isolation.

Temperature

The higher the temperature the output power is reduced from a module, due to power loss. It is tested at standard temperature at 25°C. During the bright sunlight, cell may reach 70°C also. If crystalline silicon decrease from 0.4 to 0.5% per°C temperature increases above 25°C. Amorphous silicon module temperature coefficient is 0.2 to 0.25 % per°C of temperature increase.

Charge controller

If the charger controller is in continuous operation and draws a small current of about 5mA to 25mA, then the power loss is around 1%.

Semiconductor energy loss

The charge controller is having the components as MOSFET and blocking diodes, which is cause for heat energy loss.

Cabling loss

The cables are also cause for power loss, It can be minimized by choosing a large diameter of wire size.

Improper connection

If the electrical connections are not made properly, it results in less power is fed to the battery. It can be reduced by keeping clean, and tight connections.

Wind power generation

Objectives: At the end of this lesson you shall be able to
• **explain the features of wind power generation**
• **state the advantages and disadvantages of wind power generation.**

The method of generating the electrical energy by using the wind is termed as wind power generation. Since the wind has velocity and kinetic energy, it can be used to

produce electricity. For that, we can use windmills. The important part of a windmill is a structure with large leaves, fixed at the top of a high tower. The speed of leaves

changes with the speed of the wind. If the rotation of the windmill is given to the rotor of a generator, then the electricity will be obtained from the generator. If the windmill is connected to a water pump, the leaves of the windmill rotate the pump and pumping out the water.

Wind power can be usefully exploited for the generation of electricity as there are large, coastal, hill and desert areas. Wind turbines comprising of machines with blade diameter of 17 m, which can generate about 100 kilowatts. A strike of blowing wind on specially designed blades of a windmill's rotor causes both to rotate. This rotation, which is the mechanical energy, when coupled to a turbine, drive the power generator.

Operation

The schematic arrangement of wind power station is given in Fig 1.

WIND POWER GENERATION
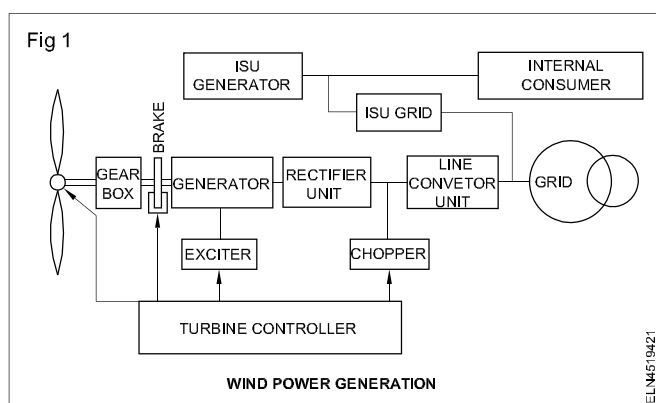
When the wind strikes the rotor blades, blades start rotating. Rotor is directly connected to high speed gear box. Gear box converts the rotor rotation into high speed which rotates the electrical generator. An exciter is needed to give the required excitation to the coil so that it can generate required voltage. The exciter current is controlled by a turbine controller which senses the wind speed based on that it calculate the power what we can achieve at that particular wind speed.

The output voltage of electrical generator is given to a rectifier and rectifier output is given to line converter unit to stabilise the output AC that is fed to the grid by a high voltage transformer. An extra units is used to give the power to internal auxiliaries of wind turbine (like motor, battery etc), this is called **internal supply unit**. ISU can take the power from grid as well as from wind. Chopper is used to dissipate extra energy from the Rectifier Unit (RU) for safety purpose.

Advantages

1 The wind energy is free, inexhaustible and does not need transportation.

2 Wind power plant on the other hand does not take long time to construct. Such wind mills will be highly desirable & economical to the rural areas which are far away from the existing grids.

3 There is a strong reason why wind power should be welcome by grids which have some hydroelectricity inputs in India. The water level in the hydel reservoir is at its lowest before the onset of the South West monsoon. If less water is drawn during the monsoon, a high level could be maintained for longer period. During the monsoon period wind energy can be used to feed the grid.

4 It is non polluting

5 It does not require high technology.

6 Electricity can be produced at a lower cost after installation.

Disadvantages

1 The major disadvantage associated in the wind power is that it is not constant and steady, which make the complications in designing the whole plant.

2 The rotor blades of wind turbine generators must sweep out large areas to produce worthwhile amount of power.

3 The wind is a very dangerous such storms can cause tremendous shear stresses which may spoil the whole plant within no time. To avoid this, special and costly designs and controls are always required.

4 Among all the disadvantages mentioned above, the cost factor is the major which has restricted the development of wind power on large scale for feeding to the existing grid. The estimated cost of wind electricity generation, storage & distribution system is over 1 lakh rupees which may be considered beyond the means of most Indian villages.

Modern wind machines are still wrestling with the problem of what to do when the wind is not blowing. Large turbines are connected to the utility power network some other type of generator picks up the load when there is no wind. Small turbines are often connected to diesel/electric generators or sometimes have a battery to store the extra energy they collect when the wind is blowing hard.

The wind energy is utilized by means of a wind mill or a series of wind mills. A wind mill consists of few vanes (normally 3 to 6) which rotate about their axis, when the wind blows against them. The rotational motion (i.e. mechanical energy) thus created is utilized for various applications, such as,

1 Lifting water from the well

2 Battery charging

3 Water pumping

4 Operating a simple machine

5 Wind energy is used for agricultural & rural applications such as grinding flour mills, wood cutting saw, stone crushers, mixers, water pumps and irrigation facility etc.

Electrical supply system - transmission - line insulators

Objectives: At the end of this lesson you shall be able to
• **explain the electrical supply system and layout of AC power supply scheme**
• **list out the various power transmission**
• **compare AC and DC transmission**
• **state the advantages of high voltage transmission**
• **state single phase and 3 phase - 3 wire system in transmission.**

Electrical supply system

The electrical energy generated from the power plants has to be supplied to the consumers. This is large network, which can be broadly divided into two stages, (ie.) Transmission and distribution.

The conveyance of electric power from a power station to the consumers / premises is called is Electrical supply system.

The Electrical power supply system consists of 3 main components viz (i) The power station / plant (ii) The transmission lines and (iii) The distribution systems. The power is produced at power plant which is away from the consumers, It has to be transmitted over long distances to load centres by transmission and to consumers through distribution network.

This supply system can be classified into

- DC or AC system

- Over head lines (or) underground system

Now a days, 3 phase, 3 -wire AC system is universally adopted as an economical proposition. In some places 3 phase - 4 wire AC system is adopted.

The underground system is more expensive than the over-head system, therefore in our country O.H system is almost adopted.

Types of power transmission system

Universally, 3 - phase - 3 wire AC system is adopted in most of the places. However other systems can also be used for transmission under special circumstances.

Possible systems are :-

1   DC system

i   DC two wire

ii   DC two - wire with mid point earthed

iii DC three wire

2   AC single phase system

i   Single-phase two wire

ii   Single - phase two wire with mid point earthed

iii Single phase three wire

3   AC Two - phase system

i   Two- phase three wire

ii   Two - phase - four wire

4   AC three phase system

i   Three - phase - three wire

ii   Three - phase - four wire

The line network between generating station (Power station) and consumer of electric power can be divided into two parts.

- Transmission system

- Distribution system

This system can be categorized as primary transmission and secondary transmission. Similarly primary distribution and secondary distribution. This is in Fig 1.

It is not necessary that the entire steps which are shown in the diagram must be included in the other power schemes. There may be difference, there is no secondary transmission in many, schemes, in some (small) schemes there is no transmission, but only distribution.

Various stages of a typical electrical power supply system, are as follows

1   Generating station

2   Primary transmission

3   Secondary transmission

4   Primary distribution

5   Secondary distribution

Generating station

The place where electric power produced by the parallel connected three phase alternators / generators is called generating station (i.e power plant).

Fig 1

GENERATING STATION
11/11.5/12KV

11KV / 220KV

PRIMARY TRANSMISSION

220 / 132 OR 66KV

RECEIVING STATION

SECONDARY TRANSMISSION

132 OR 66KV / 11KV

SUB STATION

PRIMARY DISTRIBUTION

11KV / 415V
DISTRIBUTION
SUB STATION

SECONDARY DISTRIBUTION

415 & 240 V

CONSUMERS

TYPICAL AC POWER SUPPLY SCHEME

The ordinary power plant capacity and generating voltage may be 11KV, 11.5 KV, 12KV or 13KV. But economically. It is good to step up the produced voltage from (11KV, 11.5KV or 12KV) to 132KV, 220KV, 400KV or 500KV or greater (in some countries, up to 1500KV) by step up transformer (power transformer).

Primary transmission

The electric supply (132KV, 220 KV, 500KV or greater) is transmitted to load center by three phase three wire (3 phase - 3 wires) overhead transmission system.

Secondary transmission

Area far from city (outskirt) which have connected with receiving station by line is called secondary transmission. At receiving station, the level of voltage reduced by step-down transformers up to 132KV, 66 or 33KV and electric power is transmitted by three phase three wire (3 phase - 3 wires) overhead system to different sub stations. So this is a secondary transmission.

Primary distribution

At a sub station, the level of secondary transmission voltage (132KV, 66 or 33KV) is reduced to 11KV by step down transformers.

Generally, electric supply is given to heavy consumer whose demands is 11KV, from these lines which carries 11KV (in three phase three wire overhead system) and they make a separate sub station to control and utilize this power.

In other cases, for heavier consumer (at large scale) their demand is about 132 KV or 33KV they take electric supply from secondary transmission or primary distribution (in 132KV, 66KV or 33KV) and then step down to the level of voltage by step -down transformers in their own sub station for utilization (i.e for electric traction etc).

Secondary distribution

Electric power is given to (from primary distribution line (i.e.) 11KV) distribution sub station. This sub station is located near by consumers area where the level of voltage reduced by step down transformers is 415V. These transformers are called distribution transformers, in 3 phase four wire system (3 phase - 4 wires), there is 415 volts (Three phase supply system) between any two phases and 240 volts (single phase supply) between neutral and any one of the phase (lives) wire.

Residential load (i.e. Fans, light, and TV etc) may be connected between any one phase and neutral wires, while three phase load may be connected directly to the three phase lines.

Elements of distribution system

Secondary distribution may be divided into three parts.

1 Feeders

2 Distributors

3 Service lines or service mains

Those electric lines which connect generating station (power station) or sub station to distributors are called **feeders.** Remember that current in feeders (in each point) is constant while the level of voltage may be different, the current flowing in the feeders depends on the size of conductor.

Distributors

Those tapings which extracted for supply of electric power to the consumers or those lines, from where consumers get electric supply is called **distributors** (Fig 2). Current is different in each section of the distributors while voltage may be same. The selection of distributors depends on voltage drop and may be designed according to voltage drop. It is because consumers get the rated voltage according to the rules.

Fig 2

DISTRIBUTION SYSTEM

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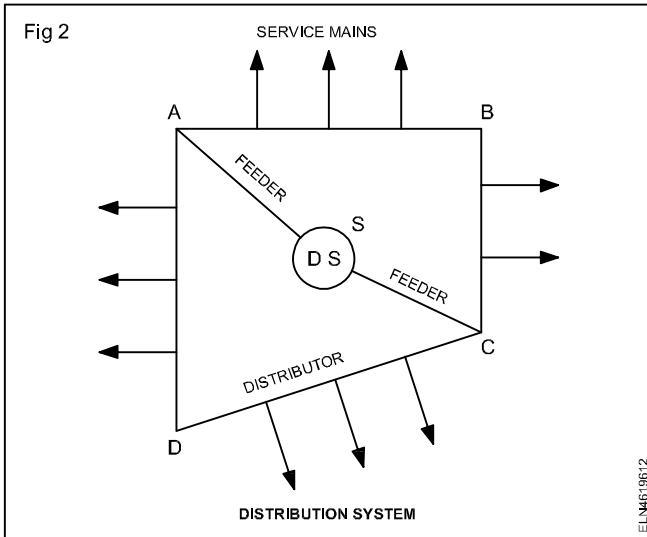
Service lines or service mains

The normal cable which is connected between distributors and consumer load terminal are called **service line or service mains.** A complete typical AC power supply system scheme is in Fig 3.

Fig 3

A.C.POWER SUPPLY SYSTEM

ELN4619613
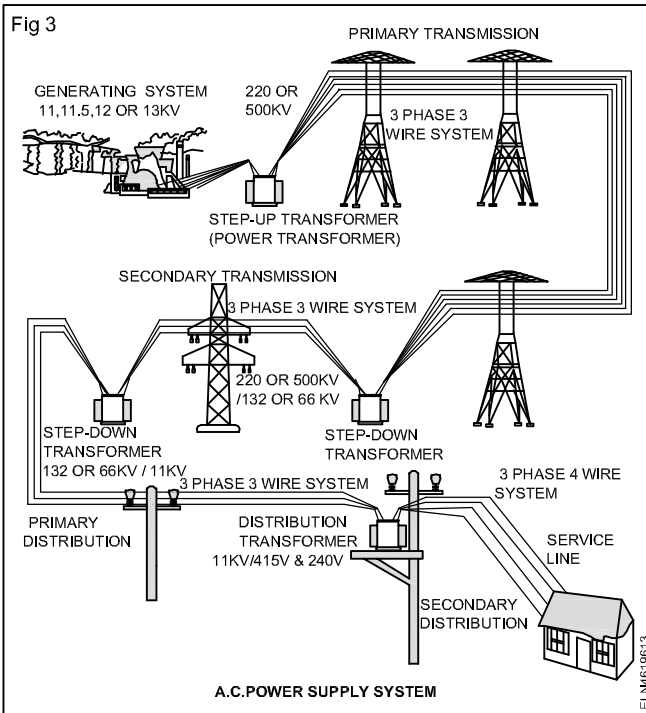
Comparison of DC and AC transmission

The electric power can be transmitted either by means of DC (or) AC. Each system has it's own merits and demerits. Some technical advantages and disadvantages of two systems are stated below.

AC transmission

Some years ago, the transmission of electric power by DC has been receiving of the active consideration of engineers due to it's appreciable advantages.

Advantages of DC electric power transmission

1   It requires only two conductors

2   There is no problem of inductance, capacitance and phase displacement which is common in AC transmission.

3   For the same load and sending end voltage, the voltage drop in DC transmission lines is less than that in AC transmission.

4   As there is no skin effect on conductors, therefore entire cross - section of conductor is usefully utilized thereby affecting saving in material.

5   For the same value of voltage insulating material on DC lines experience less stress as compared to those on AC transmission lines.

6   A DC line has less corona loss and reduced interference with communication circuits.

7   There is no problem of system instability which is so common in AC transmission.

Disadvantages of DC transmission

1   Generation of power at high DC voltages is difficult due to commutation problems and cannot be usefully utilized at consumer ends.

2   Step up or step -down transformation of DC voltages is not possible in equipment like transformer.

Advantages of AC electric power transmission

1   Power can be generated at high voltages as there is no commutation problems.

2   AC voltages can be conveniently stepped up or stepped down by using transformers.

3   High voltage transmission of AC power reduces losses.

Disadvantages of AC electric power transmission

1   Problems of inductances and capacitances exist in transmission lines.

2   Due to skin effect, more copper is required.

3   Construction of AC transmission lines is more complicated as well as costly.

4   Effective resistance of AC transmission lines is increased due to skin effect.

From the above comparison, it is clear that high voltage DC transmission is superior to high voltage AC transmission. At present, transmission of electric power is carried by AC and effort is making towards DC transmission also. The convertor and inverter have made it possible to convert AC into DC and vice versa easily. Such devices can operate upto 30MW at 400KV in single units. The present day trend is towards AC for generation and distribution at high voltage DC for transmission.

The single line diagram of high voltage DC transmission is in Fig 4. The power is generated as AC and stepped up to high voltage by the transformer at sending end (T_s) .

The AC power at high voltage is fed to the convertor which convert AC to DC. The transmission of electric power is carried at high DC voltage. At the receiving emf DC is converted into AC with the help of invertors. The AC supply is stepped down to low voltage by receiving end transformer (T_R) for distribution.


HIGH VOLTAGE D.C.TRANSMISSION
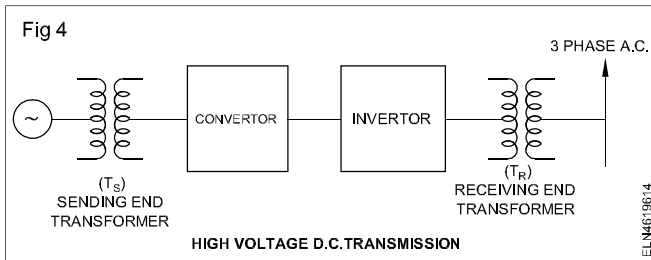
Advantages of high voltage transmission

Very high voltages are used for transmission systems because, as a general principle, the bigger the voltage the cheaper is the supply.

Since power in an AC system is expressed as **P=VI cosθ,** that means increase in voltage will reduce the current for a given amount of power. A lower current will result in reduced cable switch gear size and the line power losses, given by the equation $P = I^2R$ will also be reduced.

The 132KV grid and 400KV **supergrid transmission lines** are for the most part, steel - cored aluminimum conductors suspended on steel lattice towers, since this is about 16 times cheaper than the equivalent underground cable.

The conductors are attached to porcelain insulator strings which are fixed to the cross - members of the tower is in Fig 5. Three conductors comprise a single circuit of a three phase system so that towers with six arms carry two separate circuits.

CROSS MEMBER OF THE TOWER
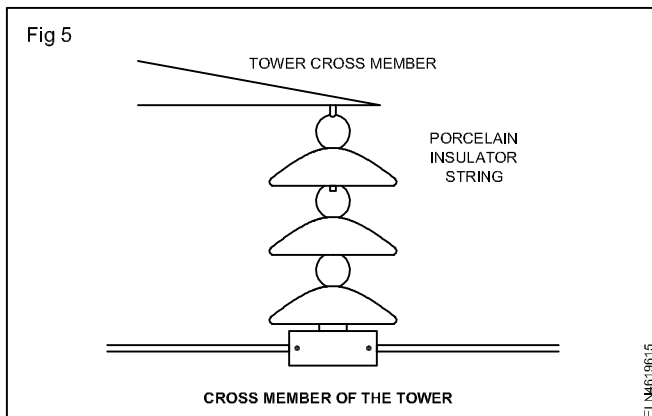
Primary distribution to consumers is from 11KV substations, which for the most part are fed from 33 KV substations, but direct transformation between 132 and 11KV is becoming common policy in city areas where over 100 MW can be economically distributed at 11KV from one site.

Fig 6 shows a block diagram indicating the voltage at the various stages of the transmission and distribution system.

**VOLTAGE STAGES OF TRANSMISSION AND DISTRIBUTION SYSTEM**
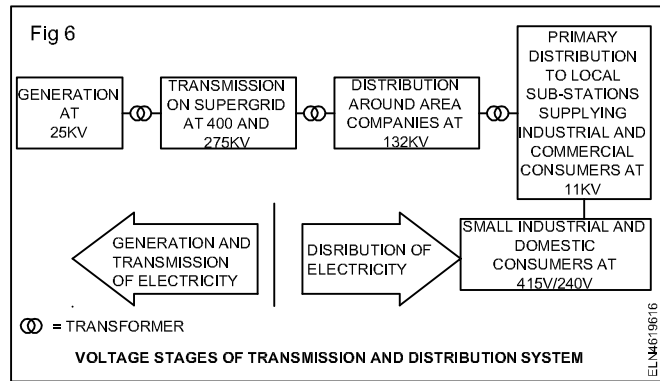
Distribution system at 11KV may be radial system offers continuous supply.

The maintenance of a secured supply is an important consideration for any electrical engineer or supply authority because in industrial society, a loss of supply may cause inconvenience, financial loss and danger to the consumer or the public.

The principle employed with a ring system is that any consumer's substation is fed from two directions, and by carefully grading the overload and cable protection equipment a fault can be disconnected without loss of supply to the consumers.

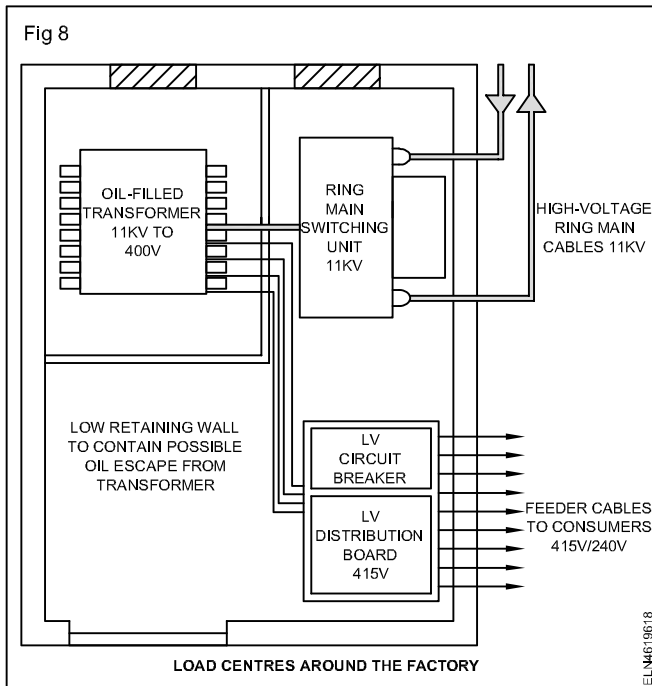Fig 7 is a simplified diagram of distribution of electricity from power station to consumer.

DISTRIBUTION OF ELECTRICITY FROM POWER STATION TO CONSUMER
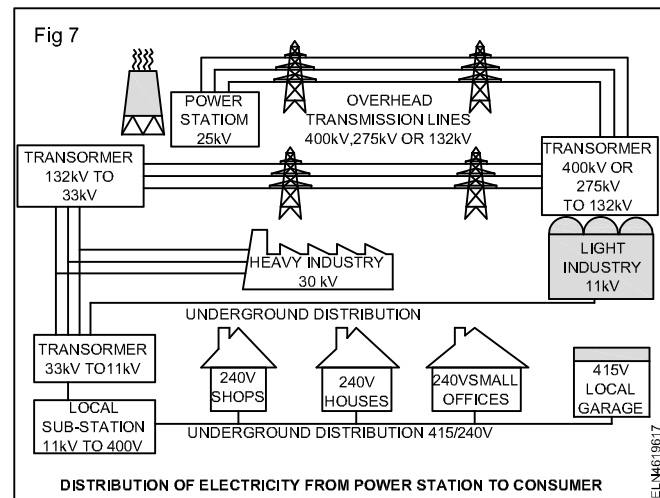
High voltage distribution

High voltage distribution to primary substation is used by the electricity boards to supply small industrial, commercial and domestic consumers.

This distribution method is also suitable for large industrial consumers where 11KV substations as in Fig 8 may be strategically placed at load centres around the factory site.

The final connections to plant, distribution boards, commercial or domestic loads are usually by simple underground radial feeders 415V/240V.

Fig 8

OIL-FILLED TRANSFORMER 11KV TO 400V

RING MAIN SWITCHING UNIT 11KV

HIGH-VOLTAGE RING MAIN CABLES 11KV

LOW RETAINING WALL TO CONTAIN POSSIBLE OIL ESCAPE FROM TRANSFORMER

LV CIRCUIT BREAKER

LV DISTRIBUTION BOARD 415V

FEEDER CABLES TO CONSUMERS 415V/240V

LOAD CENTRES AROUND THE FACTORY

ELN4619618

These outgoing circuits are usually protected by circuit breakers in a distribution board.

The 415 V/240V is derived from the 11KV/415V sub-station transformer by connecting the secondary winding in star is in Fig 9.

Fig 9

415V THREE-PHASE AND NEUTRAL LOAD

415V THREE-PHASE LOAD

BROWN PHASE

BROWN PHASE

GREY PHASE

BLUE NEUTRAL

SUB-STATION TRANSFORMER 11kV/415V

240V SINGLE-PHASE LOAD

240V SINGLE-PHASE LOAD

240V SINGLE-PHASE LOAD

415V SINGLE-PHASE LOAD

11kV/415V SUBSTATION WITH SECONDARY OF TRANSFORMER IN STAR

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The star point is earthed to an earth electrode sunk into the ground below the substation, and from this point is taken the fourth conductor, the neutral. Loads connected between phases are fed at 415V, and those fed between one phase and neutral at 240V.

A three - phase 415V, supply is used for supplying small industrial and commercial loads such as garages, schools and blocks of flats. A single - phase 240V supply is usually provided for individual domestic consumers.

Line insulators

Objectives: At the end of this lesson you shall be able to
• **explain the types of insulators and their uses**
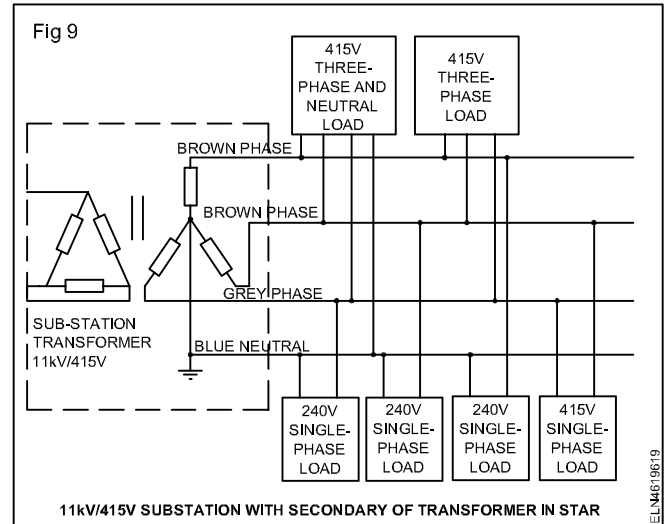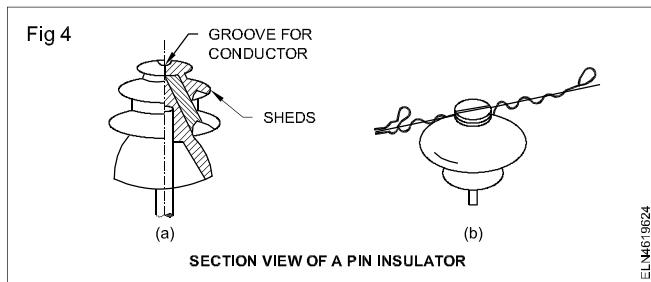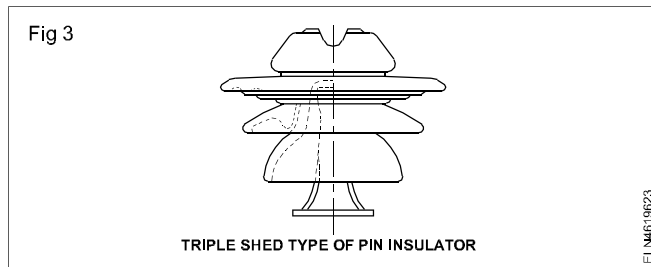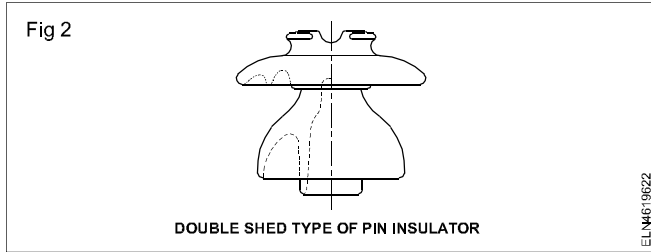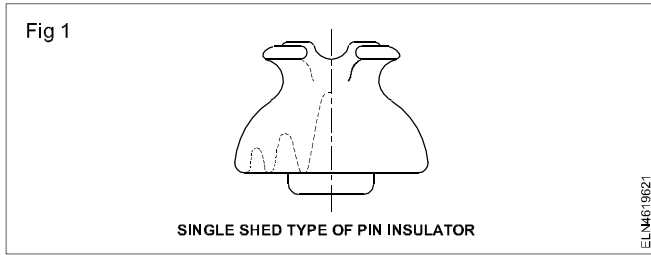• **explain the method of binding of the insulators.**

Line insulators

The aim of using a line insulator in an overhead line is to hold the live conductor to prevent leakage of current from the conductor to the pole. These are made of porcelain clay and are thoroughly glazed to avoid the absorption of moisture from the atmosphere.

Properties of insulators

i   High mechanical strength in order to withstand conductor load, wind load etc.

ii   High electrical resistance of insulator material in order to avoid leakage currents to earth.

iii   High relative permittivity of insulator material in order that dielectric strength is high.

iv   The insulator material should be non - porous, free from impurities and cracks otherwise the permittivity will be lowered.

v   High ratio of puncture strength to flash over.

The most commonly used material for insulators of overhead line is porcelain but glass, steatite and special composition materials are also used to a limited extent.

The following are the common types of insulators in use.

• Pin type insulator

• Shackle insulator

• Suspension insulator

• Strain insulator

• Post insulator

• Stay insulator

• Disc insulator

Pin Insulators : Pin insulators are used for holding the line conductors on straight running of poles. Pin insulators are three types. i.e single shed (Fig 1) double shed (Fig 2) and triple shed (Fig 3) The single -shed pin insulators are used for low and medium voltage lines. The double and triple shed pin insulators are used for over 3000V. These sheds are used to drip off the rain water.

The part section of a pin type insulator is in Fig 4a & 4b As the name suggest, the pin type insulator is secured to the cross - arm on the pole. There is a groove on the top of the insulator for housing the conductor. The conductor passes through this groove and is bound by the annealed wire of the same material as the conductor.

Fig 1

SINGLE SHED TYPE OF PIN INSULATOR

Fig 2

DOUBLE SHED TYPE OF PIN INSULATOR

Fig 3

TRIPLE SHED TYPE OF PIN INSULATOR

Fig 4

GROOVE FOR CONDUCTOR

SHEDS

(a)   (b)

SECTION VIEW OF A PIN INSULATOR

Shackle insulators : Shackle insulators are generally used for terminating on corner poles. These insulators are used for medium voltage line only. (Fig 5a & 5b)

Fig 5

Ø115
Ø20
100
Ø55
Ø100

PIN

SHACKLE INSULATOR TYPE II

SHACKLE INSULATOR TYPE III

(a)   (b)
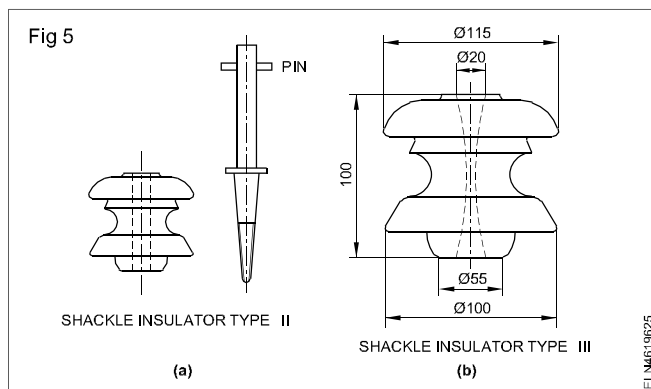
But now a days, they are frequency used for low voltage distribution lines. Such insulators can be used either in horizontal position or in a vertical position. They can be directly fix to the pole with a bolt or to the cross arm. Fig 6 shows a shackle insulator fixed to the pole. The conductor in the groove is fixed with a soft binding wire.

Fig 6

BOLT

SHAKLE INSULATOR

POLE

D - STRAP

SHACKLE TYPE INSULATOR
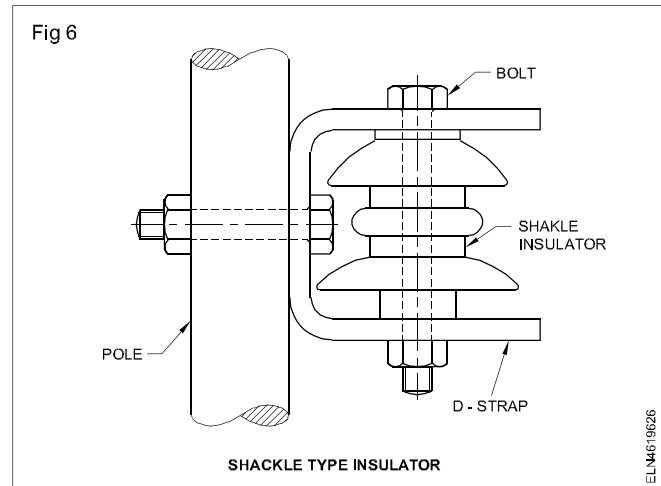
Suspension type insulators

The cost of pin type insulator increases rapidly as the working voltage is increased. Therefore, this type of insulator is not economical beyond 33 KV. For high voltage (>33KV), it is a usual practice to use suspension type insulators as in Fig 7. They consist of a number of porcelain discs connected in series by metal links in the form of a string. The conductor is suspended at the bottom end of this string while the other end of the string is secured to the cross- arm of the tower. Each unit or disc is designed for low voltage, say 11KV. The number of discs in series would obviously depend upon the working voltage. For instance, if the working voltage is 66KV, then six discs in series will be provided on the string.

Fig 7

INSULATOR

LINE CONDUCTOR

SUSPENSION INSULATOR
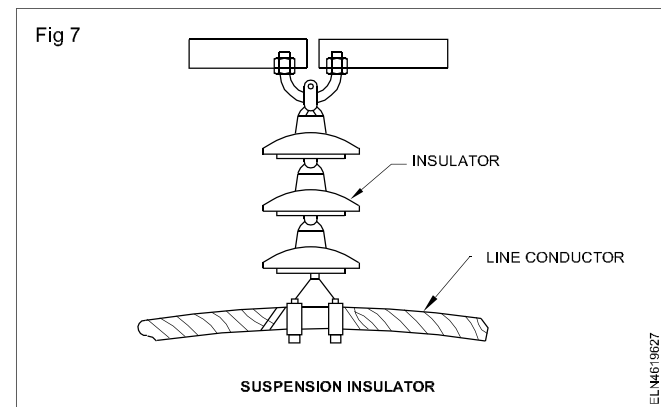
Advantages

1   Suspension type insulators are cheaper than pin type insulators for voltage beyond 33 KV.

2   Each unit or disc of suspension type insulator is designed for low voltage, usually 11KV. Depending upon the working voltage, the desired number of discs can be connected in series.

3   If any one disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.

4   The suspension arrangement provides greater flexibility to the line. The connection at the cross arm is such that insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.

5   In case of increased demand on the transmission line it is found more satisfactory to supply the greater demand by raising the line voltage than to provide another set of conductors. The additional insulation required for the raised voltage can be easily obtained in the suspension arrangement by adding the desired number of discs.

6   The suspension type insulators are generally used with steel towers. As the conductors run below the earthed cross arm of the tower, therefore, this arrangement provides partial protection from lighting.

Strain insulators

When there is a dead end of the line or there is corner or sharp curve, the line is subjected to greater tension. In order to relieve the line of excessive tension, the strain insulators are used. For low voltage lines (<11KV) shackle insulators are used as strain insulators. However for high voltage transmission lines, strain insulator consists of an assembly of suspension insulators. The discs of strain insulators are used in the vertical plane. When the tension in the lines is excessively high, as at long river spans, two or more strings are used in parallel.

Post insulators

Cap and pin type (Fig 8a & 8b) : Such insulators can be used for mounting of buses, dropout fuses, line conductors, G.O.A.B (Gang Operated Air Break) switches. These are of outdoor type and are available in 11, 22 and 33KV ranges.

a) CAP AND PIN INSULATOR FOR GOAB SWITCH   b) ANOTHER DESIGN OF CAP AND PIN INSULATOR FOR GOAB SWITCH
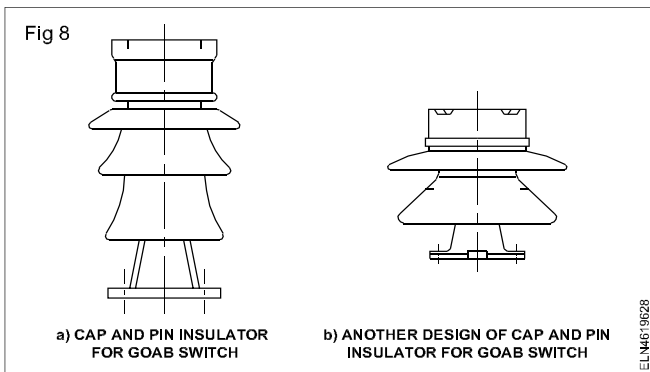
Stay insulators (Fig 9) : Stay insulators are also known as strain insulators and are generally used up to 33 KV line. These insulators should not be fixed below three metres from the ground level. These insulators are also used where the lines are strained.
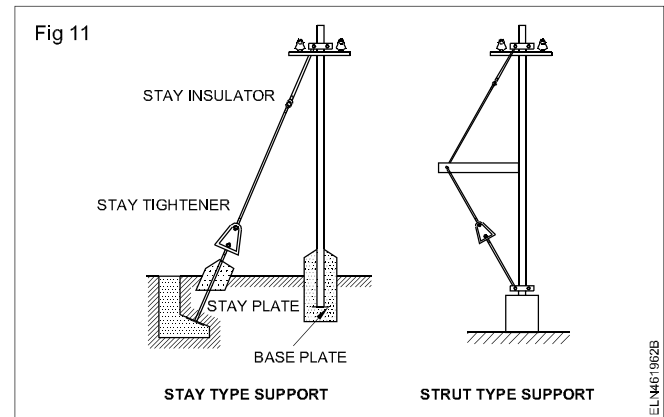

STAY INSULATOR
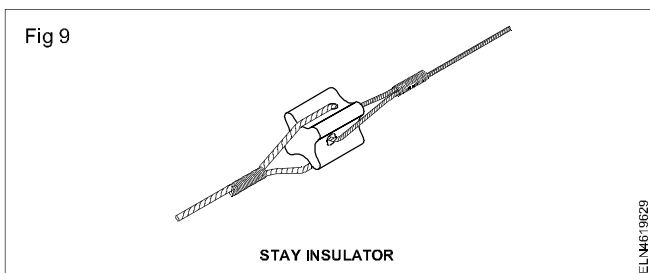
The supporting wire which is used in the opposite direction of tension on the pole due to overhead conductors is known as 'stay wire'. It prevents the bending of the pole due to tension of the conductor. These stay wires consist of 4 to 7 strands of GI wire is in Fig 10. The correct size to be used depends upon the tension on the pole.

GI STAY WIRE & CLAMP
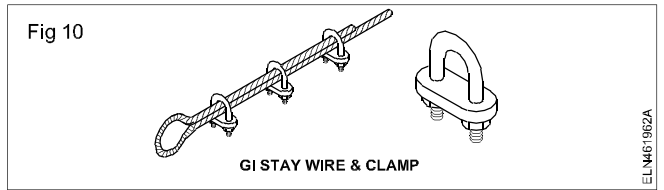
Stays and struts: Stays and struts are the different types of supporting wires for the pole. Stays are generally used for angle and terminating poles to prevent the bending of the pole whereas struts are used where space for stay is very limited. Fig 11 shows both the stay and the strut.

STAY INSULATOR
STAY TIGHTENER
STAY PLATE
BASE PLATE
STAY TYPE SUPPORT   STRUT TYPE SUPPORT

One end of the stay is fixed at the top of the pole and its other end is grouted in the concrete foundation.

Disc insulators : Disc insulators are made of glazed porcelain or tough glass and are used as insulators at dead ends, or on straight lines as suspension type for voltages 3.3 kV and above. (Figs 12, 13 and 14)

These are available in four designs:

Tongue and clevis type (Fig 12): A round pin with a cotter pin is used to hold the tongue of one unit in the clevis of the other.


DISC INSULATOR TONGUE AND CLEVIS TYPE
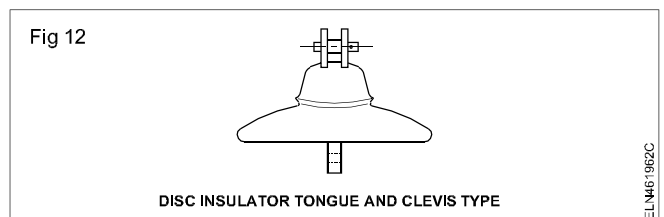
Ball and socket type (Fig 13): In this case insulators are assembled by sliding the ball of one insulator from the side. A cotter pin is slipped in from the back of the socket so that the ball cannot slide out. These are used at dead ends.

DISC INSULATOR BALL AND SOCKET TYPE
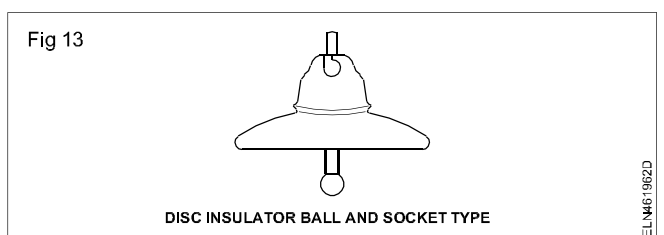
Insulators for cold climate (Fig 14): For cold climate the depth of the lower cap is increased to get creepage distance which becomes necessary in cold climates. Two designs known as fog type and anti-fog types are available.

Fig 14

DISC INSULATOR COLD AND CLIMATE TYPE
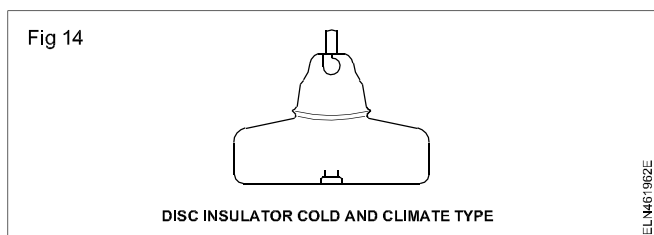
Guard wires

These are a set of wires erected as a preventive guard to falling conductors so that the live conductor after breaking does not come in touch with the public or moving vehicles. These are erected in places where the line crosses a street, road or railway line, OH power or communication lines and others.

Minimum clearance required between conductors on the same support :-

a) L.T. lines

i) Vertical configuration of conductors :-

Minimum clearance between earth and live conductors is 30 cm.

Minimum clearance between live conductors is 20 cm.

ii) Horizontal configuration of conductors :-

Minimum clearance between live wires on either side of a support is 45 cm.

Minimum clearance between live wires on the same side of support is 30 cm.

Minimum distance between the centre of insulator pin hole and end of cross-arm is 8cm.

b) H.T. lines

Triangular configuration :-

Minimum distance between the centre of insulator pin hole and end of cross arm is 10 cm.

The conductors are erected in such a way that they form an equilateral pattern of side of 1 metre minimum.

Necessity of binding: In overhead transmission lines, the line conductors have to be tied to the post type and shackle type insulators to hold the wire in the correct position, without allowing for any further change in position after stretching the wires by wire stretchers with allowable 'sag' as required.

Method of binding insulator in overhead lines: The insulators should be bound with the line conductor with the help of copper binding wire in case of copper conductors, galvanised iron binding wire for galvanised iron conductors and aluminium binding wire tape for aluminium and aluminium steel reinforced conductors (ACSR). The size of the binding wire should not be less than 2 sq mm.

After binding of the aluminium cored conductors, the binding joint is provided with protective grease. The binding turns must be very close (without any gap) and must be very tight enough so that more sparking is avoided.

While binding, only a mallet has to be used for making the conductor straight and hammer should never be used.

Current carrying capacity of a conductor

Introduction

The current carrying capacity of a insulated conductor or cable is the maximum current that it can continuously carry without exceeding its temperature rating it is also known as ampacity.

While the cables are in operation they suffer electrical losses which is manifest on heat in the conductor, insulation and any others metallic components in the construction.

The current rating will depend on hand this heat in dissipated through the cable surface and into the surrounding areas. The temperature rating of the cable is a determining factor in the current carrying capacity of the cable. The maximum temperature rating for the cable is essentially determined by the insulation material.

By choosing an ambient temperature as a base for the surroundings, a permissible temperature rise is available from which a maximum cable rating can be calculated for a particular environment. If the thermal resistivity values are known for the layers of materials in the cable construction then the current rating scan be calculated.

The formula for calculating current carrying capacity in given an

$$I = \left(\frac{\Delta\theta - W_d \left[\frac{1}{2}T_1 + \eta(T_2 + T_3 + T_4) \right]}{RT_1 + \eta R(1+\lambda_1) + T_2 + \eta R(1+\lambda_1+\lambda_2)(T_3+T_4)} + \right)^{\frac{1}{2}}$$

where

I = Permissible current rating

$\Delta\theta$ = Conductor temperature rise in (K)

R = AC resistance per unit length of the conductor at maximum operating temperature (Ω/m)

T_1 = Dielectric loss per unit length between one conductor and the sheath (K_m/W)

T_2 = Thermal resistance per unit length of the bedding between sheath and the armour (K_m/W)

T_3 = Thermal resistance per unit length of the external sheath of the cable (K_m/W)

T_4 = Thermal resistance per unit length between the cable surface and the surrounding medium (K_m/W)

W_d = Dielectric loss per unit length for the insulation surrounding the conductor. (W/m)

η = Number load carrying conductors in the cable (conductors of equal size and carrying the same load)

λ_1 = Ratio of loses in the metal sheath to total losses in all conductors in that cable.

λ_2 = Ratio of losses in the armouring to total losses in all conductors in that cable.

NEC (National Electrical Code)

When selecting a cable it must know its wire ampacity rating. This rating has been determined by the NEC (National Electrical Code)

Overhead lines /poles erection-fastening of insulator

Objectives: At the end of this lesson you shall be able to
• **state the power transmission and distribution by O.H lines**
• **list out the main components and explain each of them**
• **explain the line supports used in transmission lines**
• **state the types of power lines with respect to the classification of voltage**
• **state about corona effect, sag and skin effect in O.H lines.**

Overhead lines

Electric power, which is generated from generating plant / station to the consumer end is transmitted and distributed either by means of overhead lines (O.H) or by under ground cables (U.G. cables).

Electrical power transmission is the bulk movement of electrical energy from generated power plant to electrical substation. This inter connected lines are known as **transmission network.** The electrical link from substations to customer is typically referred as electrical power **distribution.** The combined transmission and distribution network is known as the **'Power Grid'.**

Electricity is transmitted at high voltages (11, 33, 66, 230, 400, and 500 Kv) to reduce the energy loss which occurs in long distance transmission. The power is actually transmitted through O.H lines (or) underground cables.

The O.H lines are high voltage three phase alternating current, and also single phase A.C sometimes used in Railway Electrification system. High voltage Direct-Current (HVDC) is used for greater efficiency even for very long distances, used in submarine power cables and to stabilize large power distribution network.

Main components used in O.H lines

An overhead line may be used to transmit or distribute electric power. The successful operation of an overhead line depends to a great extent upon the mechanical design of the line. While constructing an overhead line, it should be ensured that mechanical strength of the line is such so as to provide against the most probable weather conditions. In general, the main components of an overhead line are,

i   Conductors which carry electric power from the sending end station to the receiving end station.

ii Supports which may be poles or towers and keep the conductors at a suitable level above the ground.

iii Insulators which are attached to supports and insulate the conductors from the ground.

iv Cross arms which provide support to the insulators.

v   Miscellaneous items such as phase plates, danger plates, lightning arrestors, anti-climbing wires etc.

Conductor materials

The conductor is one of the important items as most of the capital outlay is invested for it. Therefore, proper choice of material and size of the conductor is of considerable importance. The conductor material used for transmission and distribution of electrical power should have the following properties.

i   High electrical conductivity

ii High tensile strength in order to withstand mechanical stresses.

iii Low cost so that it can be used for long distances.

iv Low specific gravity so that weight per unit volume is small.

Commonly used conductor materials

The most commonly used conductor material for overhead lines are copper, aluminium, steel reinforced aluminium, galvanized steel and cadmium copper. The choice of a particular material will depend upon the cost and the required electrical and mechanical properties and the local conditions.

All conductors used for overhead lines are preferably stranded in order to increase the flexibility. In stranded conductors, there is generally one central wire and round this, successive layers of wires containing 6, 12, 18, 24... wires.

Copper

Copper is an ideal material for overhead lines owing it its high electrical conductivity and greater tensile strength. It is always used in the hard drawn form as stranded conductor. Although hard drawing decreases the electrical conductivity slightly yet it increases the tensile strength considerably.

Aluminium

Aluminium is cheap and light as compared to copper but it has much smaller conductivity and tensile strength. The relative comparison of the two materials is briefed below.

The conductivity of aluminium is 60% that of copper. The smaller conductivity of aluminium means that for any particular transmission efficiency, the cross sectional area of conductor must be larger in aluminium than in copper. For the same resistance, the diameter of aluminium conductor is about 1.26 times the diameter of copper conductor.

Steel cored aluminium

In order to increase the tensile strength, the aluminium conductor is reinforced with a core of galvanized steel wires. The composite conductor thus obtained is known as steel cored aluminium and is abbreviated as ACSR (Aluminium Conductor Steel Reinforced).

Steel-cored aluminium conductor consists of central core of galvanized steel wires surrounded by a number of aluminium strands (Fig 1). Usually, diameter of both steel and aluminium wires is the same.

STEEL CORED ALUMINIUM CONDUCTOR
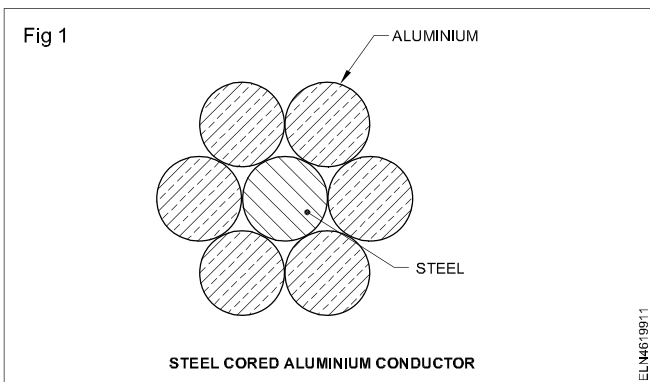
Galvanised steel

Steel has a very high tensile strength. Therefore, galvanized steel conductors can be used for extremely long-spans, or for short line sections exposed to abnormally high stresses due to climatic conditions. They have been found very suitable in rural areas where cheapness is the main consideration. Due to poor conductivity and high resistance of steel, such conductors are not suitable for transmitting large power over a long distance.

Line Supports

The supporting structures for overhead line conductors are various types of poles and towers called line supports. In general, the line supports should have the following properties:

i   High mechanical strength to withstand the weight of conductors and wind loads etc.

ii Light in weight without the loss of mechanical strength

iii Cheap in cost and economical to maintain.

iv Longer life

v   Easy accessibility of conductors for maintenance

The line supports used for transmission and distribution of electric power are of various types including wooden, poles, steel poles, R.C.C poles and lattice steel towers. The choice of supporting structures for a particular case depends upon the line span, cross sectional area, line voltage, cost and local conditions.

Wooden poles

These are made of seasoned wood (sal or ehir) and are suitable for lines of moderate cross sectional area and of, relatively shorter spans, say up to 50 metres. Such supports are cheap, easily available, provide insulating properties and, therefore are widely used for distribution purposes in rural areas as an economical proposition. . Double pole structures of the 'A' or 'H' type are often used (see Fig 2) to obtain a higher transverse strength than could be economically provided by means of single poles.

The main objections to wooden supports are: (i) tendency to rot below the ground level (ii) comparatively smaller life (20 – 25 years) (iii) cannot be used for voltage higher than 20 kV (iv) less mechanical strength and (v) require periodical inspection.

Steel poles

The steel poles are often used as a substitute for wooden poles. They possess greater mechanical strength, longer life and permit longer spans to be used. Such poles are generally used for distribution purposes in the cities. This type of supports need to be galvanized or painted in order to prolong its life. The steel poles are of three types viz (i) rail poles (ii) tubular poles and (iii) rolled steel joints.

RCC Poles

The reinforced cement concrete (RCC) poles have become very popular as line supports in recent years. They have greater mechanical strength, longer life and permit longer spans than steel poles. Moreover, they give good outlook, require little maintenance and have good insulating properties. Fig 3 shows R.C.C poles for single and double circuit. The holes in the poles facilitate the climbing of poles and at the same time reduce the weight of line supports.

The main difficulty with the use of these poles is the high cost of transport owing to their heavy weight. Therefore, such poles are often manufactured at the site in order to avoid heavy cost of transportation.

Steel towers

In practice, wooden, steel and reinforced concrete poles are used for distribution purpose at low voltages, say upto 11 KV. However for long distance transmission at higher voltage, steel towers are invariably employed. Steel towers have greater mechanical strength, longer life, can withstand more severe climatic conditions and permit the

use of longer spans. The risk of interrupted service due to broken or punctured insulation is considerably reduced owing to longer spans. Tower footings are usually grounded by driving rods into the earth. This minimizes the lightning troubles as each tower acts as a lightning conductor.

Fig 4 (a) shows a single circuit tower. However, at a moderate additional cost, double circuit tower can be provided as shown in Fig 4(b). The double circuit has the advantage that it ensures continuity of supply. In case there is breakdown of one circuit, the continuity of supply can be maintained by the other circuit.

Fig 2

INSULATORS

CROSS ARMS

STEEL BRACING

POLES

WOODEN POLES
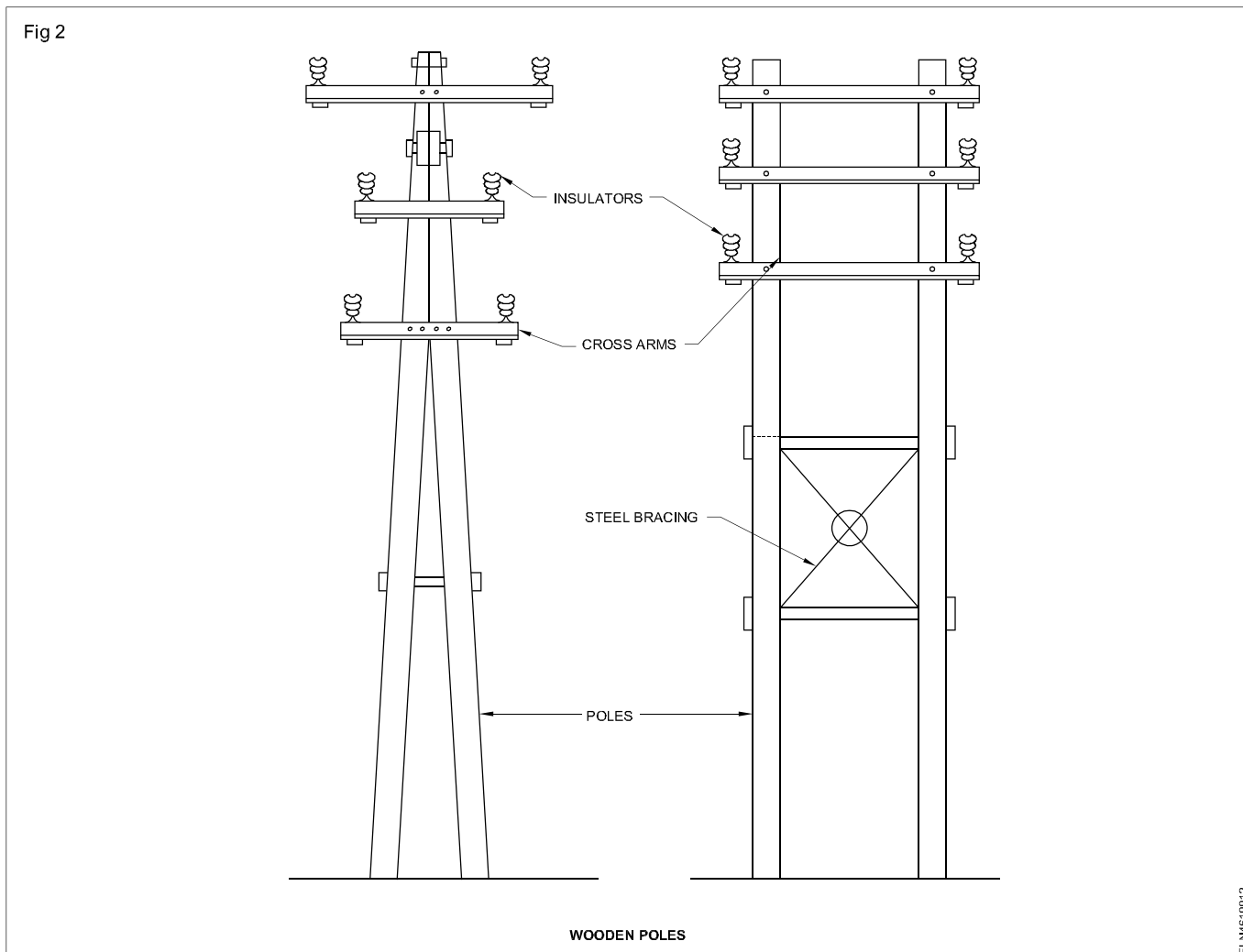
Types of power line

Electrical energy is generated, transmitted and distributed in the form of alternating current as an economical proposition. The electrical energy produced at the power station is transmitted at very high voltages by 3-phase, 3-wire system to step-down sub stations for distribution. The distribution system consists of two parts viz. primary distribution and secondary distribution. The primary distribution circuit is 3-phase, 3-wire and operates at voltages 3.3 or 6.6. or 11 KV which is somewhat higher than general utilisation levels. It delivers power to the secondary distribution circuit through distribution transformers situated near consumers' localities. Each distribution transformer steps down the voltage to 415 V and power is distributed to ultimate consumers by 415/240 V, 3-phase, 4-wire system.

The electric supply is transmitted at different voltages through over head lines and the types of power lines are furnished below:

a. Low voltage line (should not exceed 250V)

b. Medium voltage line (should not exceed 650V)

c. High voltage line (should not exceed 33000V (33 KV)

d. Extra high voltage line (above 33KV)

Voltage standard

The voltage standard of above types have been defined in I E Rules 2

"Voltage" means the difference of electric potential measured in volts between any two conductors or between any part of either conductor and the earth as measured by a suitable voltmeter and is said to be;
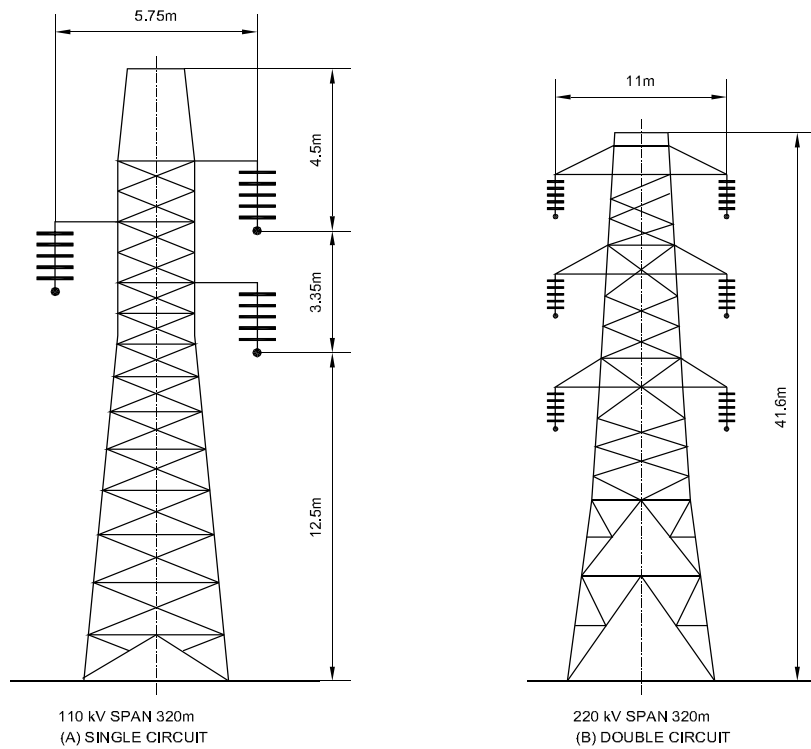
Fig 3

0.8m
0.8m
1.5m
10m
7.5m

0.35m

(A) SINGLE CIRCUIT

0.35m
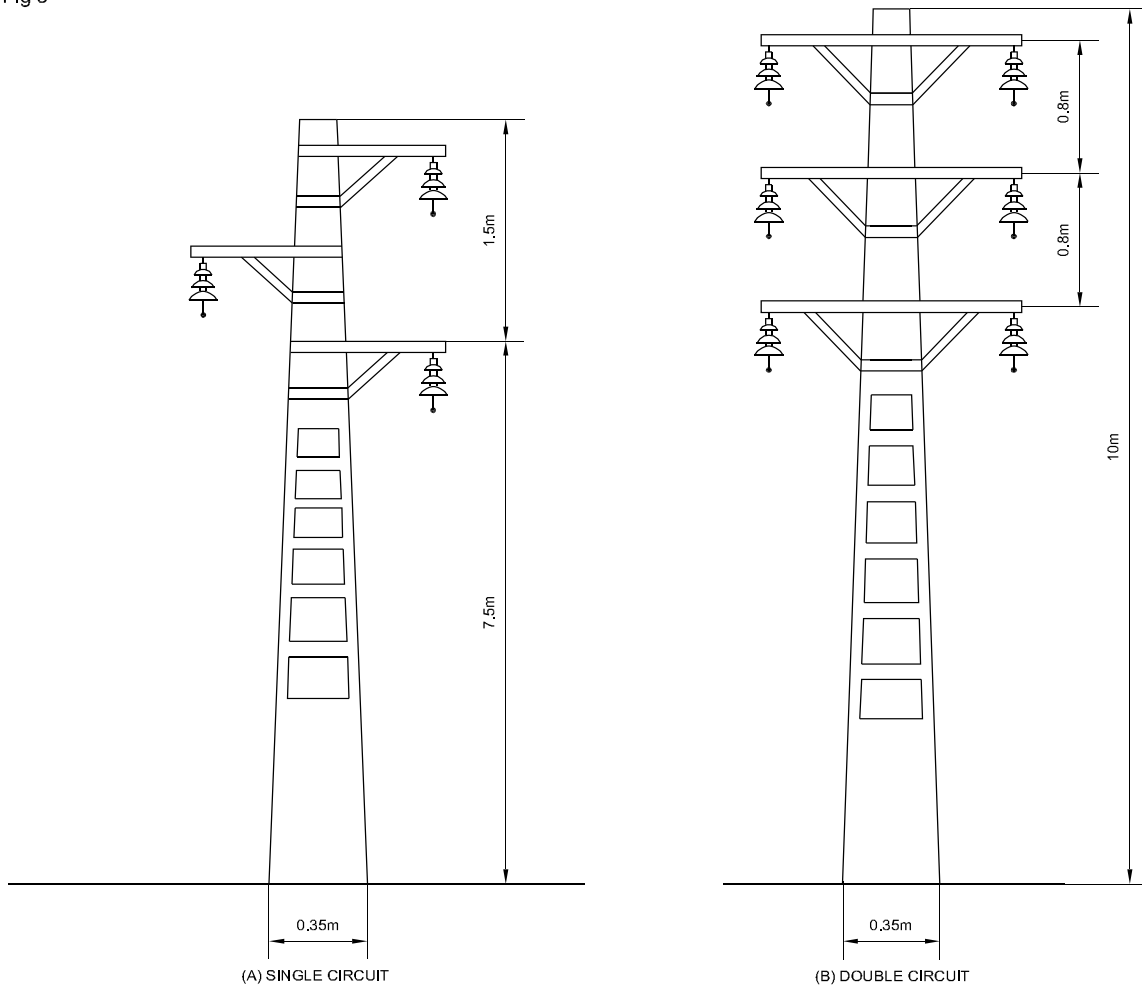
(B) DOUBLE CIRCUIT

RCC POLES

Fig 4

5.75m

4.5m

3.35m

12.5m

11m

41.6m

110 kV SPAN 320m
(A) SINGLE CIRCUIT

220 kV SPAN 320m
(B) DOUBLE CIRCUIT

STEEL TOWERS

ELN4619913

ELN4619914

Low where the voltage does not exceed 250 volts

Medium where the voltage does not exceed 650 volts

High where the voltage does not exceed 33,000 volts

"Extra high" where the voltage exceeds 33,000 volts

The nominal system voltage generally used is given below:

a) 240 V

b) 415 V

c) 650 V

d) 11 kV

e) 33 kV

f) 66 kV

g) 110 kV

h) 132 kV

i) 220 kV

j) 400 kV

k) 800 kV

Corona

The phenomenon of violet glow, hissing noise and production of ozone gas around an overhead transmission line is known as **corona.**

When an alternating potential difference is applied across two conductors whose spacing is large as compared to their diameters, there is no apparent change in the condition of atmospheric air surrounding the wires if the applied voltage is low. However, when the applied voltage exceeds a certain value, called critical disruptive voltage, the conductors are surrounded by a faint violet glow called **corona.**

Factors affecting Corona

The phenomenon of corona is affected by the physical state of the atmosphere as well as by the conditions of the line. The following are the factors upon which corona depends:

1 Atmosphere

2 Conductor size

3 Spacing between conductors

4 Line voltage

Advantages and Disadvantages of Corona

Corona has many advantages and disadvantages.

Advantages

(i) Due to corona formation, the air surrounding the conductor becomes conducting and hence virtual diameter of the conductor is increased. The increased diameter reduces the electrostatic stresses between the conductors.

(ii) Corona reduces the effects of transients produced by surges.

Disadvantages

(i) Corona is accompanied by a loss of energy. This affects the transmission efficiency of the line.

(ii) Ozone is produced by corona and may cause corrosion of the conductor due to chemical action.

(iii) The current drawn by the line due to corona is non-sinusoidal. This may cause inductive interference with neighbouring communication lines.

(e.g. bigger cross arms and supports) may increase to a considerable extent.

Sag in Overhead Lines

The difference in level between points of supports and the lowers point on the conductor is called **'Sag'.**

Fig 5 (a) shows a conductor suspended between two equal level supports A and B. The conductor is not fully stretched but is allowed to have a dip. The lowest point of the conductor is O and the sag is S. Fig 5(b) shows unequal level supports.

Fig 5

(a) EQUAL LEVEL SUPPORTS   (b) UNEQUAL LEVEL SUPPORTS

SAG
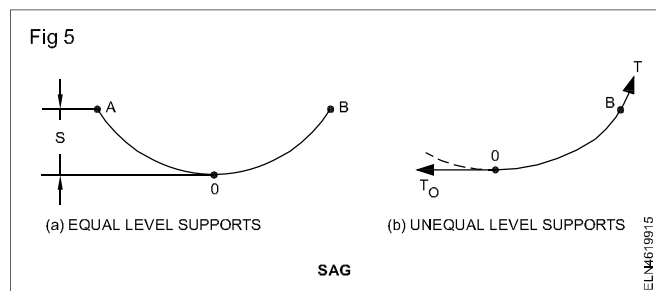
Conductor sag and tension

This is an important consideration in the mechanical design of overhead lines. The conductor sag should be kept to a minimum in order to reduce the conductor material required and to avoid extra pole height for sufficient clearance above ground level.

Classification of Overhead Transmission Lines

The capacitance effect introduces complications in transmission line calculations. Depending upon the manner in which capacitance is taken into account, the overhead transmission lines are classified as:.

(i) Short transmission lines: When the length of an overhead transmission line is up to about 50 km and the line voltage is comparatively low (<20 KV), it is usually considered as a short transmission line. Due to smaller length and lower voltage, capacitance effects are small and hence can be neglected.

(ii) Medium transmission lines : When the length of an over-head transmission line is about 50 – 150 km and the line voltage is moderately high (20 KV - 100 KV), it is considered as a medium transmission line. Due

to sufficient length and voltage of the line, the capacitance effects are taken into account.

(iii) Long transmission lines: When the length of an over-head transmission line is more than 150 km and line voltage is very high (>100 KV), it is considered as a long transmission line. For the treatment of such a line, the line constants are considered uniformly distributed over the whole length of the line.

The two important terms for performance of transmission lines are

(i) Voltage Regulation

The difference in voltage at the receiving end and sending end of a transmission line is called Voltage regulation and is expressed as a percentage of the receiving end voltage.

Mathematically, %age Voltage regulation =

$$\frac{V_S - V_R}{V_R} \times 100$$

V_s = Sending end voltage

V_R = Receiving end voltage

Obviously, it is desirable that the voltage regulation of a transmission line should be low i.e. the increase in load current should make very little difference in the receiving end voltage.

(ii) Transmission efficiency: The power obtained at the receiving end of a transmission line is generally less than the sending end power due to losses in the line resistance.

The ratio of receiving end power to the sending end power of a transmission line is known as the transmission efficiency of the line.i.e.

Percentage of Transmission efficiency =

$$\frac{\text{Receiving end power}}{\text{Sending end power}} \times 100$$

$$= \frac{V_R I_R \cos\phi_R}{V_S I_S \cos\phi_S} \times 100$$

Where, $V_R I_R$ and $\cos\phi_R$ are the receiving end voltage, current and power factor while $V_S I_S$ and $\cos\phi_S$ are the corresponding values at the sending end.

Constants of a Transmission Line

A transmission line has resistance, inductance and capacitance uniformly distributed along the whole length of the line.

(i) Resistance: It is the opposition of line conductors to the current flow. The resistance is distributed uniformly along the whole length of the line as shown in Fig 6

(ii) Inductance: When an alternating current flows through a conductor, a changing flux is set up which links the conductor. Due to these flux linkages, the conductor possesses inductance. Mathematically, inductance is defined as the flux linkage per ampere i.e.

Inductance, $L = \frac{\varphi}{I}$ henry

Where ϕ = flux linkages in weber-turns

         I = current in amperes.

The inductance is also uniformly distributed along the length of the line is in Fig 6 (a). Again for the convenience of analysis, it can be taken to be lumped as in Fig 6 (b).


Fig 6

(a) UNIFORM DISTRIBUTION OF INDUCTANCE

(b) LUMPED INDUCTANCE
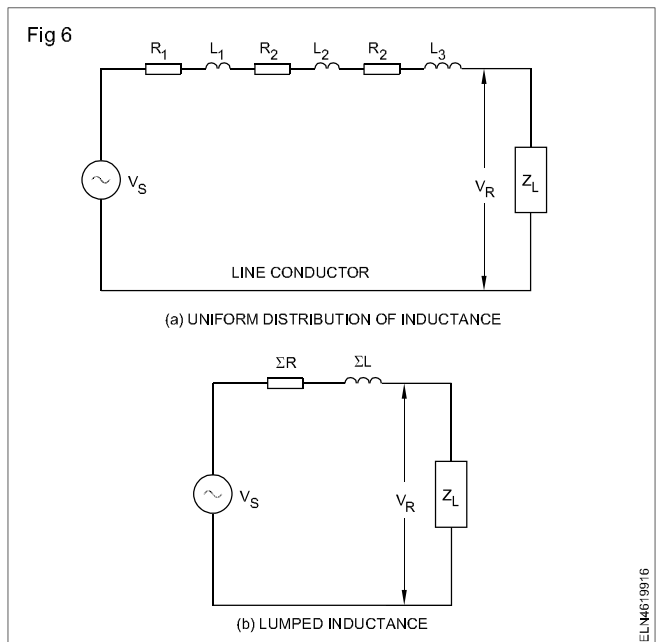
(iii) Capacitance.   If any two conductors of an overhead transmission line are separated by air which acts as an insulation. The capacitance exists between any two overhead line conductors. The capacitance between the conductors is the charge per unit potential difference i.e.

Capacitance, $C = \frac{q}{v}$ farad

Where   q =   charge on the line in coulomb

v =   p.d. between the conductors in volts.

The capacitance is uniformly distributed along the whole length of the line and may be regarded as a number of capacitors connected between the conductors as in Fig 7 (a). When an alternating voltage is impressed on a transmission line, the charge on the conductors at any point increases and decreases with the increase and

decrease of the instantaneous value of the voltage between conductors at the point.

Fig 7

(a) UNIFORM DISTRIBUTION OF CAPACITANCE

(b) LUMPED CAPACITANCE
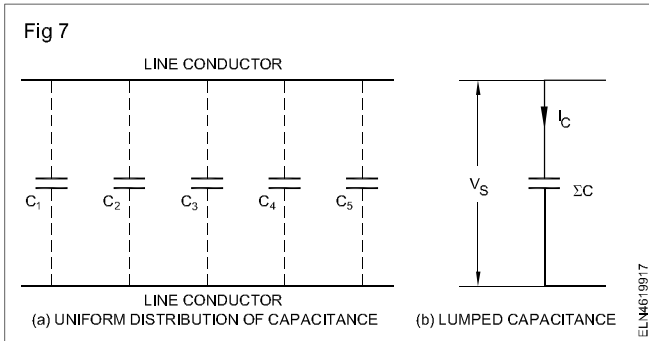
The result is that a current (known as charging current) flows between the conductors [see Fig 7 (b)]. This charging current flows in the line even when it is open-circuited i.e. supplying no load. It affects the voltage drop along the line as well as the efficiency and power factor of the line.

Resistive Line

The resistance of transmission line conductors is the most important cause of power loss in a transmission line. The resistance R of a line conductor having resistivity ρ length $l,$ and area of cross section a is given by

$$R = \rho \frac{l}{a}$$

(i) In a single phase or 2-wire d.c. line, the total resistance (known as loop resistance is equal to double the resistance) of either conductor.

(ii) In case of a 3-phase transmission line, resistance per phase is the resistance of one conductor.

Skin Effect

The tendency of an alternating current to concentrate only near the surface of a conductor is known as **Skin effect.**

Due to skin effect, the effective area of cross-section of the conductor through which current flows is reduced. Consequently, the resistance of the conductor is slightly increased when carrying an alternating current.

The skin effect depends upon (Fig 8)

Fig 8

CURRENT FLOWS INSIDE THE SURFACE

NO CURRENT FLOW IN CENTER PORTION
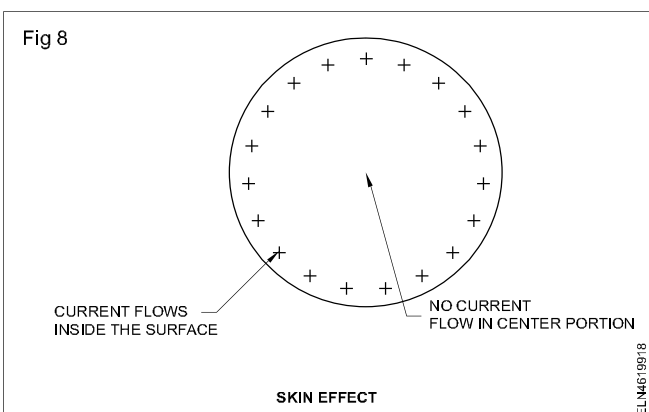
SKIN EFFECT

(i) Nature of material

(ii) Diameter of wire – skin effect increases with the diameter of wire

(iii) Frequency – increases with the increase in frequency

(iv) Shape of wire – less for stranded conductor than for solid conductor.

It may be noted that skin effect is negligible when the supply frequency is low (< 50 Hz) and conductor diameter is small (<1 cm).

Erection of overhead line poles

Length of span

The length of span of line supports will depend upon various factors like the type of pole and conductors used, voltage of transmission, environment, ground clearances for safety etc.

However, following data given in Table 1 may be taken as a rough guide.

Table 1

Type of poles and permissible span

Sl.No	Type of pole	Span length in m.
1	Wooden poles	40 - 50
2	Steel tubular poles	50 - 80
3	RCC poles	60 - 100
4	Steel tower	100 - 300
5	G.I pipe (Medium)	30 - 50

When distribution lines and street lighting fixtures are erected on the same support, the span should not exceed 45 metres.

The recommended span for power lines over 11KV is given in Table 2.

Table 2

Relation between voltage, circuits and span

| Nominal system voltage KV (rms)	No. of circuits	Span range in m
33 (over poles)	1	90 - 135
	2	180 - 305
66	1	240 - 305
	2	240 - 320
110	1	305 - 335
	2	305 - 365
132	1	305 - 365
	2	305 - 380
220	1	320 - 380
	2	320 - 380

Choice of spans : The following factors influence the choice of spans

i   Ease of construction and the cost of the line

ii Ease of maintenance and cost of line maintenance

iii Terrain conditions

The depth of the pit depends upon the soil and height of the pole: The depth of pit below the ground level should be about 1/6 of the length of the pole. (ie) a 9 metres long pole should go down atleast 1.5 metres below the ground level leaving 7.5 metres above the surface.

The depth of foundation setting is dependent upon the density of the soil and depth of frost penetration. In addition to the above we should take into account disturbances to the structure of the earth as the soil filled up is always less strong than the natural earth.

Wooden and reinforced concrete : Supports for the 33 KV overhead lines with pin insulators are placed directly in the earth with no special foundations. Holes for these supports having a diameter 5 -10 cm greater than that of the pole to be erected as in Fig 9.


Fig 9

FOUNDATION ON ROCKY TERRAIN
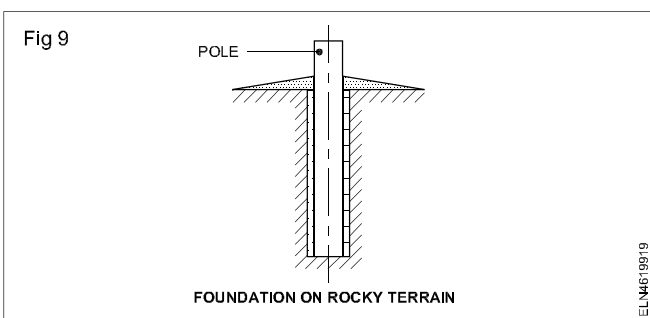
The poles are also reinforced by log heels placed at the pole inside the area of excavation bottom as in Fig 10.


Fig 10

FOUNDATION ON SOLID GROUND
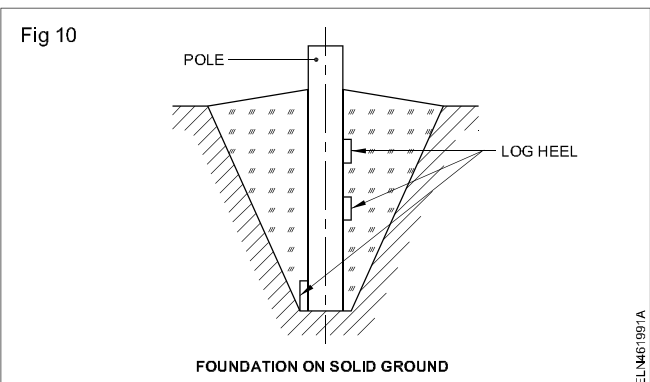
If water is found at a depth of 1.5 to 2 metres, the poles are generally placed above the underground water level and reinforced by embankment or special measures are taken as in Fig 11.

In such locations mass concrete foundations are to be adopted to avoid collapse of foundation in the black cotton soil.

Fig 11

FOUNDATION ON CLAY SOIL
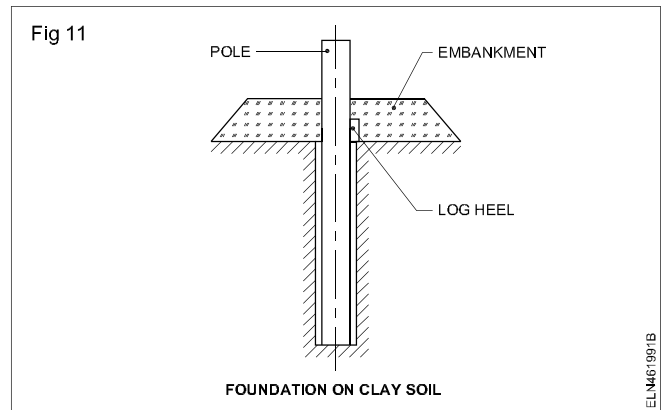
Method of erection of poles : The poles to be erected may be brought to the pit location by manual labour or by improvised carts. Then the pole may be erected in the pit. Wooden support poles may be utilized to facilitate lifting of the pole at the pit locations as in Fig 12.

Fig 12

ERECTION OF POLES
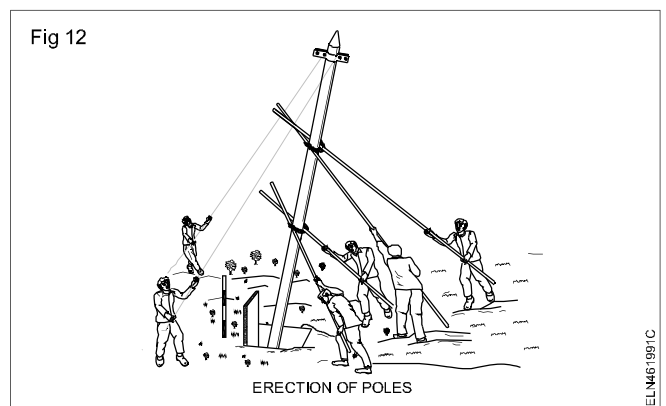
Before the pole is placed into the pit, RCC padding or alternatively a suitable base plate maybe given below the pole to increase the surface contact between the pole and the soil. The padding will distribute the density of the pressure due to the weight of the pole on the soil.

Having lifted the pole, the same should be kept in a vertical position with the help of Manila /sisal ropes of 20/25 mm dia. using the rope as a temporary anchor. As the poles are being erected, say, from an anchor point to the next angle point, the alignment of the poles are to be checked and set right by visual check. The verticality's of the poles are to be checked with a spirit level on both transverse and longitudinal directions.

Having satisfied that the vertical and longitudinal alignment are all right, earth filling is to be done. In some soils the poles are to be concreted up to ground level of the pit. After the poles have been set, the temporary anchors are to be removed.

Use of cross - arms : These are also known as insulator supports and are made of either wood or angle iron. Cross-arms are installed at the top of the pole for holding the insulators on which conductors are fastened. They are also known according to their relative position on the poles. If the cross - arm is fixed in the centre of the poles then it is called a cross - arm (Fig 13a) and if installed on one side of the pole, then it is termed as side cross -arm

(Fig 13b) U-shaped cross - arms are specially used for three phase lines.

Channel iron cross-arms fabricated from channels of size 75 mm x 40 mm x 5.7 kg/m or size 100mm x 50 mm x 7.9 kg/m are used for H.T. lines, and those made from angle irons of size 50 mm x 50 mm x 6 mm are used for L.T lines.

CROSS-ARMS
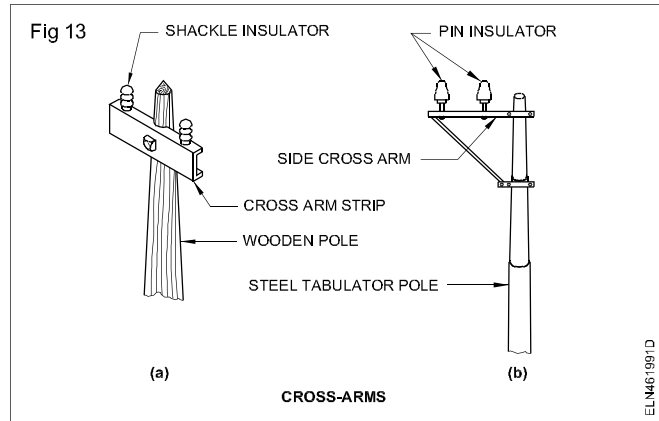
Joining of aluminium conductors

**Objectives:** At the end of this lesson you shall be able to
• **state the type of joints**
• **explain the type and use of connectors used to joining conductors**
• **explain the steps to testing of O.H lines**
• **state the preliminary safety procedure for OH line erection.**

Joining accessories in O.H lines: Normally connectors are used for joining the O.H. aluminium conductors. Connectors maybe of several types of which few are described below.

1 Sleeved joints

2 Straight through connectors / taps

3 Vice - clamp connectors /taps with parallel grooves

4 Nut and bolt connector

Sleeved joints

Twisted joints: Oval shaped aluminium sleeves are inserted over the conductors to be joined and then twisted as in Fig 1. Only one sleeve is sufficient for all aluminium conductors whereas two concentric sleeves are used for ACSR conductors. One each for the aluminium and steel portions. Twisting joints are recommended for conductors up to 15 mm diameter. Only special wrenches should be used for twisting the sleeves.


TWISTED JOINTS
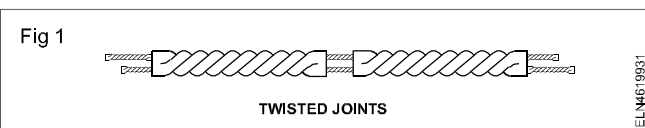
Compression joints : ACSR conductors are joined by compression joints having two sleeves as in Fig 2. The larger sleeve is of aluminium , fitting over the entire conductor, and the smaller one is of steel fitted on the steel portion of the wire eccentrically. Conductors to be joined are inserted into the sleeves one after the other and compressed either by hand or by hydraulic compressors. Compression joints for all aluminium conductors consist of aluminium sleeve only .

Straight through connectors / taps : Two types of connectors are used to join two straight through run of wires in such locations where mass concrete foundations

are to be adopted to avoid collapse of foundation in the black cotton soil.

COMPRESSION JOINT FOR ASCR
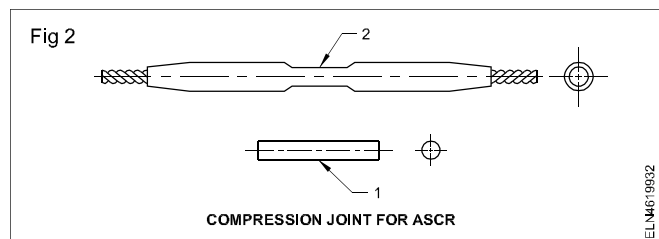
Straight sleeve and nut connector: This is in Fig 3. It has a sleeve (round or oval in section) made of cadmium plated brass or aluminium. The conductors are inserted into the sleeve and tightened by the nuts.

STRAIGHT SLEEVE AND NUT
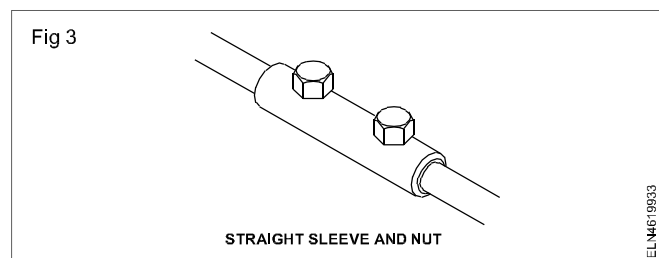
Compression connector: In this, the conductors are wrapped at both ends and then compressed with nuts as in Fig 4.


COMPRESSION CONNECTOR

Vice-clamp connectors/taps with parallel grooves (PG): There are several types as explained below.

Standard P.G. clamps: This clamp as in Fig 5 consists of two aluminium halves, having two semi-circular parallel grooves in each half. After inserting the conductors to be joined, the galvanized steel nuts are

tightened. As the grooves are of the same size, it is useful only when the joining conductors are also of the same size.


P.G. VICE CONNECTOR
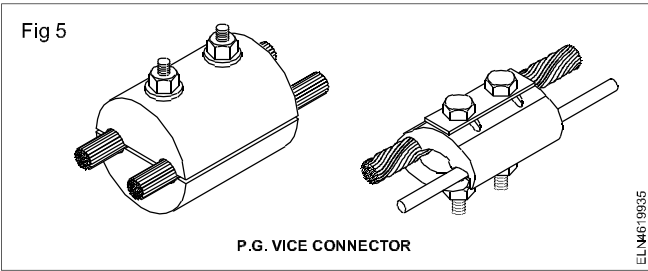
Universal P.G. clamp: This is in Fig 6. It has grooves of slightly different shape to accommodate different sizes of conductors, and has only one bolt. This clamp is not for heavy duty service but can be used for tapping connections from the distribution line to individual consumers through aluminium conductors.
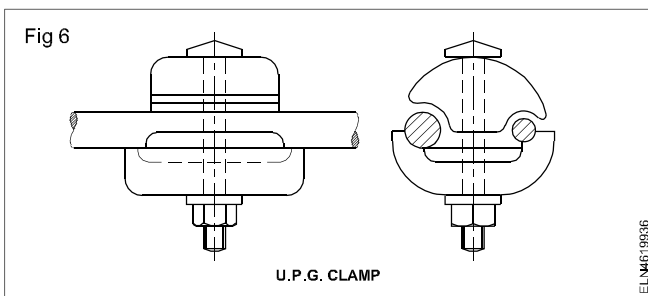

U.P.G. CLAMP

Bimetallic universal parallel groove clamps (B.M.P.G. clamps)

This clamp is in Fig 7. It has a brass body with cadmium plating. The two halves are tightened by a galvanised bolt. This is used for connecting copper wire to aluminium conductors in the case of consumer service connections.


CENTRAL BOLT GALVINISED

CENTRAL BOLT IS OF GALVANISED IRON
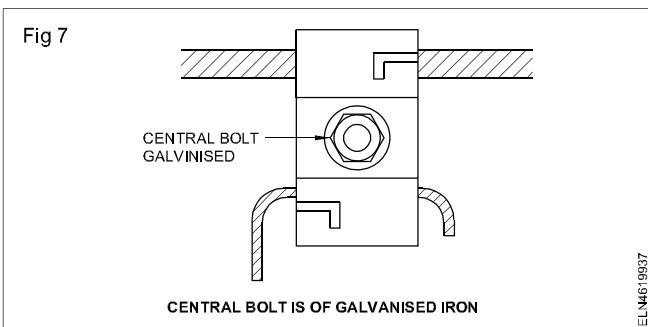
U bolt clamps: This is in Fig 8. It uses 'U' bolts as these bolts exert 4 times more pressure than the conventional straight bolts. Such clamps are suitable for heavy duty conductors.


U BOLT

U BOLT CLAMP
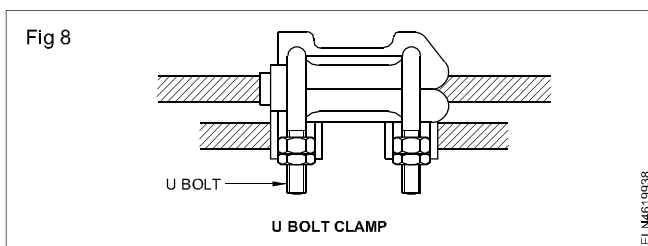
Nut and bolt connectors are of two types

Nut connector

This is in Fig 9. It has a transverse hole through which the conductors to be joined are inserted and then tightened by the bolt.
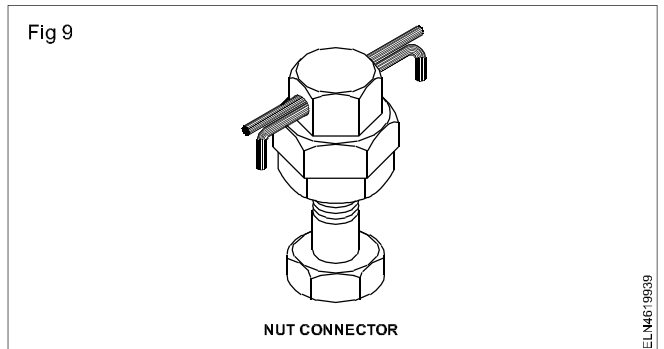
NUT CONNECTOR

Split bolt connector: This is in Fig 10. It is split at the stem. The conductors to be joined are to be inserted into the split and then tightened by the external nut.

SPLIT BOLT CONNECTOR
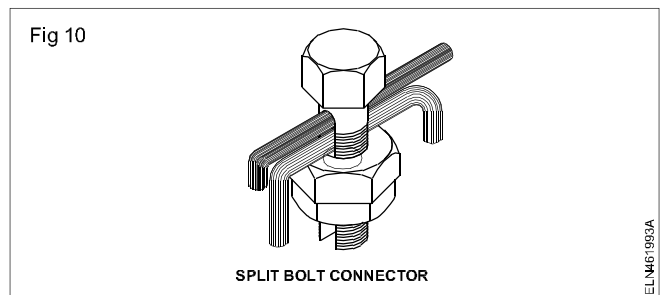
Precautions to be followed while using aluminium conductors: Technical problems involved in electric connections in connectors for aluminium wire, are quite different from those encountered, with copper conductors. There are several ways to approach these problems, but it is essential that connectors for aluminium must be specially designed for aluminium.

Several problems arise which must be taken into account when aluminium is to be connected to copper. All these technical problems are related to the oxide film on the surface of aluminium, the contact pressures exerted by the connector, and the possibility of galvanic corrosion between dissimilar metals.

Basically, the efficiency of any electrical contact depends on the cleanliness of the contacting surfaces, the area of the contacting surfaces, and the pressure applied. A joining compound applied just after abrading will protect the surface from further oxidation and prevent the formation of an oxide film thick enough to interfere seriously with most connections.

To ensure complete elimination of the oxide film under the most extreme service conditions, apply the joining compound prior to abrading so that the oxide film underneath the compound will be removed. The joining compound prevents or retards re-formation of the oxide film and so it should not be removed before the connection is made.

A satisfactory connector for aluminium will exert about the same overall pressure as on satisfactory for copper, but will provide considerably more contact area and thus hold unit stresses to values the aluminium is capable of withstanding.

If a connector is made of a metal different from that of the conductors, the difference in the rates of expansion and contraction of the two metals, with changes in temperature, will cause contact pressure to vary with the temperature.

Very often, aluminium conductors must be connected to copper conductors and the possibility of galvanic corrosion must be forestalled. When two different metals are in contact with each other in the presence of moisture, (thereinafter called the electrolyte) a small voltage is developed between them which causes a flow of electric current.

This electric current ultimately tends to corrode the conductor. The possibility of galvanic corrosion is completely eliminated if connectors used to connect the aluminium conductors to other aluminium or copper conductors are made of aluminium.

It is recommended that a good joining compound must always be used on electrical connections to aluminium regardless of the metals involved. The joining compound, when liberally applied, will fill all voids in the contacting surface and all voids in the vicinity of the contacting surfaces. By doing so, it excludes the entry of air and moisture and makes oxidation or corrosion impossible.

There are several good joining compounds in the market, all of which are grease-type materials. However, the period of time a joining compound will provide protection cannot be established except by experience, but when liberally applied, they will last for many years under any service condition.

Testing of overhead line: Before connecting the services to the transformer, equipments etc., a pressure voltage test of appropriate standard shall be carried out on the line, as desired by the Engineer in-Charge.

Before charging the M.V. lines, the same shall be tested with a 500V Megger for insulation.

Where pressure test is not done on H.V. lines, it shall be tested with a 2500V/5000V Megger for insulation, before charging.

The distribution lines shall be charged only if the pressure/ Megger test is satisfactory.

The lines shall be commissioned in the presence of the Engineer in-Charge.

Preliminary safety procedures: Before starting any major work on a pole, carry out the following drill.

– Before working on an overhead line which already exists, shut down permission should be taken from competent authorities.

– Before working on overhead lines which are already supplying power, the line should be made dead by opening the concerned switches and the line should be earthed through earth rods.

– Use a safety belt while working on poles.

– Inspect the structure, Eg. pole etc.

– Decide the best way to approach the job.

– Select the best ladder position.

– Erect the ladder. The ladder must be 'footed', that is, the ladder feet should be prevented from slipping and the ladder should be held by other workmates until the ladder head has been secured.

Domestic service line - IE rules

Objectives: At the end of this lesson you shall be able to
• **explain the domestic service connection with bare and insulated conductors**
• **state the method of laying the service cable from the pole to the consumer premises**
• **state the safety precautions to be followed in domestic service connections**
• **list out the IE rules pertaining to domestic service connections**
• **explain the methods of taping service connections.**

Service connections

The distribution networks ends at consumer premises either single phase or three phase connections. The category of connections either single phase or three phase depends as the maximum load demand by the consumer and the wiring of the house or the premises. The decision of power allocation by the electricity officials after surveying the wiring and load demand by the consumer.

Once the power requirement finalised and arrived the connection to the consumer the point from where the service line to be connected. It is also decided the drawing of line from the pole cross arm structure to the consumer mains panel either in over head or through UG cable. If the distance from over head pole terminal to consumer panel board is more than 50 Mtrs separate pole should be erected and OH line to be drawn from the distribution pole cross arm structure.

Service connection with bare conductor: Any of the following methods shall be adopted as specified.

The bare conductors shall be strung with shackle insulators fixed to the cross arms on both ends. The feeding end cross-arms shall be fixed to the support and the one at the receiving end shall be mounted on a G.I. pipe of a maximum diameter of 5 cm. The bare conductors shall be kept at a height of atleast 2.5 m from the top of the structure in accordance with Rule 79 of I.E. rules.

The G.I. pipe shall be provided with double bends at the top. The pipe shall be secured by atleast 2 clamps made of 50 mm X 6 mm. with M.S. flats fixed firmly to the wall in the vertical position. It shall in addition be provided with a G.I. stay wire of 7/3.15 mm size anchored to the building with one eye bolt. Service connection shall be given with weather proof/PVC insulated cable through this G.I. pipe. Wooden/PVC pushings shall be provided at both ends of this G.I. pipe.

The bare conductors shall be strung with shackle insulators as above except at the receiving end where the insulators shall be fixed to a bracket made of an angle iron, of a size not less than 50 mm x 50 mm x 6 mm. The ends of the bracket shall be cut and split and embedded in the wall with cement mortar. The bare conductor shall be kept

atleast 1.2 m away from the edge of the structure, in accordance with Rule 79 of I.E. Rules.

The service connection shall be given with weather proof/PVC insulated cable through GI pipe of a minimum diameter of 4 cm. fixed to the wall. The GI pipe shall be bent downwards near the service entry. Wall fitting wooden/PVC bushes shall be provided at both ends of the G.I. pipe.

Service connection with insulated conductors: Service connection may be given by weather-proof/PVC insulated cable on a GI bearer wire. The cables shall be supported by the bearer wire by means of suitable link clips spaced 30 cm apart or by wooden/porcelain cleats 50 cm. apart. The GI bearer wire shall be of a minimum 10 SWG size.

One end of the GI bearer wire shall be attached to a clamp which is fastened to the nearest pole carrying distribution lines from where the service connection is intended to be given. The other end of the GI bearer wire shall be fastened to a 5 cm. dia. GI pipe for a span up to 4.5m which is fixed to the wall with guy etc.

The GI pipe shall be fixed to an angle iron of size 40 mm x 40 mm x 6 mm with a suitable guy for high supports and for a span exceeding 4.5 m. Alternatively when the height of the structure permits minimum ground clearance, the other end of this GI bearer wire may be fixed to a hook, eye bolt or bracket embedded with cement mortar in the wall.

The weather proof/PVC insulated cable shall pass through a GI pipe of minimum diameter 5 cm, which is bent downwards. Wall fittings wooden/PVC bushes shall be provided at both ends of the GI pipe.

Method of laying the service cable from the pole to the consumer main: In practice either a glass or porcelain ring insulator or wooden fibre cleats are used to lay the overhead service line from the pole to the consumer mains as in Fig 1.

Safety Precautions to follow while connecting pole to consumer premises

1 The cable conductor size must be as per the IE rule standard either single phase or three phase.

2 If the service line crosses public road the clearance must be as per IE rule.

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Fig 1

LAYING OF SERVICE LINES
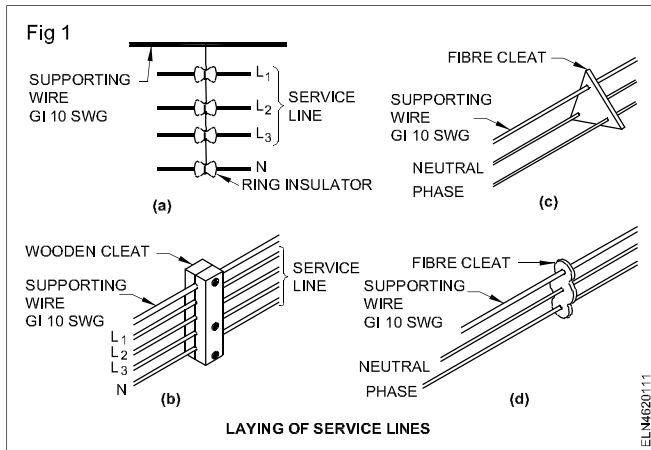
3   The conductor slag should not exceed as per the IE rules.

4   If UG cables are providing the depth of cable in ground should be as per IE rules.

5   Do not keep much more cable unused and buried in soil in the coil form in case of UG cable laying.

6   The excess cable should not be kept by making coil and kept on the pole cross arm. Use only required cable for connection.

7   If the cable passing through excess heat producing areas in near to chimney, kitchen etc; adequate protection from heat to be provided.

8   Service cable run along with stay wire tightly tied with stay wire to avoid tension on service cable.

9   No rain water flows along with service cable and reach to consumer main panel. Necessary looping of cable to be provided either side.

10 The connection to main line is to be made so tight and clean surface, so that loose contact, sparking and formation of oxide coating can be avoided.

I.E. Rules pertaining to domestic service connection

Rule 10. Construction, installation, protection, operation and maintenance of electric supply lines and apparatus

All electric supply lines and apparatus shall be sufficient in power and size and of sufficient mechanical strength for the work they may be required to do, and so far as practicable, shall be constructed, installed, protected, worked and maintained in accordance with standards of the Indian Standards Institution so as to prevent danger.

Rule 30. Service lines and apparatus on consumer's premises.

1   The supplier shall ensure that all electric supply lines, wires, fittings and apparatus belonging to him or under his control which are on a consumer's premises are in a safe condition and in all respects fit for supplying energy, and the supplier shall take due precautions to avoid danger arising in the premises from such supply lines, wires, fittings and apparatus.

2   The consumer shall also ensure that the installation under his control is maintained in a safe condition.

Rule 31. Cut-out on consumer's premises.

The supplier shall provide a suitable cut-out in each conductor of every line other than an earthed or earthed neutral conductor, or the earthed external conductor of concentric cables within a consumer's premises, in an accessible position. Such cut-out shall be contained within adequately enclosed fire-proof receptacle.

Where more than one consumer is supplied through a common service line, each such consumer shall be provided with an independent cut-out at the point of junction to the common service.

Rule 33. Earthed terminal on consumer's premises.

The supplier shall provide and maintain on the consumer's premises, for the consumer's use, a suitable earthed terminal in an accessible position at or near the point of commencement of supply as defined under Rule 58.

Provided that in the case of medium, high or extra high voltage installation the consumer shall, in addition to the afore-mentioned arrangement provide his own earthing system with an independent electrode.

Rule 48. Precautions against leakage before connecting.

1   The supplier shall not connect with his works the installation or apparatus on the premises of any applicant for supply unless he is reasonably satisfied that the connection will not at the time cause a leakage from the installation or the apparatus exceeding five thousandth part of the maximum current supplied to the premises.

2   If the supplier declines to make connection under the provisions of sub-rule(1) he shall serve upon the applicant a notice in writing stating his reason for so declining.

Rule 54. Declared voltage of supply to consumer.

Except with the written consent of the consumer or the previous sanction of the State Government, a supplier shall not permit the voltage at the point of commencement of supply as defined under Rule 58, to vary from the declared voltage by more than 5 percent in the case of low or medium voltage or by more than 12½ percent in the case of high or extra high voltage.

Rule 77. Clearances above ground of the lowest conductor.

1   No conductor of an overhead line, including service lines erected across a street shall at any part thereof be at a height less than :-

a) for low and medium voltage lines 5.791 m

b) for high voltage lines 6.096 m.

2   No conductor of an overhead line including service lines erected along any street shall at any part thereof be at a height less than:

a) for low and medium voltage lines 5.486 m

b) for high voltage lines 5.791 m.

3   No conductor of an overhead line including service lines, erected elsewhere than along or across any street shall be at a height less than:

a) for low, medium and high voltage lines upto and including 11,000 V if bare 4.572 m

b) for low, medium and high voltage lines upto and including 11,000 V if insulated 3.963 m.

Rule 79. Clearances from building of low and medium voltage lines and service lines.

1   Where a low or medium voltage overhead line passes above or adjacent to or terminates on any building, the following minimum clearances from any accessible point, on the basis of maximum sag, shall be observed.

a) for any flat roof, open balcony, verandah, roof and lean-to-roof.

i) when the line passes above the building, a vertical clearance of 2.439 m from the highest point.

ii) when the line passes adjacent to the building, a horizontal clearance of 1.219 m from the nearest point.

b) For pitched roof

i) when the line passes above the building, a vertical clearance of 1.219 m immediately under these lines.

ii) when the line passes adjacent to the building, a horizontal clearance of 1.219 m.

2   Any conductor so situated as to have a clearance less than that specified in sub-rule (i) shall be adequately insulated and shall be attached by means of metal clips at suitable intervals to a bare earthed bearer wire having a breaking strength of not less than 517.51 kg.

3   The horizontal clearance shall be measured when the line is at maximum deflection from the vertical due to wind pressure.
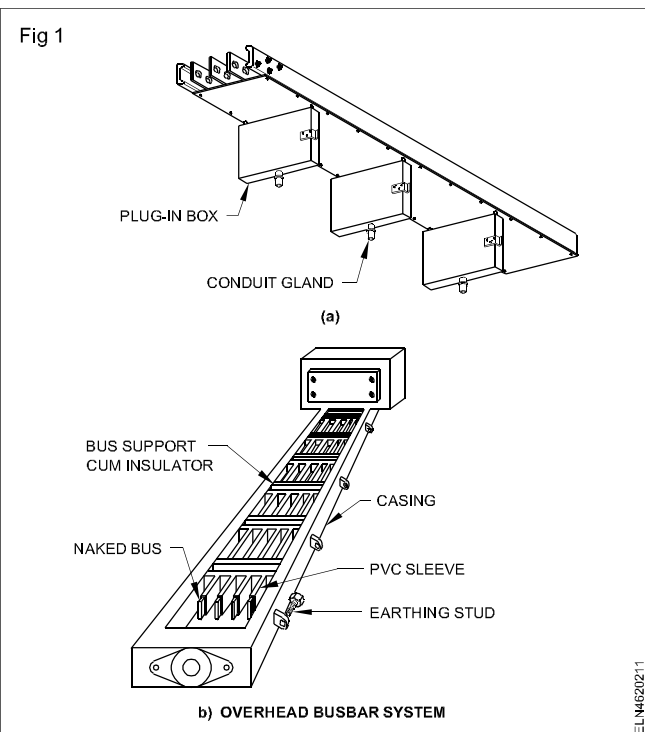
Tapping service connections: No service connection line should be tapped from an OH line from any point mid span, except at the point of support. When a service connection is taken overhead with a bare conductor, it should be provided with guard wires.

Bus-bar system - power tariff terms and definitions

Objectives: At the end of this lesson you shall be able to
• **explain the bus-bar system and the method of installation**
• **state the advantages of the bus-bar system**
• **determine the rating of the bus-bar**
• **state the use of plug-in boxes and their construction**
• **state the method of cable or conduit termination in plug-in boxes.**

In industrial workshops and factories, a number of machines are installed in the shop floor closely but apart from each other. connecting these machines to electrical supply through underground cables or overhead wires or cables may involve cumbersome methods resulting in shock hazards. For such places, an overhead enclosed bus-bar system as in Fig 1a and 1b is recommended.

Fig 1

PLUG-IN BOX

CONDUIT GLAND

(a)

BUS SUPPORT
CUM INSULATOR

CASING

NAKED BUS

PVC SLEEVE

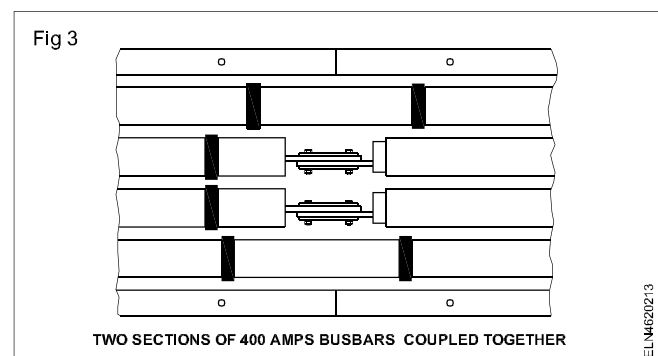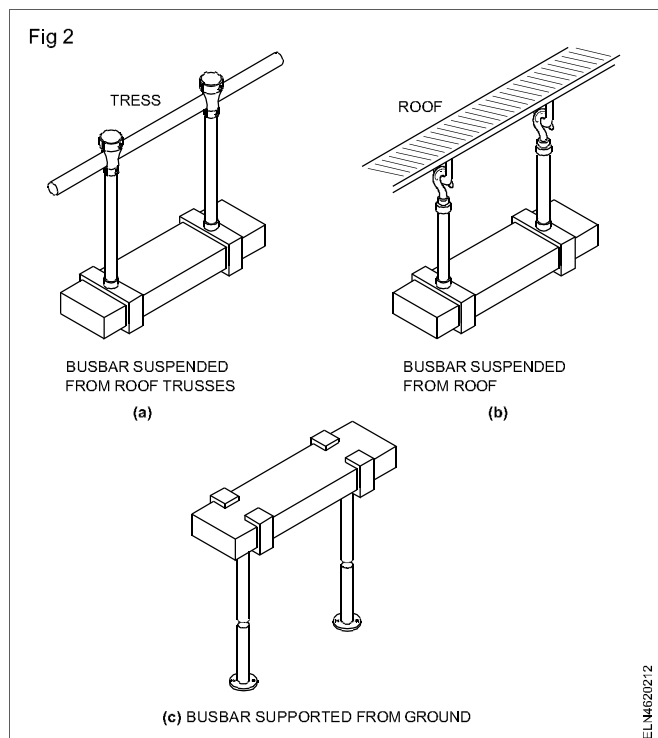EARTHING STUD

b) OVERHEAD BUSBAR SYSTEM

This bus-bar system is sometimes referred to as bus way or bus duct.

Bus-bar assembly should be installed at a height of 2.75metre from ground, suspended by M.S. angles or flats from ceiling/roof or supported by framed structure from ground as in Fig 2.

Bus coupler

The bus-bars are either of high conductivity, high purity copper or alloy aluminium having rectangular sections mounted on insulating supports enclosed in standard length of metal trunking. The bus-bar sections are available in standard lengths (3.65metre for 200 ampere and 2.44metre for 400 ampere) which can be connected to another bus-bar by blowing the respective bus-bar ends

thus forming a continuous bus-bar along the entire length of the workshop. Method of coupling two bus-bars is in Fig 3.

Fig 2

TRESS

ROOF

BUSBAR SUSPENDED
FROM ROOF TRUSSES
(a)

BUSBAR SUSPENDED
FROM ROOF
(b)

(c) BUSBAR SUPPORTED FROM GROUND

Fig 3

TWO SECTIONS OF 400 AMPS BUSBARS COUPLED TOGETHER

The standard rating of bus-bar are 100, 200, 400, 600, 800, 1200, 1600, 2000, 2400 and 3600 ampere with rated voltage of 500V. These bus-bars also available for indoor or outdoor use as point to point feeders or as plug-in take off points for power. These bus-bars are used in generating stations, sub stations, in metal industry and textile industry. These bus-bars are also used in multi storied flats to facilitate connection to various stories from the mains by

using vertically mounted bus-bars as in Fig 4. These vertical bus-bars are provided with a fine barrier made up of high grade fire-resisting material positioned at the top of each fixed section of the trucking passing through the floors. This barrier is the collecting points for dirt, dust and moisture which could be removed at intervals.

Fig 4

VERTICALLY MOUNTED BUSBAR
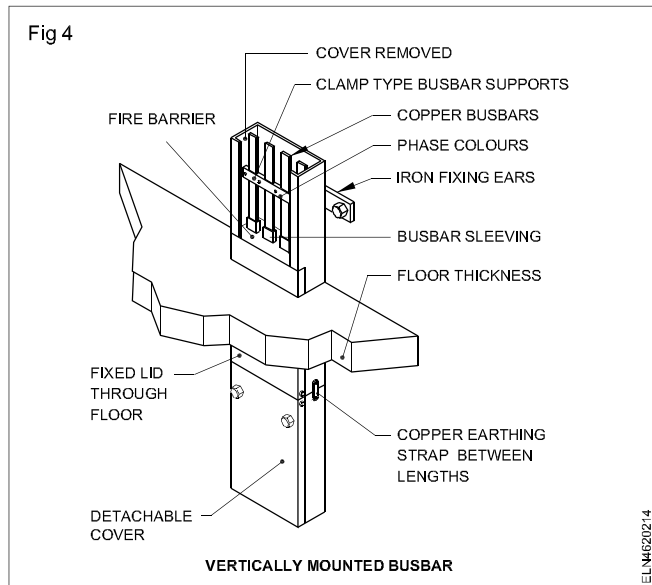
Recommended current density for a copper bus-bar which is not enclosed should not exceed 165A/sqcm and for aluminium 118A/sqcm.

Recommended section of aluminium and copper bus-bars and their respective ratings are in Table.

Earthing continuity is provided by two strips of aluminium or copper running throughout the bus-bar assembly. When extending the bus-bar lengths, these earthing strips also to be connected to have earth continuity.

> **Note:**
>
> 1 **Above rating is for rectangular cross-section of E-91 E-WP grade as per IS : 5082-1969 in still unconfined air without enclosure, presuming longer section vertical.**
>
> 2 **Denting factor of 0.88 may be applied for ambient of 30°C and temperature rise of 35°C. Similarly in outdoor application denting may be done for 0.85 to 0.9. Indoor well ventilated 0.6 to 0.8 and partly ventilated areas 0.5 to 0.6.**

| Bus-bar size in mm	Rating at 50Hz AC current at average ambient of 35°C and 40°C maximum and temperature rise of 50°C.				
	Aluminium				Copper
	Single bar	Two bars	Three bars	Four bars	Single bar
12.5 x 3	—	—	—	—	160
25 x 3	—	—	—	—	290
50 x 3	335	650	850	950	525
75 x 3	475	875	1150	1300	750
100 x 3	600	1075	1400	1600	970
12.5 x 4.5	125	260	315	370	205
25 x 4.5	225	525	635	750	365
32 x 4.5	320	660	800	940	510
50 x 4.5	500	970	1270	1425	650
25 x 6	350	700	950	1000	430
50 x 6	675	1300	1700	1925	760
75 x 6	950	1750	2300	2600	1080
100 x 6	1225	2150	2800	3200	1380
125 x 6	1500	2500	3200	3700	1680
25 x 10	—	—	—	—	540
50 x 10	85	1500	1950	2250	960
75 x 10	1180	2050	2650	3000	1350

Bus-bar size in mm	Rating at 50Hz AC current at average ambient of 35°C and 40°C maximum and temperature rise of 50°C.				
	Aluminium				Copper
	Single bar	Two bars	Three bars	Four bars	Single bar
100 x 10	1500	2475	3150	3550	1710
125 x 10	1850	2925	3600	4200	2070
150 x 10	2100	3325	4000	4606	2430
250 x 10	2750	4100	4900	5700	—
25 x 12.5	—	—	—	—	650
50 x 12.5	—	—	—	—	1120
75 x 12.5	1350	2250	800	3200	1570
100 x 12.5	1750	2700	3350	3900	2050
125 x 12.5	2100	3100	390	4500	2420
150 x 12.5	2400	3500	4450	5100	2820
200 x 12.5	3050	4500	5300	6100	—

Advantages of Bus-bar system

Following are the advantages of bus-bar system

1 **Reduced cost:** Simple rapid installation with complete elimination of expensive floor chasing (cutting) reduces cost at the initial period of installation and needs no expenditure for maintaining the bus-bar system while in regular use.

2 **Maximum flexibility:** As plug-in-points are provided at intervals of 60.96cm (2 feet) along every length of bus-bar the connections can be taken for machines installed on either side. Refer Fig 5.

Fig 5
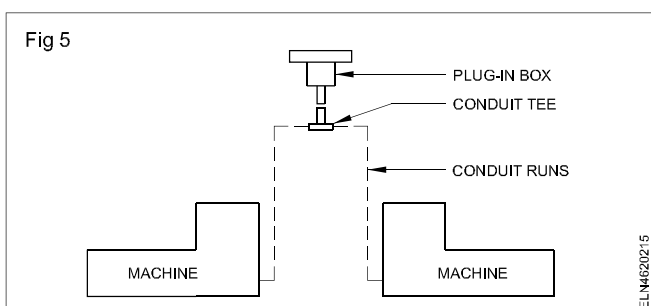
3 **Complete safety:** As the plug-in-point are completely insulated, safety is ensured for operating and maintenance personnel.

4 **'Live' connection:** As the plug-in-boxes could be connected to 'live' bus-bars quickly and safely without shut down and the time is saved without disturbing the normal work of the factory.

5 **Guaranteed protection:** As the fuse in the plug-in boxes of HRC type the circuit is protected positively and reliably against short circuit.

6 **Easily extended for layout modification in the factory:** As the bus-bars can be extended in straight lengths or at an angle to suit the layout with the help of standard accessories, the bus-bars can be remounted or rearranged within a short time.

7 **Saving of time while initial erection:** The advantages of this system are that the trucking and bus-bars can be erected before the installation of the machinery, and the latter can be connected up and set to work as soon as they are installed.

8 **Reduction of voltage drop in feeders:** By bringing the heavy main feeders near to the actual loads, the circuit wiring is reduced to a minimum and voltage drop is lower than would otherwise be the case.

9 **Addition and alterations:** Subsequent additions and alterations to plant layout can be easily accomplished, and where bus-bar sections have to be removed they can be used again in other positions.

10 **Internal grid for welders:** The overhead bus-bar system is especially advantageous where a large number of electric welders have to be fed with heavy currents from a step down transformer.

11 **Branching from plug-in-boxes for small loads:** If a large number of small machines are to be fed it is usual to fix a distribution box near the trucking system and to protect this with a tap-off fitted with HRC fuses of suitable capacity.

12 **Durable and trouble free service:** Normally bus-bars give much durable service than U.G. Cables and give many years of trouble free service.

Method of determining the ratings of the bus-bars

In a small factory, ten motors having each of 5 HP ratings to be installed. The total load is approximately 10 x 5 i.e. 50 HP Assuming 5 HP motor takes approximately full load current at 7.5A. The total current in the factory load will be 75A and has to be supplied through a single bus-bar. Normally the ratings of bus-bar is 200A or 400A. Hence a 200A rating bus-bar is selected for this case as the same bus-bar also could be used when there is expansion of load in the factory in future. Considering the overload, bus-bars are manufactured in standard sections of 3.65m (200A) and 2.44m (400A). We can decide the number of bus-bars to meet the entire length of machine layout.

Technical Data

Rating	Overall dimensions in mm	No.of plug
200A	3658 x 248 x 76	6
400A	2440 x 248 x 108	4

Bus-bar length can be increased by providing mechanical coupling and any length at run in multiples of the standard length may be thus achieved.

Plug-in-Boxes

Plug-in-boxes (Fig 6) are compact sheet steel boxes with hinged doors housing the HRC fuse holders, which are solidly connected to high conductivity copper clip on contacts reinforced by spring steel strips. These clip on contacts plug directly to the bus-bars at the plug-in-points.

Two earth pins are located at the two ends of these boxes which also serves to mount the plug-in-boxes on bus-bars.

DIAGRAM SHOWING MAIN FEATURES OF PLUG-IN BOXES FITTED TO BUSBARS
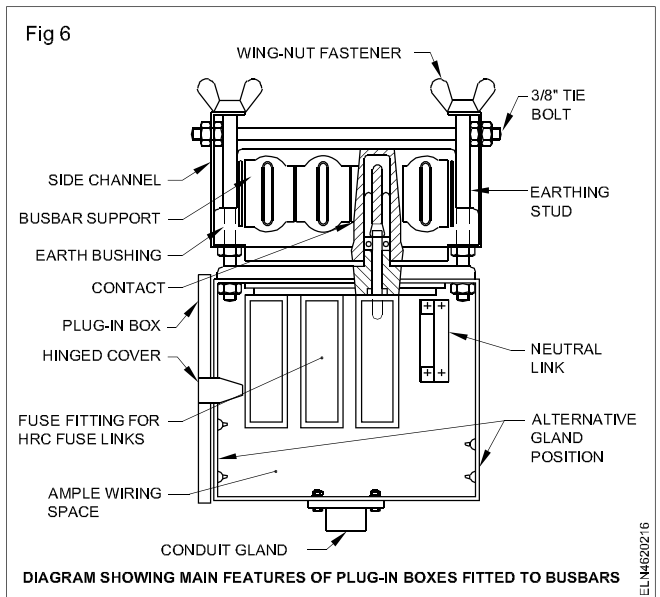
Rating of plug in boxes

Plug in Boxes must be able to withstand faults current capability of bus-bars. There are rated in 16, 32, 63 and 100Amp at 415/500V (TPN).

Cables (or) conductors with termination connection to plug-in-boxes for outgoing supply by using conduit pipe to conduit glands supplied with plug in boxes either vertically down or on to either side.

However remember to use oxide inhibiting grease at all aluminium joint to maintain conductivity.

Power tariff - terms and definitions

Objectives: At the end of this lesson you shall be able to
• **state the term maximum demand**
• **explain the concept of average demand**
• **explain load factor**
• **state the term of diversity factor and its application**
• **explain the importance of plant utility factor.**

Introduction

The alternators in the power station should run at their rated capacity for maximum efficiency and on the other hand, the demands of the consumers have wide variations from time to time due to uncertain demands of the consumers. This makes the design of a power station highly complex. We shall focus our attention on the problems of variable load on power stations.

Maximum Demand

It is the highest level or greatest electrical demand monitored in a particular period or a month.

The maximum demand is in between 18 hours and 24 hours in the night during summer as well as in winter seasons as in Fig 1. All other times the maximum demand falls very low to the connected load. However the maximum load demand less than the connected load because all the consumers do not switch 'ON' their connected load of the system at a time.

The importance of the maximum demand knowledge is very important as it helps in determining the installed capacity of the stations, and the station must be capable of meeting the maximum demand.

The ratio of maximum demand as the power station to its connected load is known as demand factor; Mathematically

Fig 1
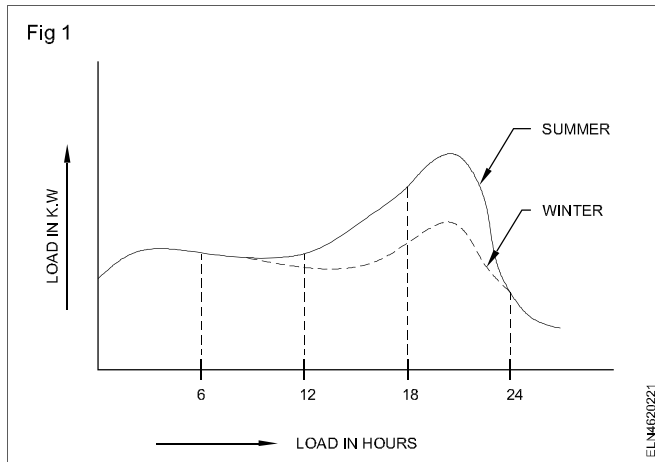
$$\text{Demand factor} = \frac{\text{Max. Demand}}{\text{Connected load}}$$

Usually it always less than one. The knowledge of demand factor is vital in determining the capacity of the plant equipment.

Average demand

It is the total demand in a month divided by number of days in that time period.

The average demand in a month taken to find the load requirement for a certain period is in Fig 2. It is evident that average load requirement is not uniform among all the months consumption as it depend on the environmental conditions; such as Winter, Summer, Monsoon seasons.

Fig 2
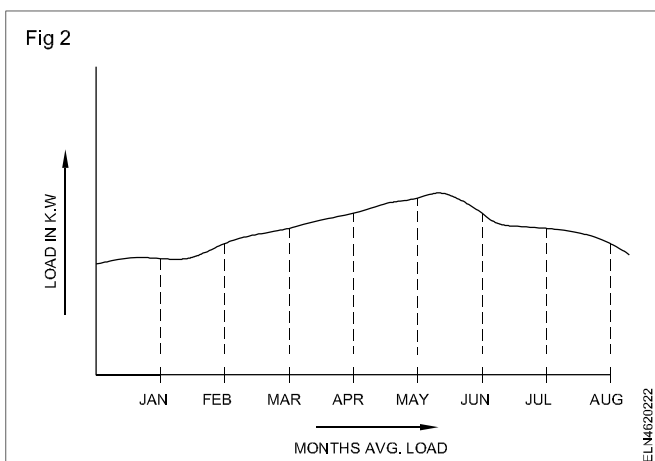
Load factor

In electrical engineering the load factor is defined as the total load divided by the peak load in specified time period. It is a measure of the utilization rate, or efficiency of electrical energy usage; a low load factor indicates that load is not putting a strain on the electric system, whereas consumers or generators that put more of a strain on the electric distribution will have a high load factor.

$$f_{Load} = \frac{\text{Total load}}{\text{Maximum load in given time period}} \text{ or } \frac{\text{Total load}}{\text{Peak load.}}$$

An example, using a large commercial electrical bill:

*   peak demand = 436 KW

*   use = 57 200 kWh

*   number of days in billing cycle = 30

Hence:

*   load factor = { 57 200 kWh/ (30 d x 24 hours per day x 436 kW) } x 100% = 18.22%

It can be derived from the load profile of the specific device or system. Its value is always less than one because maximum demand is always higher than average demand, since facilities likely never operate at full capacity for the duration of an entire 24 hours day. A high load factor means power usage is relatively constant. Low load factor shows that occasionally a high demand is set. To service that peak, capacity while remaining idle for long periods, thereby imposing higher costs on the system. Electrical rates are designed so that customers with high load factor are charged less over all per kWh.

The load factor is closely related to and often confused with demand factor.

$$f_{Demand} = \frac{\text{Maximum load in given time period}}{\text{Maximum possibe load}}$$

The major difference to note is that the denominator in the demand factor is fixed depending on the system. Because of thiss the demand factor cannot be derived from the load profile but needs the addition of the full load of the system in question.

Diversity factor

Diversity factor (Or simultaneity factor K_S) is a measure of the probability that a particular piece of equipment will turn on coincidentally to another piece of equipment. For aggregate system it is defined as the ratio of the sum of the individual non - coincident maximum loads of various sub divisions of the system to the maximum demand of the complete system.

$$\text{Diversity factor} = \frac{\text{Sum of individual max Demands}}{\text{Maximum Demand}}$$

The diversity factor is almost always larger than 1 since all components would have be on simultaneously at full load for it to be one. The aggregate load is time dependent as well being dependent upon equipment characteristics. The diversity factor recognizes that the whole loads does not equal the sum of its parts due to this time interdependence (i.e. diverseness). For example, we might have ten air conditioning units that are 20 tons each at a

facility. We typically assume that the average full load equivalent operating hours for the units are 2000 hours per year. However, since tha units are each thermostatically controlled, we do not known exactly when each unit turns on. If the ten units are substantially bigger than the facility's actual peak A/C load, then fewer than all ten units will likely come on at once. Thus, even though each unit run a total of 2000 hours a year, they do not all come on at the same time to affect the facility's peak load. The diversity factor gives us a correction factor to use, which results in a lower total kW load for the ten A/C units. If energy balance we do for this facility comes out within reasons, but the demand balance shows far to many kW for the peak load, then we can use the diversity factor to bring the kW into line with facility's true peak load. The diversity factor does not affect the kWh; it only affects the kW.

Plant utility factor

The utility factor or use factor is the ratio of the time that a piece of equipment is in use to total time that it could be in use. If is often averaged over time in the definition such that the ratio becomes the amount of energy used divided by the maximum possible to be used. These definitions are equivalent.

The utility factor, K_u, is the ratio of the maximum load which could be drawn to rated capacity of the system. This is closely related to the concept of load factor. The factor is the ratio of the load that piece of equipment actually draws (time averaged) when it is in operation to the load it could draw (which we call full load.

$$\text{Utility Factor} = \frac{\text{Ratio of maximum power}}{\text{Plant capacity}} \times 100$$

For example, an oversized motor - 15 kW - drives a constant 12 kW load whenever it is on. The motor load factor is then 12/15 = 80%. The motor above may only be used for eight hours a day, 50 weeks a year, The hours of operation would then be 2800 hours, and the motor use factor for a base of 8760 hours per year would be 2800/8760 = 31.96%. With a base of 2800 hours per year, the motor use factor would be 100%.

In power plant utility factor various according to the demand on the plant from the electricity market.

Line protective relays - types - operation

Objectives: At the end of this lesson you shall be able to
• **state the classification of relays**
• **list the types of relays and their uses**
• **explain the principle of operation of over current, differential, earth fault, distance and non directional relays**
• **state the characteristics of relays**
• **explain the principle of operation of a over voltage end under voltage relay**
• **state the necessity of time multiplier setting of relay.**

Introduction

The relays is the element that senses as abnormal condition in the circuit and commands the operation of the breaker. It interpret the fault quantities ie, CT output current and PT output voltage and sending the command to the tripping circuits of breaker for operation in accordance with the characteristic set in the relay and the value of the time multiplier setting.

Classification of Relays

Relays are classified mainly in three categories; they are according to:

1 **Quantity sensed :** Current, Voltage, active power, reactive power & impedance

2 **Tripping :** Instantaneous trip, delayed trip inverse time response and definite time

3 **Operating principle:** Electro magnetic relays, Induction relays, Thermal relays and static or digital relays

Types or relays : Various types of relays are used as per the requirement; they are:

1 Over current relay

2 Over voltage relay

3 Under voltage relay

4 Differential relay

5 Earth fault relay

6 Distance relay

7 Impedance relay

8 Admittance relay

9 Reactance relay

Relay is one of the main device used for switch gear protection networks to protect the transmission lines, transmission equipments and sub station equipments. The equipments used for transmission and in substation for distribution such as transformers, lightening arrestors, earth switches, isolators, CTs & PTs etc; are very costly and needs continuous protection from damage. Replacement or repairs are not easy and to provide an uninterrupted supply to consumers. So, protection of these devices/equipments are very essential

Reasons for over current, Over voltage and under voltage fault:

Many reasons constituted for over current, over and under voltage or earth faults; type of fault and the cause effect is listed in Table 1.

Table 1

SI No	Type of Fault	Cause	Effect
1	Phase to neutral short	- Insulation failure - Components failure - Human error	- High current flow in line. - Fire
2	Phase to phase short in transmission lines	- Tree branches falls on line - Snakes crossing on tower lines and - Birds falls - Strong winds - Natural calamities - Riots, and human made faults	- Very high current flows - Fire - Extensive damage of equipments
3	Phase to ground fault	- Insulation failure - Component failure	- High current flow in line - Fire - Low voltage

SI No	Type of Fault	Cause	Effect
4	Lightening storm etc;	- Natural calamities	- Very high current flows - Fire - High voltage spikes
5	Sudden removel of heavy load	- Fuse failure	- High voltage
6	Increasing Load beyond the rated level	- Human Error	- Low voltage in line - Over loading the line

Sensors used for Relays

The relay cannot accept the total line voltage or load current. A small part of the electrical quantity is supplied to the relay through sensors. A current transformer popularly known as CT and a potential transformer PT, is serves the purpose of sensors in current relay and voltage relay. Various input and output ratios are in practice to supply the sensing quantity to the relays according to the load conditions.

Working principle of current relay

The electro magnetic relay widely using in the substation and transmission lines are serves the protection from the disaster conditions. The latest version of modern static or digital relays are now a days out dated the conventional electro magnetic relays, because of their many of advancements compare to electro magnetic relay. (Fig 1)
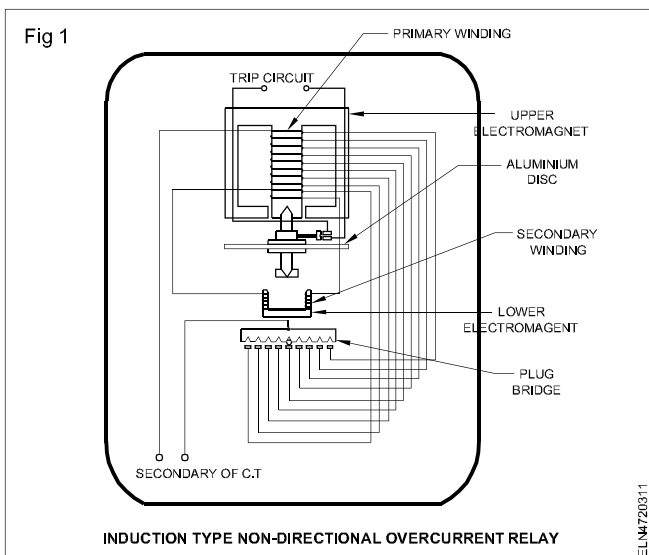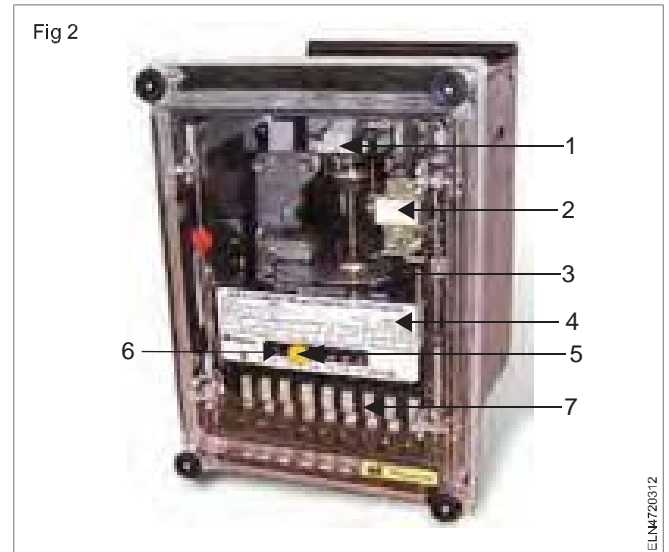

Fig 1

INDUCTION TYPE NON-DIRECTIONAL OVERCURRENT RELAY

Fig 2 shows the front panel setting of a electric magnetic relay.

1 Time multiplier setting (TMS)

2 Trip flag

3 Aluminium rotating disc

4 Percentage fault quantity time reference dial

Fig 2

5 Tap setting plug

6 Input fault quantity (V_{ONI})

7 Contact plug terminals

An induction type over current relay giving inverse time operation with a definite minimum time characteristic is in Fig 1. It consists essentially of an ac energy meter mechanism with slight modification to give required characteristics. The relay has two electromagnets. The upper electromagnet has two windings, one of these is primary and is connected to the secondary of a CT in the line to be protected and is tapped at intervals.

The tappings are connected to a plug setting bridge by which the number of turns in use can be adjusted, thereby giving the desired current setting. The plug bridge is usually arranged to give seven sections of tappings to give over current range from 50% to 200% in steps of 25%. If the relay is required to response for earth fault the steps are arranged to give a range from 10% to 70% or 20 to 80% in steps of 10%. The values assigned to each tap are expressed in terms of percentage of full-load rating of CT with which the relay is associated and represents the value above which the disc commences to rotate and finally closes the trip circuit.

Thus pick-up current equals the rated secondary current of CT multiplied by current setting. For example suppose

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that an over current relay having a current setting of 150% is connected to a supply circuit through a CT of 500/5A. The rated secondary current of CT is 5A and, therefore, the pick-up value will be 1.5 x 5i.e., 7.5 A. It means that with above current setting, the relay will actually operate for a relay current equal to or greater than 7.5 A.

Similarly for current settings of 50, 100 and 200% the relay will operate for relay currents of 2.5A, 5 A and 10 A respectively. Adjustment of current setting is made by inserting a pin between the spring loaded jaws of the bridge socket at the tap value required. When the pin is withdrawn for the purpose of changing the setting value while the relay in service, the relay automatically adopts higher setting, thus the CT's secondary is not open-circuited.

The disc spindle carries a moving contact which bridges two fixed contacts (trip circuit contacts) when the disc has rotated through a preset angle. The angle can be set to any value between 0° and 360° and there by giving desired time setting. This adjustment is known as time-setting multiplier. Time multiplier setting is generally in the form of an adjustable back-stop which decides the arc length through which the disc travels, by reducing the length of travel, the operating time is reduced.

The time setting multiplier is calibrated from 0 to 1 in steps of 0.05. These figures do not represent the actual operating times but are multipliers to be used to convert the time known from the relay name plate curve (time-PSM curve) into the actual operating time. Thus if time setting is 0.2 and the operating time obtained from the time-PSM curve of the relay is 5 seconds, then actual operating time of the relay will be equal to 0.2 x 5 i.e., 1 second.

Since the time required to rotate the disc through a preset angle depends upon the torque which varies as the current in the primary circuit, therefore, more the torque lesser will be the time required. So the relay has inverse-time characteristic.

Relay Time setting characteristics

**1 Instantaneous over current/voltage relay**

Definite current/voltage (over or under) relay operate instantaneously when the fault quantity reaches a predetermined value. (Fig 3)

Fig 3
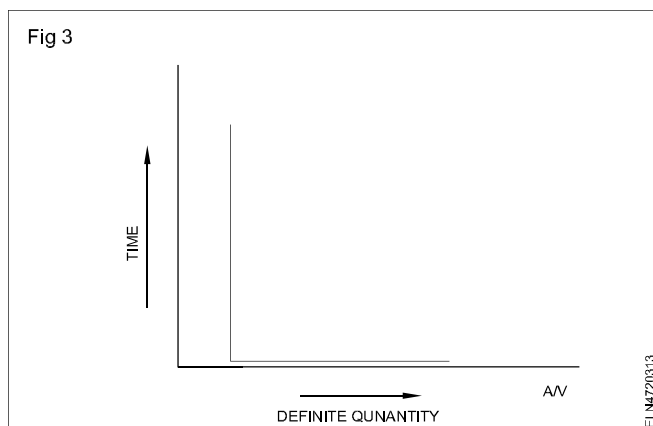
- Operates in a definite time when fault quantity exceeds its pick-up valve.

- Its operation criteria is only fault quantity magnitude

- Operating time is constant

- No intentional time delay

- These are varies with position of the fault occurred because of the difference in impedance between the fault and the source

- It can operates in 0.1s or less.

2 Definite time

Two conditions must be satisfied on the fault quantity continued to be present up to the time setting of the relay. (Fig 4)

Fig 4
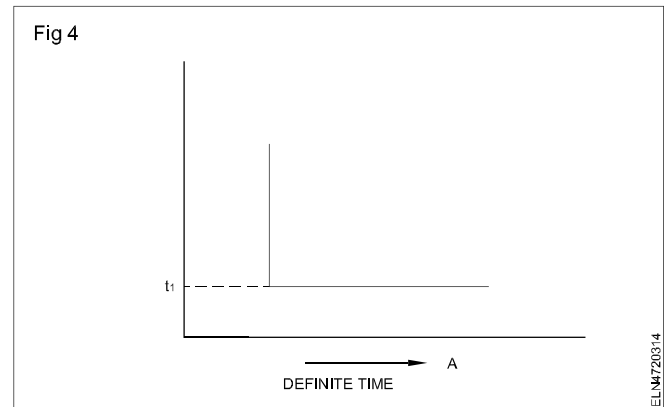
- Its operating time is constant

- Its operation is independent of the magnitude of the fault quantity

- It has time dial settings; Time delay can be varied

- Tripping time independent on fault location.

3 Inverse time

Operating time is inversely changed fault quantity. So, high the fault quantity will operate relay faster than lower ones (Fig 5). There are few more settings also in practice, They are;

Fig 5
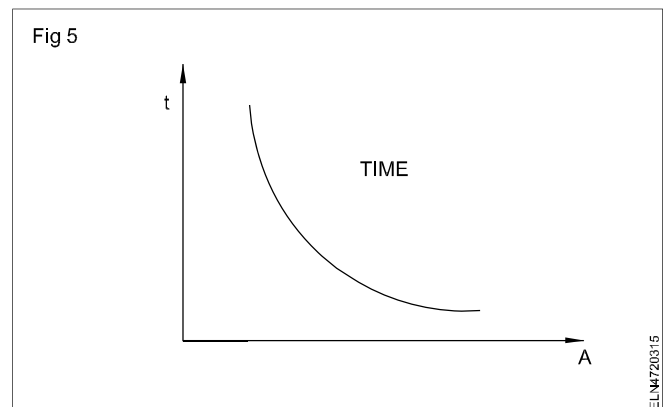
- Standard inverse

- Very inverse

- Extremely inverse

Discrimination by both time and fault quantity, the relay operation time is inversely proportional to the fault quantity.

Inverse time relays also referred as Inverse Definite Minimum Time (IDMT) relays.

The operating time of relay can be moved up (made slower) by adjusting the time dial setting. The lowest time dial setting (fastest operating time) is generally 0.5 seconds and the slowest is 10s.

Silent features of inverse time settings

*   Operates when fault quantity exceeds its pick-up value.

*   Operating time depends on the magnitude of the fault quantity

*   It gives inverse time current characteristics at lower values of fault quantity and definite time characteristics at higher values.

*   An inverse characteristics is obtained if the value of plug setting multiplier is below 10, for values between 10 and 20 characteristics tends towards definite time characteristics. Fig 6 shows the different inverse types. Based on the inversness it has three different types of curves shown in Fig 6.
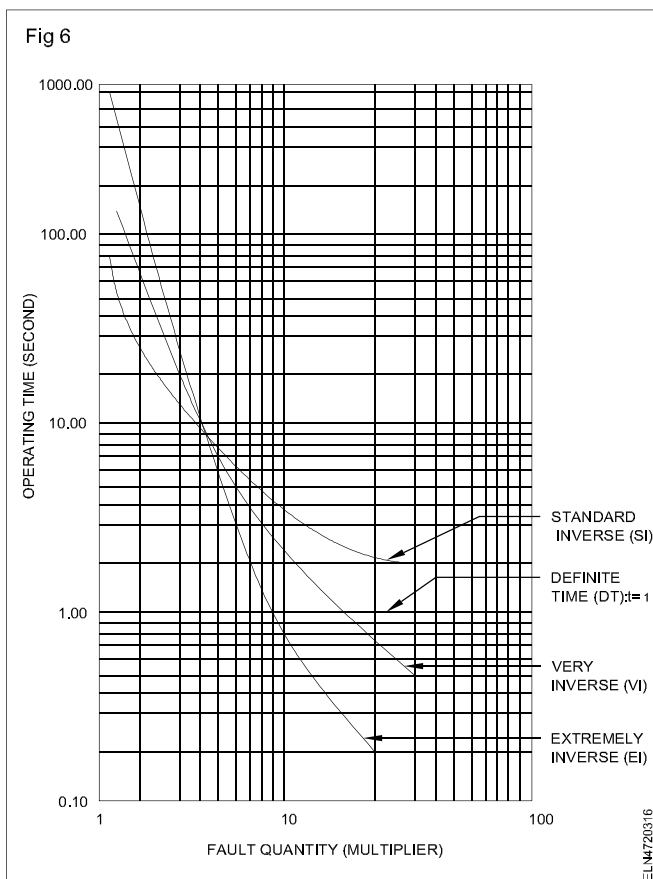
Fig 6

Normal inverse time over current relay is relatively small change in time/unit of change of current

Very inverse time characteristics

*   Gives more inverse characteristics than that of IDMT

*   Used when there is a reduction in fault quantity, as the distance from source increases

*   Effective with ground faults because of their steep characteristics

*   Suitable where the fault distance from the power source increase

*   Particularly suitable if the short circuit fault current drops rapidly with the distance from the substation

*   The grading margin may be reduced to very low time (0.1 second) in this characteristics

*   Used when fault quantity is dependent on fault location

Extremely inverse time characteristics

*   It has more inverse characteristics than that of IDMT and very inverse characteristics

*   Suitable for protection against over heating

*   Operative time approximately inversely proportional to the square of the fault quantity

*   It makes possible to use short time delay in spite of high switching in current

*   Used when fault quantity is dependent on fault location

*   Suitable for protection of feeders, with peak current on switching (refrigerators, pumps water heaters etc) and also for alternator transformers and expensive cables.

Long time inverse characteristics

This characteristics is used as back up earth fault protection as the time inversely proportional to the intensity of fault quantity.

Over voltage and under voltage relays

This electromagnetic relays are working on the same principle of induction type disc type relays. The sensor used in this relay input is from PT (potential transformer) where output generally kept on 110v AC.

When the fault occurs the PT output produces a voltage which in turn energise the disc mechanism to rotate. As the fault continue to represent; and the trip time settled, the relay disc rotates and make the trip coil to activate in the trip mechanism in the breakers. The tripping time settled as per the characteristics selected. The pick up voltage has to be verified with the plug setting value of fault voltage which can be selected in different fault voltages in both over/ under voltage relay. Time Multiplier Setting (TMS) shorten the trip time if necessary on the fault quantity is more as the case may be.

Normal Inverse Characteristics

The accuracy of the operating time may range from few percentage of the nominal operating time. The uncertainty of the operating time and the receiving operating time may require a grading margin of less than one seconds.

Time multiplier setting

This setting is helps the relay to shorten the time selected without change of any other settings made in the relay. Time multiplier helps the relay to activate fast the breaker in case the fault quantity is more than 50% of the fault quantity selected by the tap setting.

Differential protection relay

Differential protection is a very reliable method of protecting generators, transformers, busbar and transmission lines from the effects of internal faults. In normal operating conditions the current through the CTs is the same. So the relay sense no differential current. This is also the case for external faults. Differential protection can be used for protecting generators from faults to ground. Differential protection of busbars in substations uses one CT for each incoming line. All incoming currents are added up and compared to the sum of all out going currents.

General schematic diagram of differential protection relay is in Fig 7.


Fig 7

DIFFERENTIAL RELAY
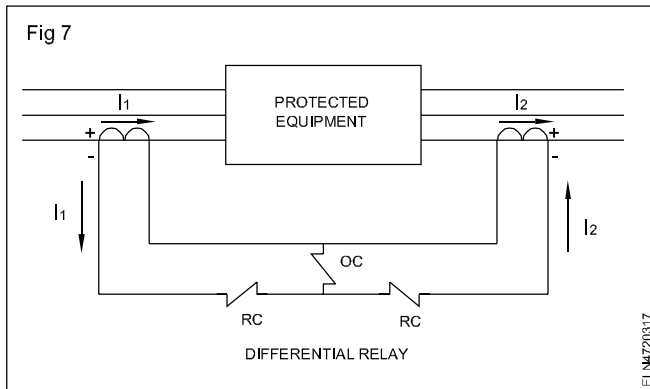
The installation of differential relay for protection of power transformers used in transmission line is in Fig 8.

Distance relays / Admittance relay

The impedance of a transmission line is proportional to its length, for distance measurement it is appropriate to use a relay capable of measuring the impedance of a line up to a predetermined point (the reach point) Such a relay is described as a distance relay and is designed to operate only for faults occurring between the relay location and the selected reach point thus giving discrimination for faults that may occur in different line sections

Fig 8

DIFFERENTIAL PROTECTION IN TRANSFORMERS
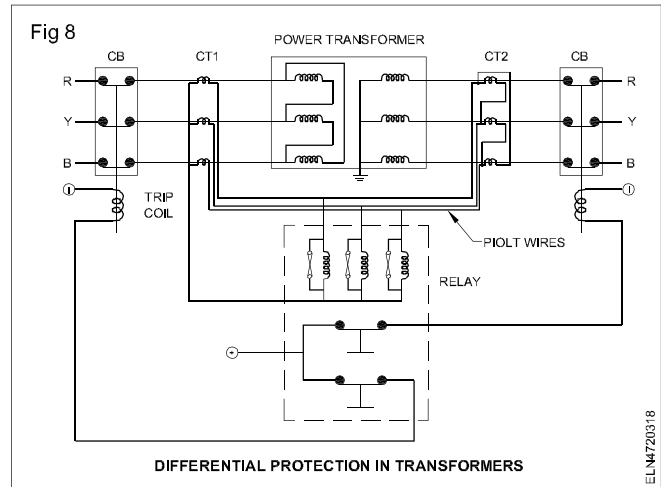
Reactance relays (or) Shaded pole type non directional relay

The reactance relay is a straight line characteristic that responds only to the reactance (X_L) of the protected line . It is non directional and is used to supplement the admittance relay as a tripping relay to make the overall protection independent of resistance. It is particularly useful on short lines where the fault arc resistance is the same order of magnitude as the line length.

The relay serves an important part in switchgear protection. The electromagnetic relay is the first generation of protective relays and it has many moving parts and working in the principles of induction. Electromagnetic relay can carry one function ie., over current, over voltage or under voltage at a time. This draw back is overcome by the use of static or digital relay which can use for multi function, as well as more accurate than electromagnetic relays.

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Circuit breakers - parts - functions- tripping mechanism

Objectives: At the end of this lesson you shall be able to
• **state about circuit breaker**
• **list the various types of circuit breakers**
• **explain the parts of each circuit breakers**
• **explain the principle of operation of circuit breaker**
• **explain the application and uses of circuit breaker.**

Circuit breaker

Circuit breakers are the electrical device (or) equipment, which makes or breaks the electrical circuit. In a 240 volt single phase system a low rated single pole switch can use the circuit to break or make. But in this case the resultant spark at the contacts are negligible and this will not make any fire, in the circuit or contacts since the current is very low.

But in the case of heavy loads; say some hundreds, of ampere are flowing in a circuit the resultant spark at contact are heavy and this leads to electrical fire. To overcome this problem the sparks at the contacts are to be controlled or quenched, when any load makes or breaks. The equipment or device used to make or break a circuit under control at the same time it prevents or quenching the resultant fire is called as a circuit breaker. The breakers are named after the quenching medium used to control the fire such (1) air circuit breaker, (2) oil circuit breaker, (3) vaccum circuit breaker and (4) Sulphur hexafluoride (SF_6) circuit breaker.

Air circuit breaker (ACB)

A circuit breaker which uses the either natural air or blast air as an Arc quenching medium is termed as Air-circuit breakers.

ACB is widely used upto 15KV in place of oil circuit breaker because there is no chance of the fire due to the quenching oil as in case of OCB.

Air- Circuit breakers are widely used in industries as well as power system for controlling and protection of different section of the circuit like, Transformers, Motors, Generators / Alternator etc and leads the system stable and reliable. Other components are also associated with circuit breakers like fuses, relays, switches etc.

Construction of air - circuit breaker

External lables / parts of ACB in Fig.1

1 OFF button (O)

2 ON button (I)

3 Main contact position indicator

4 Energy storage mechanism status indicator

Fig 1

Air Circuit Breaker External Labels

EXTERNAL VIEW OF ACB
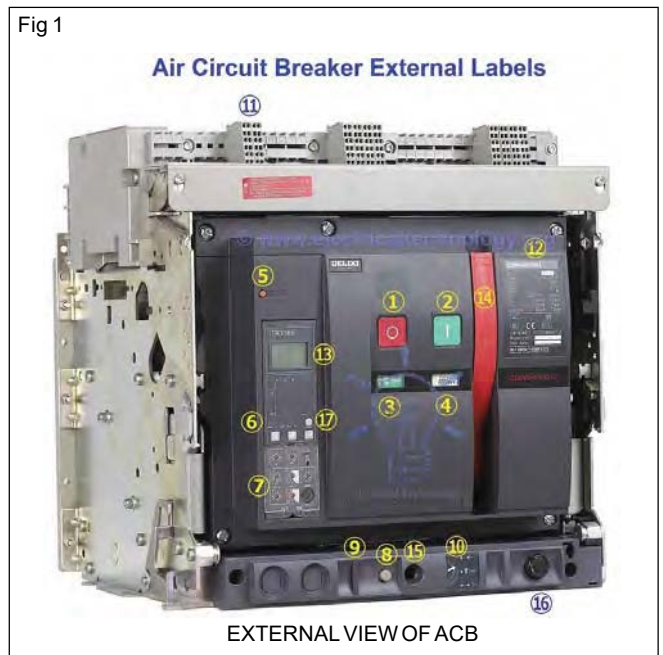
5 Reset button

6 LED indicators

7 Controller

8 "Connection" "Test" and "isolated" position latching / locking mechanism

9 User padlock

10 Connection, "Test", and isolated position indication

11 Connection test and isolated position indication contacts

12 Name plate

13 Digital displays

14 Energy storage handle

15 Draw out /in hole

16 Rocker repository

17 Trip reset button

Internal construction of air circuit breaker

The internal parts of an ACB in Fig.2

1 Sheet steel supporting structure

2 Current transformer for protection trip unit

233

Fig 2

INTERNAL VIEW OF CIRCUIT BREAKER
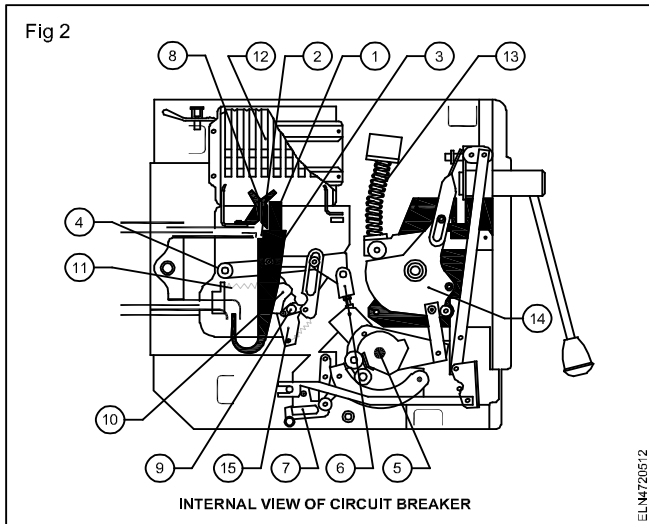
3   Pole group insulating box

4   Horizontal rare terminals

5   Plate for fixed main contacts

6   Plates for fixed arcing contacts

7   Plate for main moving contacts

8   Plates for moving arcing contacts

9   Arcing chamber

10 Terminal box for fixed version - sliding contacts for withdrawable version

11 Protection trip unit

12 Circuit breaker closing and opening control

13 Closing springs

14 Spring loading arrangement

15 Manual releasing lever

Principle of operation of air circuit breaker

• When the circuit breaker opens the circuit either under the normal condition or in the fault condition, some Arc is produced between the main contacts and some current flows to the load, called **transition current** through the arc.

• This Arc and the current should be suppressed / eliminated especially during the fault condition otherwise the severity of the fault level will be more and damages the circuit which leads to the electric fire.

• During the period of Arc some voltage appears across the main contacts called **transition voltage**, which will be more than the rated system / supply voltage.

• To quench the Arc, this transition voltage should be reduced or the Arc voltage to be increased. The minimum voltage required to maintain the arc is called as **Arc voltage**. In ACB, the Arc voltage is increased in the following three ways.

• Arc voltage can be increased by cooling arc plasma by air. The temperature of arc plasma is reduced, more voltage will be required to maintain the arc.

• By splitting the arc into a number of series in Arc chute will increases the arc voltage.

• Arc voltage can be increased by lengthening the arc path. As length of arc path is increased its resistance of the arc path will increase hence the arc voltage is increased.

Some ACB contains two pairs of contact . The main pair carries the current and the made of copper. An additional pair of contact (Arc contact) is made of carbon. When the breaker is opened, the main contact opens first. and the arc contact remains in touch. The arcing gets initiated when arc contacts are separated.

Hence transition voltage will be reduced.

Application and uses of air circuit breaker

• It is used for protection of plants

• It is used for common protection of electrical machines

• Air circuit breaker is also used in electricity sharing system upto 15KV

• Also used in low as well as high voltage and current applications.

• It is used for protection of transformers, capacitors and generators.

Types of air circuit breaker

• Plain air circuit breaker

• Air blast circuit breaker

Plain air circuit breaker

In this circuit breaker a chamber is fitted surrounding the contact. The chamber is known as **"arc chute"**. The arc chute will help in achieving cooling. Arc chute is made from some refractory material.

The arc chute is divided into a number of small compartments by using metallic separation plates called **arc splitters** and behave as a mini arc chute as in Fig.3. Initial arc will split into a series of arcs and make the arc voltages higher than system voltage. They are preferable choice in low voltage application.

Fig 3

AIR BLAST CIRCUIT BREAKER
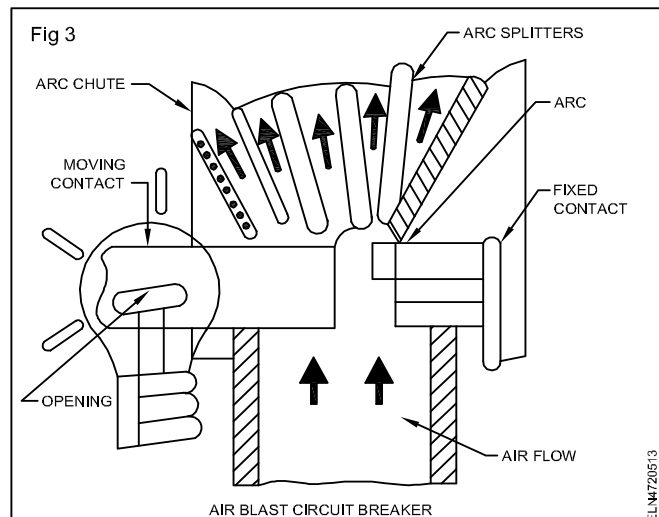
Air blast circuit breaker

ACB which uses the high pressure (blast) air as an Arc quenching medium is known as Air-Blast- Circuit-Breaker(ABCB).

This type of circuit breaker is used for high voltage application and can be further divided into three categories.

- Axial blast air circuit breaker

- Cross blast air circuit breaker

- Radial blast air circuit breaker

Advantages of air - blast circuit breaker

- Air blast circuit breaker is used where the frequent operation is required because of lesser arc energy.

- The risk of fire due to oil is eliminated in the air blast circuit breaker

- Arc quenching is much faster

- Air blast circuit breaker is small in size, because of the fast Arc quenching.

- The duration of the arc is same for all the values of current.

- Operating speed of circuit breaker is much higher.

- Stability of operation is high because of speed of operation.

- It requires less maintenance

### Disadvantages of air -blast circuit breaker

- Additional air supply plant requires hence require additional maintenance.

- It require high capacity air compressor.

- There is a chance of air pressure leakage.

- There is chance of a high rate of re - striking voltage and current chopping.

- The air has relatively lower arc extinguishing properties than oil.

Oil circuit breakers (OCB)

Circuit breakers which uses the insulating oil (e.g transformer oil) as an arc quenching medium is called as oil circuit breaker. The main contacts of the OCB are opened under the oil and an arc is struck between them. The heat of the arc evaporates the surrounding oil and dissociates it into gaseous of hydrogen at high pressure.

The hydrogen gas occupies a volume about one thousand times that of the oil decomposed. The oil is, therefore, pushed away from the arc and an expanding hydrogen gas bubble surrounds the arc region of the contacts. The arc extinction is completed by two processes. Firstly, the hydrogen gas has high heat conductivity and cools the arc, thus aiding the de-ionization of the medium between the contacts.

Secondly, the gas sets up turbulence in the oil and forces it into the space between contacts, thus eliminating the arc as in Fig 4. The result is that arc is extinguished and circuit current is interrupted.

Fig 4
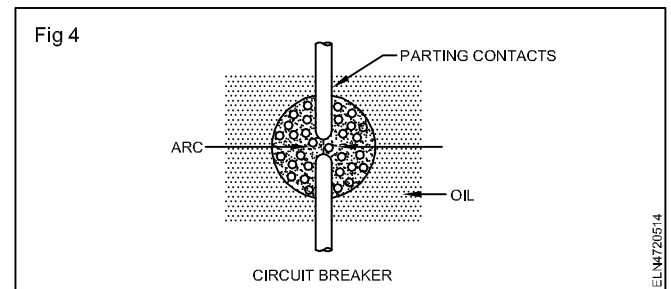
The advantages of oil as an arc quenching medium

i   It absorbs the arc energy to decompose the oil into gases which have excellent cooling properties.

ii It acts as an insulator and permits smaller clearance between main contacts.

iii The surrounding oil presents the cooling surface in close proximity to the arc.

The disadvantages of oil as an arc quenching medium.

i   It is inflammable and there is a risk of a fire.

ii It may form an explosive mixture with air.

iii The arcing products (e.g. carbon) remain in the oil and it deteriorates the quality of insulating oil.

iv Periodic checking and replacement of the insulating oil is required.

Types of oil circuit breakers

a) Plain break oil circuit breakers

b) Arc control oil circuit breakers.

ii Low oil circuit breakers

Plain break oil circuit breakers

In plain- break oil circuit breaker the main contacts are placed under the whole oil in the tank. There is no special system for arc control other than the increase in length of separation of the contacts. The arc extinction occurs when a critical gas is reached between the contacts.

The plain - break oil circuit breaker is the oldest type and has a very simple construction. It consists of fixed and moving contacts enclosed in a strong weather- tight earthed tank containing transformer oil upto a certain level and an air cushion above the oil level.

The air cushion provides sufficient room to arc gases without the generation of unsafe pressure in the circuit breaker. It also absorbs the upward oil movement. Fig 5 shows a double break plain oil circuit breaker. It is called a double break because it provides two breaks in series.

Fig 5 — (a) OCB, (b) OCB TRIP CIRCUIT
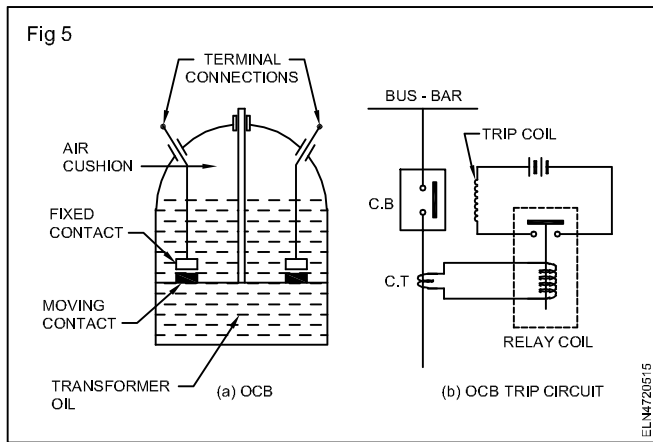
Principle of working

Under normal operating conditions, the fixed and moving contacts remain closed and carries the normal circuit current. When a fault occurs, the moving contacts are pulled down by the tripping mechanism and an arc is produced which vaporizes the oil into hydrogen gas. The arc extinction is completed by the following processes.

i   The hydrogen gas bubble generated around the arc, cools the arc.

ii The gas sets up turbulence in the oil and helps in eliminating the arc.

iii As the arc lengthens due to the separation of contacts, the Arc voltage is increased.

The result is at some critical gap, the arc is extinguished and the circuit current is interrupted.

Disadvantages

i   There is no special control over the arc other than the increase in gap length.

ii These breakers have long and inconsistent arcing times.

iii The speed of interruption is less.

Due to these disadvantages, plain - break oil circuit breakers are used only for low - voltage not exceeding 11 KV applications where high breaking- capacities are not important.

Arc control oil circuit breakers

In plain -break oil circuit breaker there is very little artificial control over the arc. Therefore long arc length is essential in order to quench the Arc. If some arc control is incorporated at still short contact gap than the breakers are called arc control oil circuit breakers.

They are two types

a   Self - blast OCB

b   Forced - blast OCB

Low oil circuit breakers

In the bulk oil circuit breaker, only a small percentage of oil (about 10% of total) is actually used for arc extinction. But the huge volume of oil used in bulk oil circuit breaker increases the expenses, tank size, weight of the breaker, increases the fire risk and maintenance problems.

To over come the above disadvantages the low oil circuit breaker is developed which employs solid materials for insulation purposes and uses a small quantity of oil which is just sufficient for quenching the arc. By using suitable arc control devices, the arc extinction can be further simplified in a low oil circuit breaker.

Construction : Fig 6 shows the single phase low oil circuit breaker. There are two compartments separated from each other and filled with oil. The upper chamber is the **circuit breaking chamber** whereas the lower one is the **supporting chamber**. The two chambers are separated and the oil from one chamber is prevented from mixing with the other chamber.

Fig 6

LOW-OIL CIRCUIT BREAKER
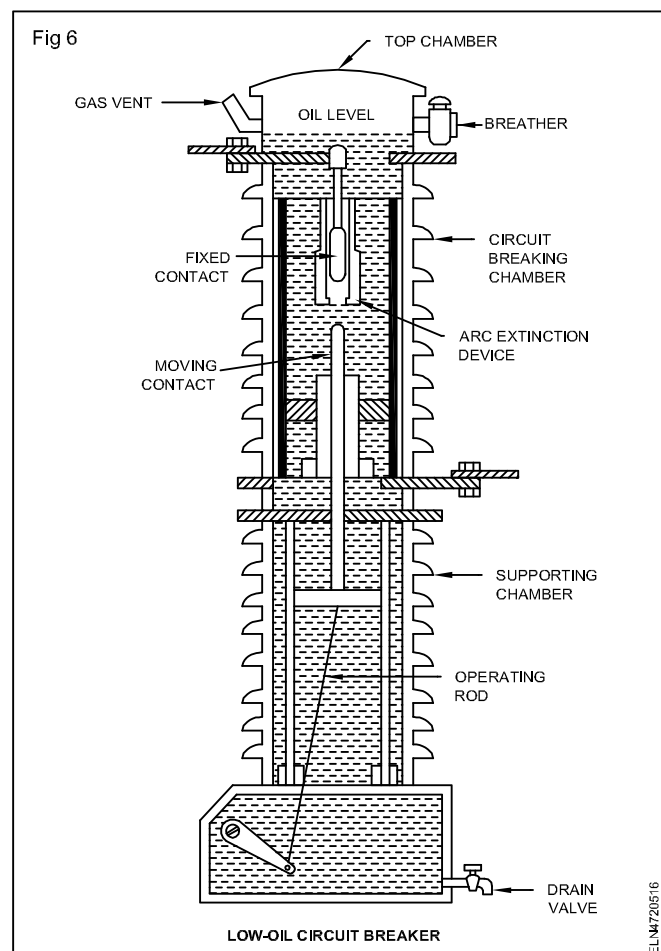
This arrangement has three advantages.

1   The circuit breaking chamber requires a small volume of oil which is enough for arc extinction.

2   The amount of oil to be replaced is considerably reduced

3   The oil in the supporting chamber does not get contaminated by the arc.

i **Supporting chamber :** It is a porcelain chamber filled with oil which is physically separated from the oil in the circuit breaking compartment. The oil inside the supporting chamber and porcelain insulation is employed for insualtion purposes only.

ii **Circuit breaking chamber :** It is a porcelain enclosure mounted on the top of the supporting chamber and filled with oil and has the following parts.

a) Fixed contacts

b) Moving contacts

c) Turbulator

The moving contact enters top chamber through a fixed piston. The turbulator is an arc control device and has both axial and radial vents. The axial vent for low currents whereas radial vent for heavy currents rating breakers.

iii **Top chamber :** It is a metal chamber mounted on top of the circuit - breaking chamber. It provides space for the oil expansion in the circuit breaking chamber. The top chamber also has a gas vent pipe and breather through which the escaping gas and entering air may pass through to the circuit breaking chamber during the breaking of fault current.

Operation : Under normal operating conditions, the moving contact engages with the fixed contact. When a fault occurs, the moving contact is pulled down by the tripping mechanism and an arc is produced. The arc vaporizes the oil and produces gas to escape through the gas vent.

This action results the oil to pass through a central hole of the moving contact and forcing the oil through the respective vents of the turbulator. The arc are successively quenched by the effect of streams of oil passes through the vent while gas passes.

Advantages : A low oil circuit breaker has the following advantages over a bulk oil circuit breaker.

i It requires lesser quantity of oil

ii Cost of the breaker is less

iii It requires smaller space

iv The weight of the breaker in less

iv There is reduced risk of fire

vi Maintenance problems and cost are reduced

Disadvantages : A low oil circuit breaker has the following disadvantages as compared to a bulk oil circuit breaker

i There is a difficulty of removing the gases from the contact space.

ii Due to smaller quantity of oil, the effect of carbonization is increased.

iii The dielectric strength of the oil deteriorates fastly due to high degree of carbonization.

Vacuum circuit breaker (VCB)

Circuit breaker which uses vacuum as an arc quenching medium is called as vacuum circuit breaker.

Vacuum offers the highest insulating strength and have the superior arc quenching properties than any other medium. When the contacts of a breaker are opened in vacuum, the interruption occurs instantly as the dielectric strength between the contacts are many times higher than the other circuit breakers.

The technology is only suitable for medium voltage application. For higher voltage application, the vacuum technology has been developed.

Principle of vacuum circuit breaker

• When the contacts of the breaker are opened in vacuum (10^7 to 10^5 torr), an arc is produced between the contacts by the ionisation of metal vapours i.e, combination of electrons and ions of contacts. However, the arc is quickly extinguished because the metallic vapours, rapidly cools resulting quick recovery of dielectric strength.

• The salient feature of vacuum is, as soon as the arc is produced in vacuum, it is quickly extinguished due to the rapid recovery of dielectric strength of vacuum.

Construction of vacuum circuit breaker

Fig 7 shows the typical parts of vacuum circuit breaker

Fig 7
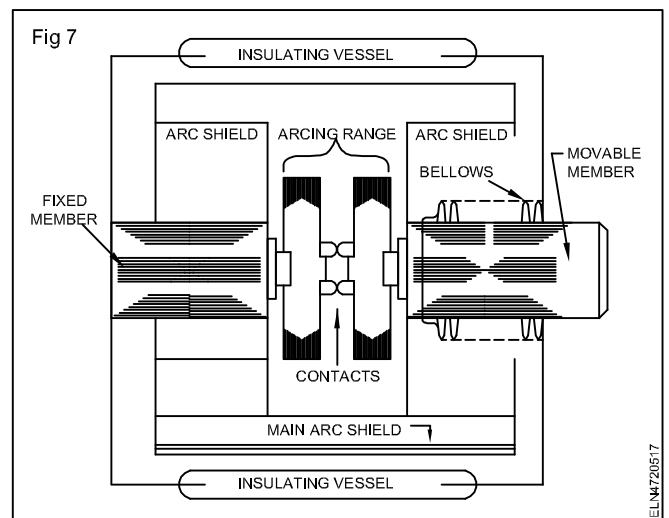
• It consists of the fixed contact, moving contact and arc shield mounted inside a vacuum chamber.

• The movable member is sealed by a stainless steel bellows, is connected to the control mechanism. This enables the permanent sealing of the vacuum chamber, to eliminate the possibility of leak.

• A glass vessel or ceramic vessel is used as the outer insulating body.

• The arc shield prevents the metallic vapours falling on the inside surface of the outer insulating cover.

Working of vacuum circuit breaker

• When the breaker opens, the moving contact is separated from the fixed contact and an arc is produced between the contacts. The production of arc is due to the ionisation of metal ions and depends upon the material of contacts.

• The arc is quickly extinguished because the metallic vapours, are diffused in a short time and condensed on the surfaces of moving and fixed members and arc shields.

• Since vacuum has rapid Arc recovery rate of dielectric strength, the arc extinction in a vacuum breaker occurs with a short separation (say 0.625 cm) of contacts.

Application of VCB

• Vacuum circuit breakers are employed for outdoor applications ranging from 22KV to 66KV.

• They are suitable for majority of applications in rural areas.

Sulphur hexafluoride (SF$_6$) circuit breaker

Circuit breakers which uses the sulphur hexafluoride gas (SF$_6$) as an arc quenching medium is called as SF$_6$ circuit breaker.

The sulphur hexafluoride gas (SF$_6$) is an electronegative gas and has a strong tendency to absorb the free electrons. When the contacts of the breaker are opened in a high pressure sulphur hexafluoride (SF$_6$) gas medium and an arc is struck between them.

The SF$_6$ gas capture the conducting free electrons in the arc and form immovable   negative ions. This loss of conducting electrons in the arc quickly improve the insulation strength to extinguish the arc.

The sulphur hexafluoride (SF$_6$) circuit breakers are very effective for high power and high voltage applications.

Construction of SF6 circuit breaker

A sulphur hexafluoride (SF$_6$) circuit breaker consists of fixed and moving contacts enclosed in a chamber as in Fig 8. The chamber is called arc interruption chamber which contains the sulphur hexafluoride (SF$_6$) gas and it is connected to sulphur hexafluoride (SF$_6$) gas reservoir.

When the contacts of breaker are opened, the valve mechanism permits a high pressure sulphur hexafluoride (SF$_6$) gas from the reservoir to flow towards the arc interruption chamber.

The fixed contact is a hollow cylindrical contact fitted with an arc horn. The moving contact is also a hollow cylinder with rectangular holes in the sides. The holes permit the sulphur hexafluoride gas (SF$_6$) to let out through them after flowing along and across the arc.

Fig 8

TYPICAL INTERNAL VIEW OF SF$_6$ - CB
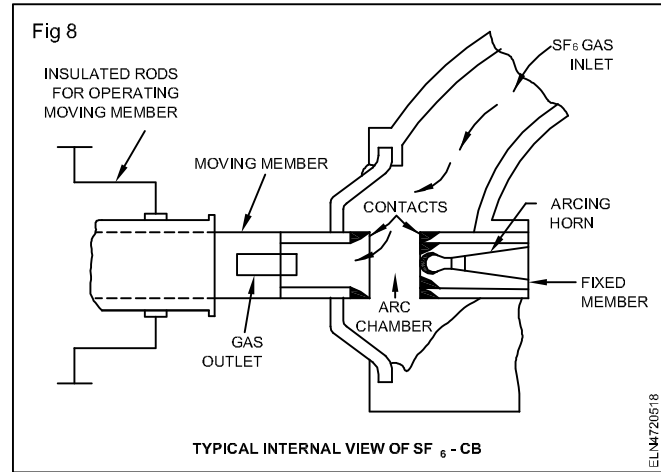
The tips of fixed contact, moving contact and arcing horn are coated with copper - tungsten arc resistant material. Since sulphur hexafluoride gas is costly, it is reconditioned and reclaimed using suitable auxiliary system after each operation of breaker.

Working of SF$_6$ circuit breaker

In the closed position of the breaker, the contacts remain surrounded by SF$_6$ gas at a pressure of about 2.8 kg/cm^2. When the breaker opens, the moving contact is pulled apart and an arc is struck between the contacts. The movement of the moving contact is synchronized with the opening of a valve which permits SF$_6$ gas at 14kg /cm^2 pressure from the reservoir to the arc interruption chamber.

The high pressure flow of SF$_6$ gas rapidly absorbs the free electrons in the arc path to form immovable negative ions which are ineffective as charge carriers. The result is that the medium between the contacts rapidly improve the dielectric strength and causes the extinction of the arc. After the breaker operation (i.e. after arc extinction), the valve mechanism is closed by a set of springs.

Advantage of SF$_6$ circuit breaker

Due to the superior arc quenching properties of SF$_6$ gas, the sulphur hexafluoride gas circuit breakers have many advantages over oil or air circuit breakers. Some of them are listed below.

1   Such circuit breakers have very short arcing time.

2   Since the dielectric strength of SF$_6$ gas is 2 to 3 times more than the air, such breakers can interrupt much larger currents.

3   SF$_6$ circuit breaker gives noiseless operation due to its closed gas circuit and no exhaust to the atmosphere unlike the air blast circuit breaker.

Tripping mechanism of circuit breakers

Objectives: At the end of this lesson you shall be able to
* **State the necessity of tripping mechanism**
* **state the types of tripping mechanism.**

Tripping mechanism of circuit breakers

Trip mechanism : Trip mechanism is incorporated in the circuit breaker to switch off the circuit breaker at faulty condition either automatically or manually at the desired time.

Fig 1 shows the arrangement. When the circuit breaker is closed, the mechanism is locked in position by a system of linkages. This lock can be released by lifting the trip bar.


Fig 1
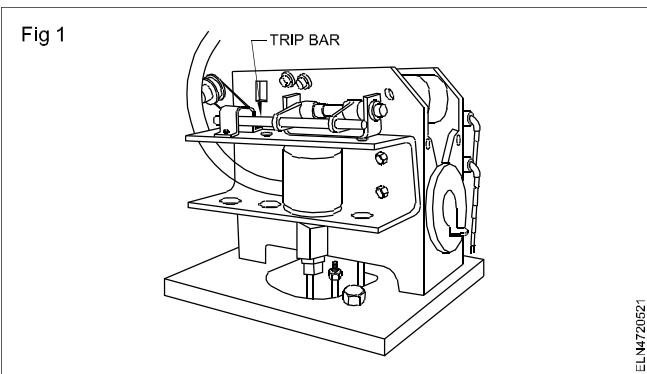
Trip bar is attached to the tripping lever which in turn can be operated manually. The tripping lever is generally kept locked. When the trip bar is lifted the mechanism opens the breaker contacts.

Trip coils: When remote operation is desired, trip coils are used. The trip coils are small solenoids either operated by AC or DC supplies. Fig 2 shows the general arrangement of the trip coil mechanism. A plunger moves freely inside the solenoid. When the solenoid is energised by the trip switch the plunger moves up and release the lock which holds the trip bar. Further the trip coils are also actuated by short circuit /overload and under -voltage relays as described in the following paragraphs.

Fig 2
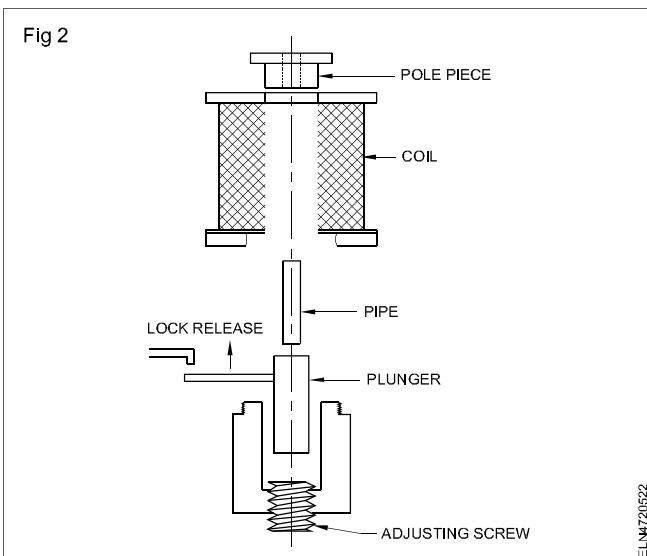
Shunt trip coils : The shunt trip coil requires an auxiliary supply, a C.T and a relay. The relay can be set to give time-graded protection. The relay closes the trip coil circuit when the load current exceeds the stipulated value. This relay is in Fig 3.

Fig 3
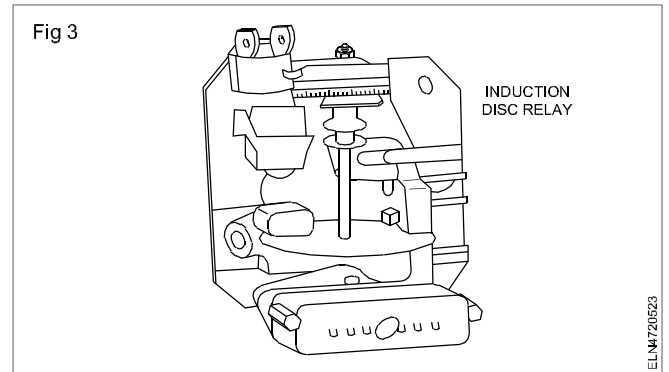
Series trip coil: The series trip coil mechanism is in Fig 4 consists of a series solenoid with a plunger controlled by a spring. When current in the load become excessive the plunger rises and trips the mechanism.
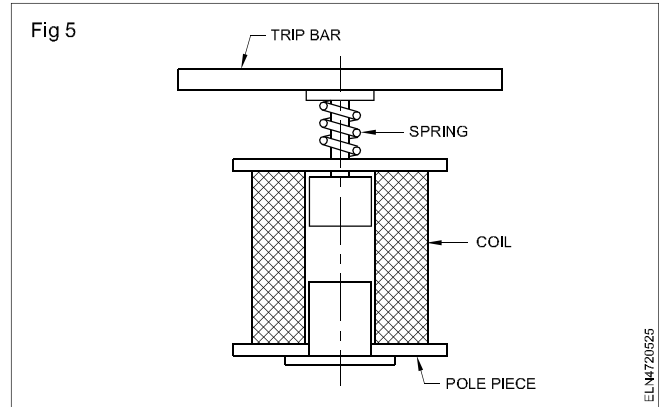

Fig 4
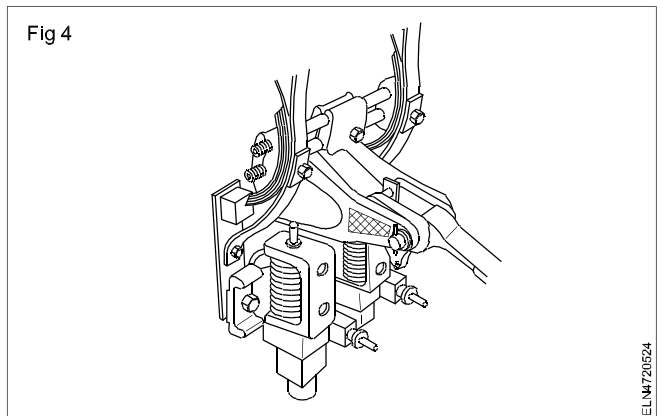
The current necessary to trip the circuit breaker is regulated by a screw which adjusts the tension of the spring controlling the plunger. Time-lag can be adjusted by the position of the dash pot which holds the piston of the plunger in the oil bath.

In three-phase circuit breakers, there are three series trip coils, three dash pots, three plungers. They can operate the trip mechanism together or independently.

Under voltage release coils : The under-voltage release coil is used in installations where detection and isolation of abnormally low voltage is required. The construction of the under-voltage trip coil is in Fig 5 is similar to the trip coils discussed above except that the plunger is held away from the pole piece by a coiled spring. Under normal operating conditions, the solenoid is energised and the plunger is held down against the force of the spring. When

the supply voltage falls, the under - voltage release coil will not be in a position to hold the plunger down against the spring tension. Thus the plunger moves up and pushes the trip bar to trip the circuit breaker.

Fig 5

TRIP BAR

SPRING

COIL

POLE PIECE

ELN4720525

Electrical : Electrician (NSQF LEVEL - 5) - Related Theory for Exercise 4.7.205 & 4.7.206

Repair and maintenance of CBs

Objectives: At the end of this lesson you shall be able to
• **explain the procedure to carry out maintenance and repair of a OCB**
• **state the method to adopt checking and maintenance/repair of ACB & VCB**
• **explain the procedure of the condition of SF$_6$ circuit breakers and their repair and maintenance.**

Any circuit breaker has the fundamental operation is to make and break the circuit. The design and operating procedure depends on the breaking/making load current in the circuit. Selection of quenching medium (oil, air, vacuum or gas) and the volume is involved main factors and proper maintenance is very important to keep the breaker accurate performance and long life.

Maintenance & repair of oil breaker

It is the first generation of circuit breaker used in the electrical protection circuit and it is still in use. High insulated oil is the main quenching medium and the oil storage maintenance is quite difficult. Frequent purification, reconditioning, refilling and leak proof storage etc. keeps the breaker always healthy. Due to this oil storage, recondition and refilling problem, oil circuit breakers are replaced by modern vacuum circuit breaker. Troubleshooting chart at this end will help to carryout smooth maintenance and repair of OCB.

Maintenance & repair of ACB, & VCB

Air circuit breaker are found in variety of applications such as very low, low, medium and high current applications. Natural air with arc chutes in chamber found useful in very low and low to medium circuit breaker. Very high voltage to EHT lines the VCB are used very extensively.

Natural air or forced air used for ACBs arc chutes are common in both ACB chamber, but in high voltage ACB forced or compressed air blow is used. To produce compressed air, air chamber, air compressor is necessary inorder to operate ACB.

Maintenance is also required at fixed and moving contacts of OCB. Alloy metals are used to make the tips of contacts part in conductors. But in usage these contacts are partially melted or damaged or repaired frequently otherwise quenching time will increase rapidly.

The tension of loading springs and manual operating levers are to be checked and rectified if any mechanical part is found defective. The coils, electromagnets and other electrical parts are to be checked for its effectiveness. A comprehensive service flow chart is attached for detailed repair and maintenance.

Maintenance & repair of SF$_6$ circuit breaker

It is a advanced version and compact to use mainly for indoor substation. Since the SF$_6$ gas is poisonous proper protective gadgets are to be used while handling SF$_6$ circuit breaker.

The loading, tripping mechanism almost same as that of VCB and air blast ACB. The maintenance and repair mentioned may have to follow in this case also.

The main maintenance requirement in SF$_6$ circuit breaker are handling gas or charging gas. No recondition is possible the SF$_6$ total replacement is required in case of any gas failure. More cycle of operation will cause the reduction of gas strength and reducing gas pressure also will be the reason of SF$_6$ circuit breaker failure.

The SF$_6$ chart illustrate the relevant failure/repair of the circuit breaker.

Troubleshooting chart - 1

S.No	Type of fault	Cause	Effects/remedy
1	Excesive heat in oil	- Poor dielectric strength	- Heavy spark inside the tank in long duration - Change the oil
2	Oil level diminishing fast	- Leak in tank	- Arrest the leak
3	Sledge deposit in bottom of tank	- Adultered oil, very old oil filled	- No proper contacts in the bottom of tank - Filter the oil

S.No	Type of fault	Cause	Effects/remedy
4	Spark continuing in the electrode contact after making circuit	- Conductor tip damaged - No proper contact - Pressure spring defect	- Increased oil temperature - Leads to breakage of the tank - Rectify spring (or) contact tip
5	Manual breaking not functioning	- Loading spring defect - Loading mechanism defective	- No breaking is possible - Rectify
6	No tripping in fault condition	- Defective tripping mechanism - Defective tripping coil	- Fault condition will continue - Damage the machine connected in line
7	Very loud noise in ACB while operation	- Insufficient air flow air pressure in chamber	- Continuous vibration once it is operated. - Maintain air pressure
8	Moving contact broken	- Excessive heat - Excess spring tension - Miss alignment	- Moving contact fail to make contact with fixed contact - Change the contact
9	Melting of electrode tip	- Excessive current produces heavy spark - Substandard alloymetal - Arc quenching is extended beyond the set values	- Check the source of excessive current - Use standard alloymetal - Maintain arc quenching medium in good condition
10	Intermittent tripping of breaker	- Wrong setting in relay - Deflective or faulty loading spring - Faulty moving mechanism	- Correct the setting - Repair spring and loading mechanism
11	Shock in the breaker	- Earth fault	- Do proper earth connection

Project work

Objectives: At the end of this project, you shall be able to
• **plan to prepare the project report for selected project**
• **draw circuit diagram/layout diagram**
• **list the specification of the material/component to be procured**
• **list the plan of action to be executed**
• **develop the project report complete and submit it.**

Selection of project and its execution

•   Discuss in details of the project - necessity, marketing facility, cost involvement, availability of material and hope of future development and expansion.

•   Collect all materials and tools required to start the work.

•   The project has to be agreed by all the members involved and get the approval of the concerned authority.

•   Prepare an action oriented plan to execute the work within a stipulated time table which is to be accepted by all the members and also the approval of instructor concerned.

•   Complete the project as per the plan.

•   Test, calibrate and finish the project as per the plan and execution.

•   Keep the project with optimum finish and good workmanship.

Preparation of project report

•   Report should start with an introductory information connected with a known subject and highlight its importance in present conditions.

•   A survey to be conducted regarding the marketing and its commercial applications.

•   A brief working principle and its operation has to be illustarted in the report.

•   Highlight the maintenance, repair and periodic servicing etc in the report.

•   Costing should be competitive and affordable to the concerned without any reservations.

•   Project should have the flexibility for further expansion to an advanced version without major changes.

•   Report should be listed with reference books and website details.

•   Complete the report and submit

List of project works

1   Battery charger/Emergency light

2   Control of motor pump with tank level

3   DC voltage converter using SCRs

4   Logic control circuits using relays

5   Alarm/indicator circuits using sensors

Note :

1   Some of the sample project works (indicative only) are given against each semester.

2   Instructor may design their own project and also inputs from local industry may be taken for designing such new project.

3   The project should proudly cover maximum skills in the particular trade and must involve some problem solving skill. Emphasis should be on Teamwork: Knowing the power of synergy/collaboration, work to be assigned in a group (Group of at least 4 trainees). The group should demonstrate Planning, Execution, Contribution and Application of Learning. They need to submit Project report.

4   If the instructor feels that for execution of specific project more time is required than he may plan accordingly to produce components /sub-assemblies in appropriate time i.e., may be in the previous semester or during execution of normal trade practical.