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DIRECTORATE OF TECHNICAL EDUCATION
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STATE PROJECT COORDINATION UNIT

Diploma in Electrical and Electronics Engineering
Course Code: 1030
M – Scheme

e-TEXTBOOK
on
Distribution and Utilisation
for
VI Semester DEEE

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SYLLABUS

RATIONALE:

Distribution system is that part of power system which distributes power to the consumers for utilization. So to have adequate knowledge in distribution and utilization of Electrical energy it becomes necessary to include this subject.

OBJECTIVES:

To Understand

- Substation arrangements.
- Distribution -classification and scheme of connection.
- Drives-Suitability for different applications.
- Track Electrification-Traction mechanics.
- Traction motors and control.
- Illumination -Design of lighting scheme-sources of light.
- Electric Heating- Different methods.
- Electric furnaces and Temperature control.
- Electric welding and welding equipments.

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CONTENTS

Unit	Name of the Topics	Hrs
I	**DISTRIBUTION** **(Pg.No. 5-36)**	18

Substation: Introduction-Sub stations-classification of sub stations-Indoor and outdoor S.S – Gas insulated S.S-comparisons-Layout 110/11KV Substation and 11KV/400V Distribution Substation-substation equipments-Bus bar- Types of bus bar arrangement -Advantages and Disadvantages.

Distribution: Distribution system-Requirements of a Distribution system-part of Distribution system- classification of Distribution systems-comparison of different distribution systems (A.C and D.C) -A.C Distribution -Types-connection schemes of Distribution system-A. C Distribution calculations-Calculation of voltage at load points on single phase distribution systems (With concentrated load only)-Distribution fed at one end, both ends and ring mains-problems- Three phase, four wire, Star connected unbalanced load circuit- Problems- consequence of Disconnection of Neutral in three phase four wire system (illustration with an example)

Unit	Name of the Topics	Hrs
II	**INDUSTRIAL DRIVES** **(Pg.No. 37-56)**	15

Introduction-Electric drive- Advantages-parts of Electric drives- Transmission of power-Types of Electric drives-Individual, group and multi motor drives – Advantages and disadvantages of Individual and group drive -Factors governing the selection of motors-Nature and classification of load Torque-Matching of speed Torque characteristics of load and motor-Standard ratings of motor- classes of load duty cycles-Selection of motors for different duty cycles-Selection of motors for specific application-Braking- Features of good braking system- Types of Braking-Advantages of- Electric braking-Plugging, Dynamic and Regenerative braking-As applied to various motors.

Unit	Name of the Topics	Hrs
III	**ELECTRIC TRACTION** **(Pg.No. 57-93)**	16

Introduction-Traction systems-Advantages and Disadvantages of Electric Traction.
System of Track Electrification:
Methods of supplying power-Rail connected system and over head system-O.H. equipments-contact wire, centenary and droppers-
current collection gear for OHE-Bow and pantograph collector-Different systems of Track Electrification-Advantages of single phase low frequency A. C. system-Booster Transformer-Necessity- Methods of connecting B.T-Neutral sectioning.
Traction Mechanics:Units and notations used in Traction mechanics-Speed time curve for different services - simplified speed time curve-Derivation of maximum speed-crest speed, Average speed, Schedule speed (definitions only)-Tractive effort and power requirement- Specific energy output- specific energy consumption.
Traction motors and control:Desirable characteristics of Traction motors-Motors used for Traction purpose-Methods of starting and speed control of D.C Traction motors-Rheostatic Control-energy saving with plain rheostatic control series- parallel control- Energy saving with series parallel starting - Shunt Transition -Bridge-Transition- multiple unit control –Regenerative braking.Recent trends in Electric Traction-Magnetic Levitation (MEGLEV) - Suspension systems.

IV **ILLUMINATION** **(Pg.No. 94-120)** 17

Introduction - Definition and units of different terms used in illumination-plane Angle, Solids angle, Light, Luminous flux, Luminous Intensity, Luminous Efficacy candle power, Lumen, Illumination,M.S.C.P, M.H.C.P, M.H.S.C.P- Reduction factor, Luminance, glare Lamp efficiency. Space-height ratio, Depreciation factor Utilization factor, waste light factor, Absorption factor, Beam factor, Reflection factor- Requirements of good lighting system- Laws of Illumination-problems. Types of lighting scheme- Factors to be considered while designing lighting scheme- Design of lighting Scheme (Indoor and outdoor)- Problems- Lighting systems- Factory lighting, Flood lighting, Street lighting.

Sources of light-Arc lamp, Incandescent lamp, Halogen Lamp, Sodium vapour lamp, High pressure mercury vapour lamp, Fluorescent Tube –Induction Lamp- Energy saving lamps (C.F.L and L.E.D lamps)-limitation and disposal of C.F.L-benefits of led lamps-comparison of lumen output for led CFL and incandescent lamp.

V **ELECTRIC HEATING AND WELDING** **(Pg.No. 121-154)**

Electric Heating: Introduction -Advantages of Electric heating-modes of heat transfer- classification of Electric Heating - Power frequency electric heating- Direct and Indirect resistance heating-Infrared heating-Arc heating –High frequency Electric heating- Induction heating-Induction Stove –Eddy current heating and Dielectric heating. 16

Electric furnaces: Resistance furnace-Requirements of Heating elements-commonly used heating element materials-Resistance furnace for special purposes-Temperature control of resistance furnace-Arc furnace -Direct and Indirect Arc furnace-Temperature control of Arc furnace-Reasons for employing low voltage and high current supply - Induction furnace-Direct and Indirect core type Induction furnace-coreless Induction furnace-Power supply for coreless Induction furnace.

Electric welding: Introduction-Types of Electric welding-Requirements of good weld- Preparation of work -Resistance welding- Butt welding, Spot welding, Seam welding, Projection welding and Flash welding-Arc welding-Carbon Arc welding, metal Arc welding, Atomic hydrogen Arc welding, Inert gas metal arc welding-Comparison between Resistance and Arc welding. Radiation welding - Ultrasonic welding, Electron beam welding, LASER beam welding-Electric welding equipments (A.C. and D.C).

TEXT BOOK:

1. **A Course in Electrical Power by Soni&Gupta DhanpatRai& Sons, Delhi.**

REFERENCE BOOKS:

1.Electric Power by SL UppalKhanna Publishers, NewDelhi

2. Modern Electric Traction by H PartabDhanpatRai& Sons, New Delhi

3.ElectricalPowerDistribution System by AS Pabla Tata McGraw Hill Publishing Co, New Delhi.

4.Utilization of Electric Power NV Suryanarayana Tata McGraw Hill Publishing Co, New Delhi.

UNIT I
DISTRIBUTION

SUBSTATIONS:

1.1 Introduction:

In all the regions the power flow of electrical energy takes place through Electrical Substations. An electrical substation is an assemblage of electrical components including bus bars, switchgear, power transformers and auxiliaries. The various substations located in generating stations, transmission systems, and distribution systems and in the consumers premises have similar layouts and similar electrical components.

1.2. Electrical Substations

Substations are integral parts of a power system and form important links between the generating stations, transmission systems, distribution systems and the load points

Basically an electrical substation consists of a number of incoming circuits and outgoing circuits connected to common busbar systems. Busbars are conducting bars to which a number of incoming or outgoing circuits are connected. Each circuit has certain electrical components such as circuit breakers, isolators, earthling switches, current transformers, voltage transformers.

A substation receives electrical power from generating station incoming transmission lines and delivers electrical power the outgoing transmission lines.

Functions of a Substation

1.3. An electricity supply undertaking generally aims at the following:

- Supply of required electrical power to all the consumers continuously at all times.
- Maximum possible coverage of the supply network over the given geographical area
- Maximum security of supply
- Shortest possible fault-duration
- Optimum efficiency of plants and the network
- Supply of electrical power within targeted frequency limits (49.5Hz and 50.5Hz)
- Supply of electrical power within specified voltage limits
- Supply of electrical energy to the consumers at the lowest cost.

1.4.The tasks associated with major substations in the transmission and distribution system include the following:

- Protection of transmission system
- Controlling the exchange of energy
- Ensuring steady state and transient stability
- Load shedding and prevention of loss of synchronism. Maintaining the system frequency within targeted limits.
- Voltage control reducing the reactive power flow by compensation of reactive power tap-changing

- Securing the supply by providing adequate line capacity and facility for changing the transmission paths.
- Data transmission power line carrier for the purpose of network monitoring: control and protection.
- Determining the energy transfer through transmission lines and tie lines
- Fault analysis and pin-pointing the cause and subsequent improvements
- Securing supply by feeding the network at various points.
- Establishing economic load distribution and several; associated functions.

These tasks are performed by the team work of load control centre control rooms of generating stations and control room of substations. The substations perform several important tasks and are integral parts of the power system.

1.5 .A typical substation has the following essential features:

- Outdoor switchyard having any one of the any bus bar schemes
- Low voltage switchgear, high voltage switchgear and control room building
- Office building
- Roads and rail track for transporting equipment
- Incoming line towers and outgoing line towers/cables
- Store
- Maintenance workshop
- Auxiliary power supply scheme
- protection system
- Battery room and low voltage dc supply system
- Fire fighting system
- Cooling water system Drinking water system
- Station earthing system
- Lighting protection system overhead shielding
- Drainage system
- Substation lighting system
- Fence and gates Security system

1.6. Types of Substations

The substations can be classified in several ways including the following:

1. **Classification based on voltage levels**

A.C.Substation: EHV, HV, MV, LV,: HVDC Substation

2. **Classification on constructional features**
   Outdoor or Indoor
   Outdoor substation is under open sky. Indoor substation is inside a building
3. **Classification based on configuration**
   Conventional air insulated outdoor substation of SF6 Gas insulated substation (GIS)
   Composite substation having **combination of the above two.**

4. **Classification** based on application
   - Switchyard in generating station
   - Switching substation
   - Sending end substation
   - Receiving end substation
   - Distribution substation
   - Factory substation
   - Compensating substation
   - Load substation eg: arc furnace substation

1.7.Comparison of indoor and outdoor S.S:

- Generally indoor equipment is preferred for voltages up to 33KV.for voltages of 33KV and above outdoor switchgear is generally preferred.
- However in heavily polluted areas indoor equipment may be preferred even for higher voltages.
- Recently indoor metal clad SF6 insulated switchgear has been introduced for medium high voltages such as 3.3KV, 6.6KV, 11KV, 33KV
- An outdoor equipment is installed under the open sky. The indoor switchgear is generally in the form of metal enclosed factory assembled units called metal clad switchgear.

a)Advantages of outdoor S.S

- Simple
- Low initial cost.
- Less quantity of building materials
- Time required for erection is less.
- Fault identification is easier.
- Extension is easier.
- Accidental occurrences can be easily solved.

b) Disadvantages of outdoor S.S

1. More space required for erection.
2. Dust and dirt are deposited over the equipments.
3. The switching operations becomes difficult during raining seasons.
4. Cost of installation is more.

5. Maintenance cost is more.

1.8. GAS INSULATED S.S

The atmospheric air insulation used in a conventional, air-insulated substation (AIS) requires meters of air insulation to do what SF6 can do in centimeters.

GIS can therefore be smaller than AIS by up to a factor of 10. A GIS is mostly used where space is expensive or not available. In a GIS the active parts are protected from the deterioration from exposure to atmospheric air, moisture, contamination, etc.SF6 gas insulated high voltage switchgear has been in commercial operation for more than 30 years. GIS is **more reliable** and requires less maintenance than AIS

a) UNIQUE FEATURES:

The modular of design of GIS offers a high degree of flexibility to meet layout requirements of both substations, as well as power station switchgear, making efficient use of available space. GIS technology has reached a stage of application and a wide range of GIS equipment up to highest voltage of 800 kV is available with many unique features. They are:

1. Wide spread application of aluminum enclosure materials for standardized component models for all voltage ranges.

2. The light weight enclosures have good conductivity, low eddy-current losses and a high resistance to corrosion.

3. Easy handling, as well as reduced stresses on foundation and support structure are additional features.

4. Standard arrangements can be easily modified and extended with good co-ordination between the manufacturer and the user.

5. A gas- tight barrier insulator in switchgear serve for the separation of gas compartments and prevents neighboring switchgear parts from being affected during maintenance.

b) A typical Gas insulated substation is shown in Fig.

The Gas insulated substation shown in above figure comprises the following components:

1. Circuit breaker2. Disconnectors switch3. Earthing switch

4. Current transformer 5. Voltage transformer6. Bus bar & connectors

7. Power transformer 8. Surge arrester9. Cable termination10. SF6 / air or SF6 / oil bushing

The GIS require less number of lightning arresters than a conventional one. This is mainly because of its compactness. The basic consideration for insulation coordination is V-T characteristic. The V-I characteristic of SF6 is considerably flat compared to that of air. Air can withstand to very high voltages for very short time. However, as the duration of voltage increases, the withstand voltage falls off considerably. On the other hand, SF6 exhibits a flat characteristic, thus the ratio of basic lightning impulse level is close to unity for GIS, whereas for the

Conventional substations this ratio varies between 0.6 and 0.86.

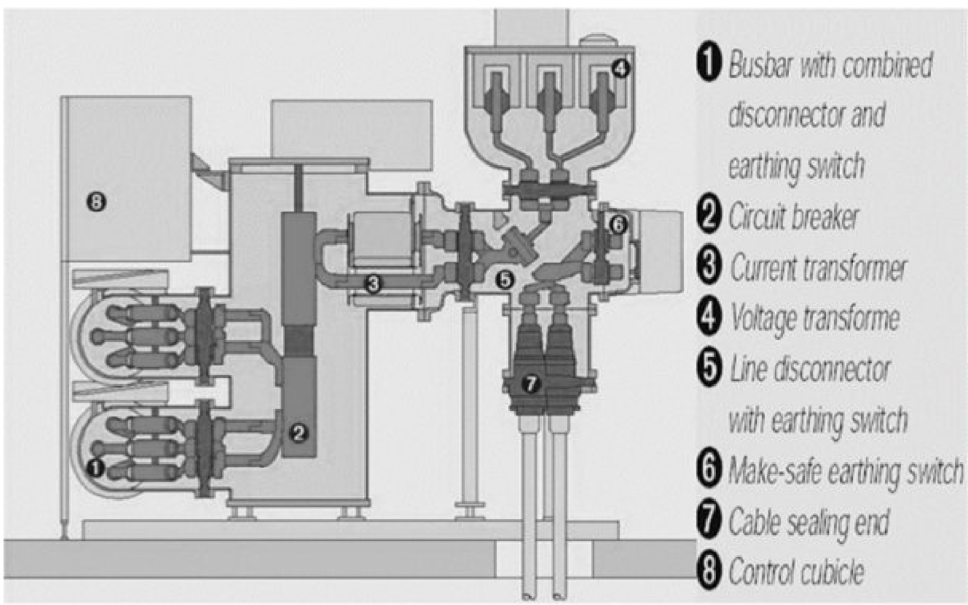


Fig: essential parts of Gas insulated substation

c) Advantages of GIS over the conventional open air substation:

The application of GIS during the last fifteen years has been very rapid. The rapid growth in GIS application is due to the following special advantages:

1. Area and volume saving in construction for over or underground applications. Therefore they offer saving in land area and construction costs.

2. Insensitivity to external influences because of grounded metal enclosures.

3. Greatly improved safety and reliability due to earthed metal housing of all high voltage parts and much higher intrinsic strength of SF6 gas as insulation.

4. Short on site erection times, based on large factory assembled and tested shipping units

5. Fulfillment of aesthetic requirements with indoor applications

6. High service reliability due to non-exposure of the use of high voltage parts to atmosphere influences

7. Reduction in radio interference with the use of earthed metal enclosures

8. Use as mobile substations for transportation to load centers on standard tracks. These substations can be located closer to load centers thereby reducing transmission losses and expenditure in the distribution network.

9. More optimal life cycle costs because of lesser maintenance, downtime and repair costs.

10. It is not necessary that high voltage or extra high voltage switchgear has to be installed outdoors.

d) Disadvantages of GIS:

Although GIS has been in operation for several years, a lot of problems encountered in practice need fuller understanding. Some of the problems being studied are:

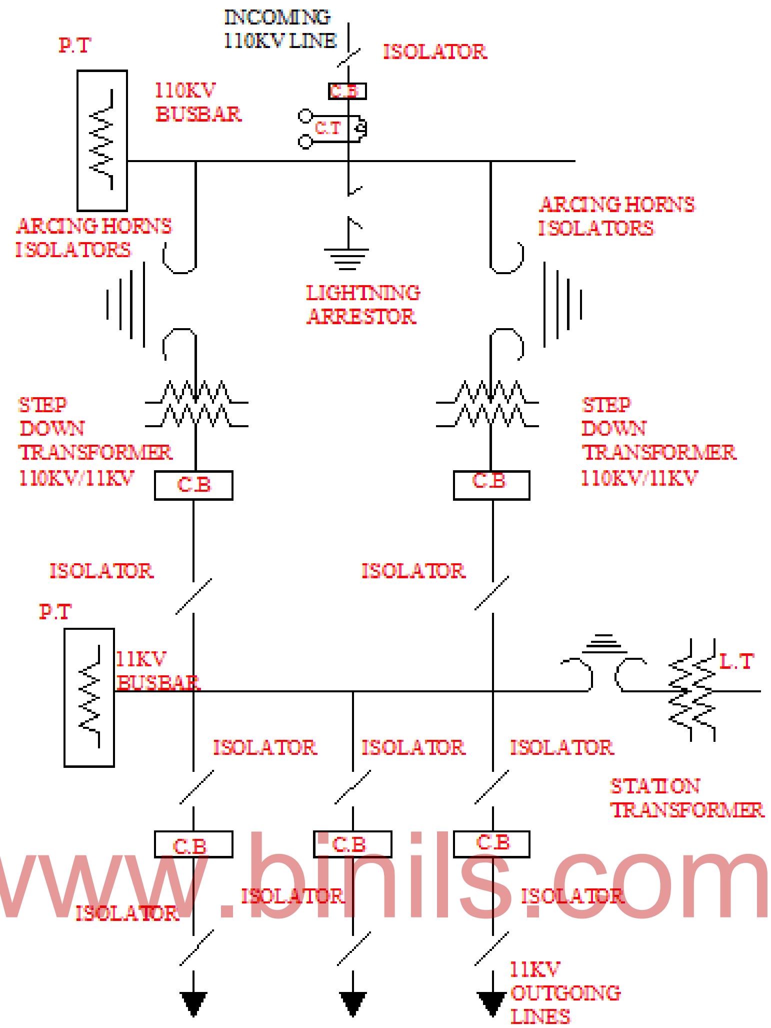
1. Switching operation generate Very Fast Transients Over Voltages (VFTOS).

2. VFTOS may cause secondary breakdown inside a GIS and Transient Enclosure Voltages (TEV) outside the GIS.

3. Field non-uniformities reduce withstanding levels of a GIS.

4. Prolonged arcing may produce corrosive/toxic by-products.

1.9. LAYOUT OF 110 /11KV SUBSTATION Fig.1.2



1.10. LAYOUT OF 11KV /400V DISTRIBUTION SUBSTATION

The conductor system by means of which electric power is conveyed from a generating station to the consumer's premises may, in general, be divided into two distinct parts *i.e.* transmission system and distribution system. Each part can again be sub-divided into two—primary transmission and secondary transmission and similarly, primary distribution and secondary distribution and then finally the system of supply to individual consumers. A typical layout of a generating, transmission and distribution network of a large system would be made up of elements as shown by a single-line diagram in Fig.

Now-a-days, generation and transmission is almost exclusively three-phase. The secondary transmission is also 3-phase whereas the distribution to the ultimate customer may be 3-phase or single-phase depending upon the requirements of the customers.

In Fig., *C.S.* represents the central station where power is generated by 3-phase alternators at 6.6 or 11 or 13.2 or even 33 kV. The voltage is then stepped up by suitable 3-phase transformers for transmission purposes. Taking the generated voltage as 11 kV, the 3-phase transformers step it up to 132 kV as shown. Primary or high-voltage transmission is carried out at 132 kV.

The 3-phase, 3-wire overhead high-voltage transmission line next terminates in step-down trans-formers in a sub-station known as Receiving Station (*R.S.*) which usually lies at the outskirts of a city because it is not safe to bring high-voltage overhead transmission lines into thickly-populated areas. Here, the voltage is stepped down to 33 kV.

From the Receiving Station, power is next transmitted at 33 kV by underground cables or by overhead lines to various sub-stations (*S S*) located at various strategic points in the city. This is known as secondary or low-voltage transmission. From now onwards starts the primary and secondary distribution.

At the sub-station (*S S*) voltage is reduced from 33kV to 3.3kV 3-wire for primary distribution. Consumers whose demands exceed 50 kVA are usually supplied from *SS* by special 3.3 kV feeders. The secondary distribution is done at 400/230 V for which purpose voltage is reduced from 3 .3kV to 400 V at the distribution sub-stations. Feeders radiating from distribution sub-station supply power to distribution networks in their respective areas. The most common system for secondary distribution is 400/230-V, 3-phase 4-wire system. The single-phase residential lighting load is connected between any one line and the neutral

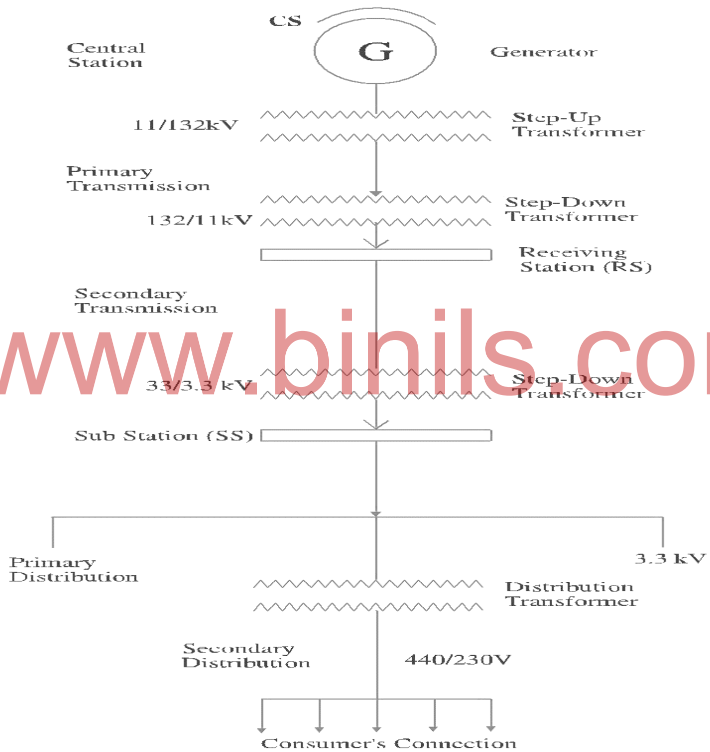


Fig.1.3.LAYOUT OF 11KV /400V DISTRIBUTION SUBSTATION

1.11. SUBSTATION EQUIPMENTS:

A sub-station is an assemblage of electrical apparatus. These include Busbars, Circuit breakers, Isolator with ear thing switch, insulator ,Surge arresters ,CTs ,PTs, Line trap unit coupling capacitors, compensation equipments, power transformers ….

1. Transformers:

Transformers are necessary in a substation for stepping – up and stepping down of ac voltage besides the transformers the substation has several others electrical equipments including busbars circuit breakers isolators surge arresters CTs, VTs, shunt Reactors and Shunt Capacitors.

2. Circuit-breakers

A device capable of making and breaking an electric circuit under normal and abnormal conditions such as short circuits. It can operate automatically and clear fault currents safely and quickly.

Circuit-breakers are the switching and current interrupting devices. Basically a circuit breaker comprises of fixed and movable contacts. The contacts can be separated by means of an operating mechanism. The separation of current carrying contacts produces an arc. The arc is extinguished by a suitable medium such as dielectric oil, vaccum,SF6gas. The circuit-breakers are necessary at every switching point in the substation.

3. Isolators:

A switching device which can be opened or closed only under no current condition. It provide isolation of a circuit for the purpose of maintenance

Isolators are disconnecting switches which can be used for disconnecting circuitbreakers. An isolator can be opened after the circuit breaker. After opening the isolator the Earthing switch can be closed to discharge the trapped electrical charges to the ground.

4. Current Transformers and potential transformers:

The current transformers and voltage transformers are used for transforming the current and voltage to a lower value for the purpose of measurement, protection and control.

a) Current Transformer (CT):

The current ratio of current transformers is generally high (500A/5A) and volt ampere capacity is relatively low (50 VA) as compared with that of the power transformers.

b) Voltage Transformer (PT):

The volt-ampere capacity of a potential transformer is low(100VA) and the voltage ratio is relatively high (132kv/100v).The protective relays are connected in the secondary circuits of CTs and PTs.

5. Busbar:

Busbars are conductors to which several circuits are connected Busbar are either flexible or rigid. Flexiblebus bars are made of ACSR conductors and are supported on strain insulators. Rigidbus bars are made up of aluminum tubes and are supported on post insulators.

6. Earthing Switch.

It is a switch which connects a conductor to the earth so as to discharge the charges on the conductor to the earth. Earthing switches are generally installed on the frames of the isolators.

7. Relay

It is an automatic device, which closes its contacts when the actuating quantity/quantities reach a certain predetermined magnitude/phase.

8. Lighting Arrester (Surge Arrester)

The equipment connected between the conductor and ground to discharge the excessive voltages to earth.

Surge arresters divert the over-voltages to earth and protect the substation equipment from over voltage surges.

9. Auto-reclosures:

Automatic closing of the circuit breaker after its opening. Autoreclosure is provided to restore the service continuity after interrupting transient fault. High voltage circuit breakers used for controlling overhead transmission lines and distance protection scheme for line protection are provided with such a feature

10. HRC Fuse

High rupturing capacity cartridge fuse is used for over current protection of low voltage and high voltage circuit.

11. Protective Scheme

A selected set of protective systems which protect one or two components of the power systems against abnormal conditions:

Eg: generator protection scheme transformer protection scheme

12. Structure:

Galvanized steel structures are made of bolted/welded structures of angles/channels/pipes. These are used for towers gantries equipment support structures. Galvanised structures provide rigid support to the various equipment and insulators. The design should be safe and economical.

Compensating substations are installed at an interval of 300km along EHV – AC lines for feeding reactive power VAR to line

13. Following compensation Equipment is necessary for voltage control:

a) Series capacitors are sometimes installed in series with long EHV AC Transmission lines to compensate line reactance.

b) Shunt capacitors are installed near load points in distribution substations receiving substations for improvement of power factor. Shunt capacitors are switched on during high inductive loads. They are switched off during low loads. Shunt capacitors are also included in static VAr sources (SVS).

c) Shunt Reactor are necessary with long EHV transmission lines to compensate the reactive power of the line capacitance during low loads.

d) StaticVAr Sources (SVS).These are thyristor controlled shunt capacitors and shunt reactors which give rapid, stepless control of reactive power VAR. These are connected in receiving stations and distribution systems.

e) Power Line Carrier Current Equipment (PLCC) is necessary for transmitting / receiving high frequency signals over the power line (transmission line) for the following:

Voice communication, Data transmission, Protection signaling, Control signaling

1.12. Functions of substation equipments:

Equipment	Function
1. Busbar	Incoming and outgoing circuits connected busbars
2. Circuit-breakers	Automatic switching during normal or abnormal conditions
3. Isolators (Disconnections)	Disconnection under no-load condition for safety isolation and maintenance
4. Earthing switch	To discharge the voltage on dead lines to earth
5. Current Transformer	To step-down currents for measurement control and protection
6. Voltage Transformer	To step down currents for measurement control and protection
7. Lighting Arrester (surge arrester)	To discharge lightning over voltages an switching over voltages to earth
8. Shunt Reactor	To provide reactive power compensation during low loads
9. Series Reactors	To reduce the short circuit current or starting currents
10. Neutral-Grounding Resistor	To limit the earth fault current
11. Coupling capacitor	To provide connection between high voltage line and power line carrier current equipment
12. Line trap	To prevent high frequency signals from entering other zones
13. Shunt capacitors	To provide compensations to reactive loads of lagging power factors
14. Power Transformer	To step-up or step-down the voltage and transfer power from one ac voltage to another ac voltage at the same frequency
15. Series Capacitors	Compensation of long lines

1.13. A substation is composed of the following distinct circuit:

1. Main circuits through which the power flows from incoming lines to the outgoing lines to the outgoing lines. These circuits are generally at high voltage AC and transfer the bulk power. Three phase AC circuits are used. Each phase is insulated from the other (except at neutral points) and from the earth

2. AC control and protection circuits connected to the secondary of CTs and VTs these circuits are at low voltage AC Protective relays and control equipment are connected in these circuits. Low voltage ac and dc circuits for metering protection and control communication
3. Auxiliary AC and DC power circuits carrying high power at high voltage. These are through underground cables

1.14. Bus bars

- Bus bars are conductors to which several circuits are connected .Bus bar are either flexible or rigid. Flexible bus bars are made of ACSR conductors and are supported on strain insulators. Rigid bus bars are made up of aluminum tubes and are supported on post insulators.

- Bus bars are either in the form of aluminum tubes of ACSR conductors Aluminum tubular bus bars are mounted on post insulators. ACSR bus bars are flexible and are supported on strain insulators. Bus bars are in two or three horizontal planes.

- The incoming circuits and outgoing circuits are connected to the bus bars the bus bars carry the main power and should be reliable.

a) The main functional requirements of bus bars system is:

- To carry normal currents and over load currents continuously with temperature rise within specified limits.
- To with stand normal system voltage specified transient over voltage without flashover
- To withstand mechanical stresses due to wind icing short circuits without damage
- To provide low resistance path for current flow.
- To provide flexibility of operation
- Simplicity, safety, Aesthetic looks, Quality Reliability
- Maintenance Requirements

b) Types of Bus bar Systems (Bus bar Layouts)

1. Single bus bar system
2. Single sectionalized bus bar system
3. Duplicate bus bar system with one breaker per circuit
4. Duplicate bus bar system with two breakers per circuit
5. Main and transfer bus bar
6. Ring bus bar
7. Breaker and a half bus bar system
8. Mesh bus bar scheme
9. Hybrid system

1. Single Bus bar scheme.

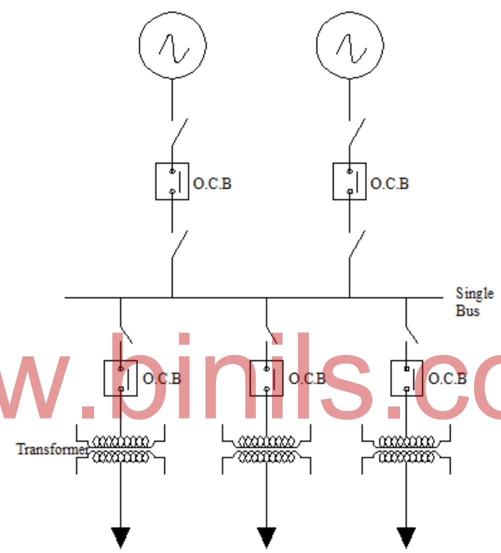
The single bus bar scheme has only one three phase bus to which the various incoming and outgoing circuits are connected

Single bus bar scheme is not preferred for major substations

In the event of a bus fault a breaker failure the entire bus has to be de energized and a major outage occurs. Dependence on only one main bus gives lack of operational flexibility

For maintenance of the main bus or while providing extension to the main bus the entire station shall be de energized

Although the protective relaying is relatively simple it lacks flexibility and during a bus fault the entire bus is switched off resulting in a major outage

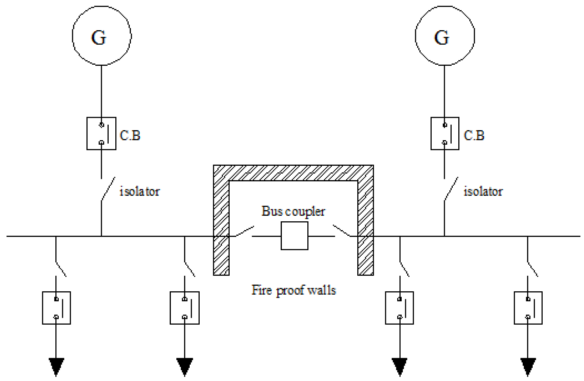


Single Bus Bar arrangement

Fig 1.4.Single bus bar scheme is used for DC switchboards and very small AC Substations or generating stations. They are used for low voltage medium voltage bus bars up to 33kv in the form of open outdoors switch yard of indoor metal clad switchgear

2. Single Sectionalized Bus bar

In a sectional bus bar the main bus is divided into two of more sections with a circuit breaker and isolators in between the adjoining sections. One section can be completely shut down for the purpose of bus maintenance repairs of extension without disturbing without disturbing the continuity of the other bus section



Sectionalized Single Bus Bar system

In Fig 1.5.**Single Sectionalized Bus bar** the number of sections depends up to the importance of the station and local switching requirements.

The fault level of each bus can be reduced by installing a current limiting reactor in between the two adjoining sections

When two parallel feeders are taken from the same bus to one load point they are connected to different bus sections so that even if one feeder is dead during maintenance of one bus section the other feeder continue to serve.

Bus sectionalizing should be through a circuit breaker so that the bus transfer can be carried out under full load conditions.

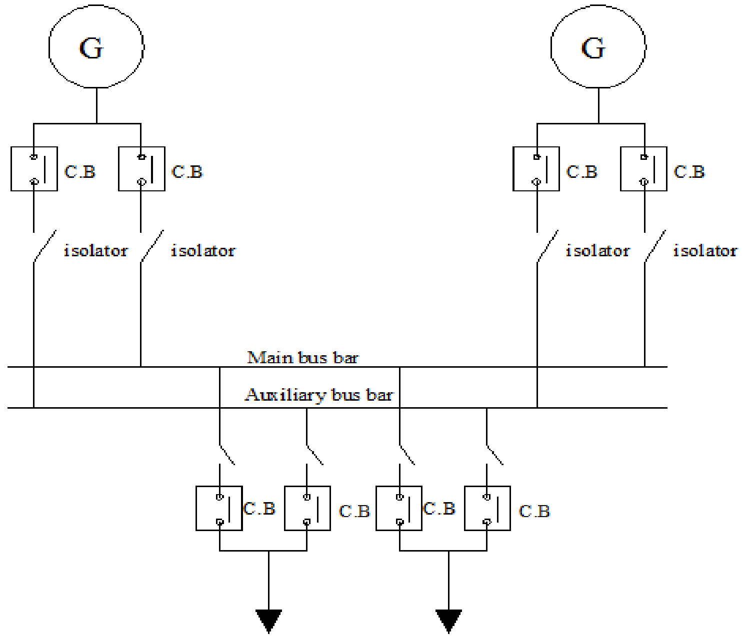
Two isolators should be provided with each sectionalizing circuit breaker to enable the maintenance of the circuit breaker.

If only isolator is used a sectionalizing switch the opening and closing of the same should be under no load condition.

In case each section is supplied from a different source there should be a provision of synchronizing the two bus sections. Before closing the circuit breaker the conditions for synchronism shall be satisfied.

3. Double Bus bar Scheme

Duplicate Bus bar Scheme is used universally for important EHV substations (110kv and above). The duplicate bus bar scheme is costlier than the single bus bar scheme is costlier than the single bus bar scheme but it gives higher operational flexibility and permits bus bar maintenance repairs or extension without shutdown.



Double Bus Bar system

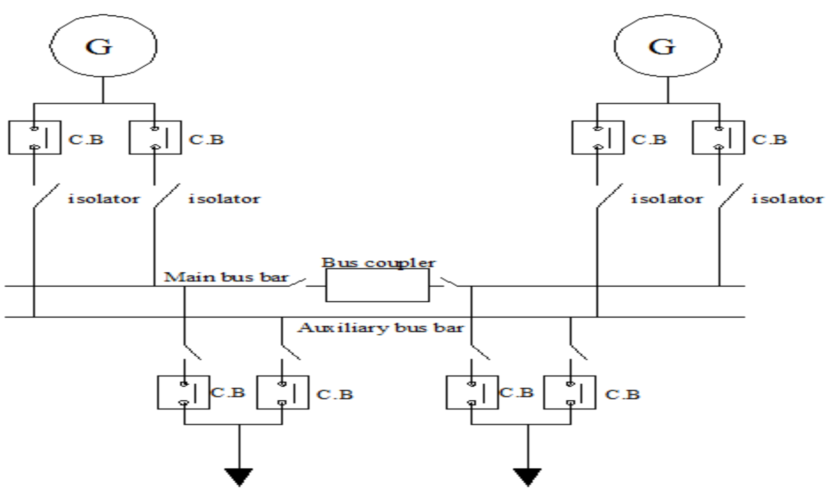
In Fig 1.6.Double Busbar Scheme These schemes have two three phase bus bars called main bus and reserve bus or bus no 1 and bus no 2. The main bus is for normal us and the reserve bus is available in case of maintenance or fault on the main bus.

The Reserve Bus can also be used for testing a new feeder charging a feeder at higher voltage for test purposes for commissioning tests on a new plant. All these activities can be carried out without disturbing the main bus.

During normal service only one of the buses is energized the other bus is in reserve. If both the buses are to be simultaneously in service the protective relaying becomes complex.

The connection between each incoming and outgoing circuits and the duplicate bus is through either one circuit breaker or two bus selecting isolators one for each bus bar through two circuit breakers and two insulators one circuit breaker one isolator for each bus bar.

3. Sectionalized Double Bus bar Scheme Fig 1.7



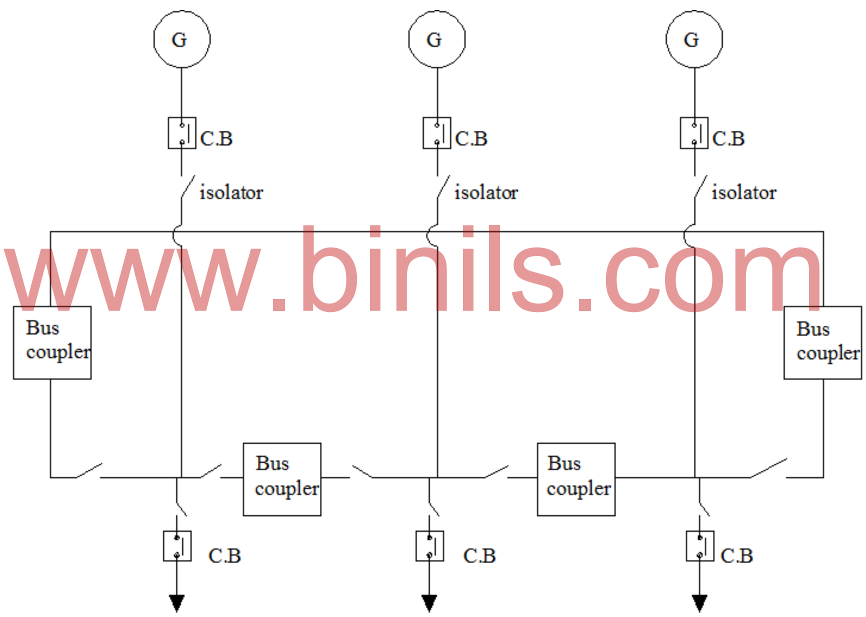
Sectionalised Double Bus Bar system

In this scheme the auxiliary bus bars are used with the sectionalized main bus bar. In this method, any section of the bus bar can be isolated for maintenance work. The auxiliary bus is not sectionalized because of avoiding un necessary expenses.

4. Ring Bus (Mesh Scheme) In the ring bus scheme the busbars and the breakers are in series to form a ring. The circuits are connected between the breakers. The number of breakers is equal to the number of circuits. During the normal operation all the circuit breakers are closed. During a circuit fault two breakers in the associated bus bar are tripped. If one of these breakers fails to clear the fault an additional circuit will be tripped by breaker stuck up back up relay. During the breaker maintenance the faint is opened but all the circuits continue to serve.

In the ring scheme sources and circuits are connected alternately. During breaker maintenance no change in protective relay is required.

The ring bus is economical in cost as it requires only one breaker per circuit. Ring bus has good reliability good flexibility and is safe to operate.



In fig 1.8. The Ring bus is considered to be suitable for important 220kv and 400kv substations having up to five circuits. For more than five circuits breaker and half scheme is preferred

Ring bus gives a better security than simple single bus because alternative route is available around the bus to the outgoing circuit.

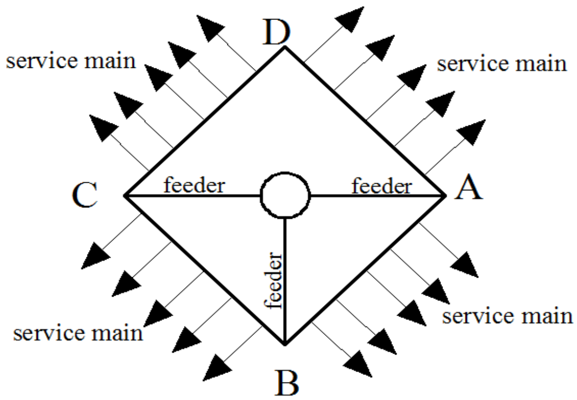
In case of bus bar fault the immediate result is similar to that of single bus bar scheme that all circuits are lost. However the fault can be isolated by opening the bus bar isolators on either sides or most of the circuit can be reenergized

Mesh scheme is called Ring Scheme in USA and Mesh scheme in England. In mesh scheme the bus forms a ring and circuit breakers are in the closed ring instead of bing in outgoing or incoming circuits

Ring bus has low cost. It is flexible for breaker maintenance

1.15. Distribution system

That part of power system which distributes electric power for local use is known as distribution system. In general the distribution system is the electrical system between the substation fed by the transmission system and the consumer's meters. It generally consists of feeder's distributors and the service mains. The single line diagram of a typical low tension distribution system is Fig 1.9



Feeders

A feeder is a conductor which connects the substation or localized generating station to the area where power is to be distributed, Generally no tapping's are taken from the feeder so that current in it remains the same throughout. The main consideration in the design of a feeder is the current carrying capacity

Distributor

A distributor is a conductor from which tapping's are taken for supply to the consumers. In BC CD and DA are the distributors. The current through a distributor is not constant because tappings are taken at various places along its length. While designing a distributor voltage drop along its length is the main consideration since the statutory limit of voltage variations is 5% of rated value at the consumer's terminals

Service mains

A service mains is generally a small cable which connects the distributor to the consumer terminals.

1.16. Classification of Distribution Systems

1. A distribution system may be classified according to Nature of current:

i) d.c. distribution system ii)a.c. distribution system

Now a days ac system is universally adopted for distribution of electric power as it is simpler and more economical than direct current method

2. Type of construction

According to type of construction distribution system can be classified as

i) Overhead system

ii) Underground system.

The overhead system is generally employed for distribution as it is 5 to 10 times cheaper than the equivalent underground system. In general the underground system is used at places where overhead construction is impracticable or prohibited by the local laws

3. Scheme of connection

According to scheme of connection the distribution system may be classified as:

i) Radial system

ii) Ring main system

iii) Interconnected system.

1.17. AC Distribution

Now a day's electrical energy is generated transmitted and distributed in the form of alternating current. One important reason for the widespread use of alternating current in preference to direct current is the fact that alternating voltage can be conveniently changed in magnitude by means of a transformer. Transformer has made it possible to transmit ac power at high voltage and utilize it at a safe potential. High transmission and distribution voltages have greatly reduced the current in the conductors and the resulting line losses

There is no definite line between transmission and distribution according to voltage or bulk capacity. However in general the ac distribution system is the electrical system between the step down substation fed by the transmission system and the consumer's meters. The ac distribution system is classified into primary distribution system and secondary distribution system.

a) Primary distribution system

It is that part of ac distribution system which operates at voltages somewhat higher than general utilization and handles large blocks of electrical energy than the average low voltage consumer uses. The voltage used for primary distribution depends upon the amount of power to be conveyed and the distance of the substation required to be fed. The most commonly used primary distribution voltages are 11KV 6.6KV and 3.3KV Due to economic considerations primary distribution is carried out by 3 phase 3 wire system

Electric power from the generating station is transmitted at high voltage to the substation located in or near the city. At this substation voltage is stepped down to 11kv with he help of step down transformer. Power is supplied to various sub stations for distribution or to big consumers at this voltage. This forms the high voltage distribution or primary distribution

b) Secondary distribution system

It is that part of ac distribution system which includes the range of voltages at which the ultimate consumer utilizes the electrical energy delivered to him. The secondary distribution employs 400/230v 3 phase 4 wire system

The primary distribution circuit delivers power to various substations called distribution substations. The substations are situated near the consumers localities and contain step down transformers at each distribution substation the voltage is stepped down to 400v and power is delivered by 3 phase 4 wire ac system. The voltage between any two phases in 400v and between any phase and neutral is 230v.The single phase domestic loads are connected between any one phase and the neutral whereas 3 phase 400v motor loads are connected across 3 phase lines directly

1.18. DC Distribution

It is a common knowledge that electric power is almost exclusively generated transmitted and distributed as ac however for certain applications dc supply is absolutely necessary. For instance dc supply is required for the operation of variable speed machinery for electro chemical work and for congested areas where storage battery reserves are necessary. For this purpose ac power is converted into dc power at the substation by using converting machinery static rectifier, mercury arc rectifiers' rotary converters and motor generator sets. The dc supply from the substation may be obtained in the form of 2 wire 3 wire for distribution

2 wire dc system as the name implies this system of distribution consists of two wires. One is the outgoing or positive wire and the other is the return or negative wire. The loads such as lamps motors are connected in parallel between the two wires as shown in fig. This system is never used for transmission purposes due to low efficiency but may be employed for distribution of dc power

3 wire dc system

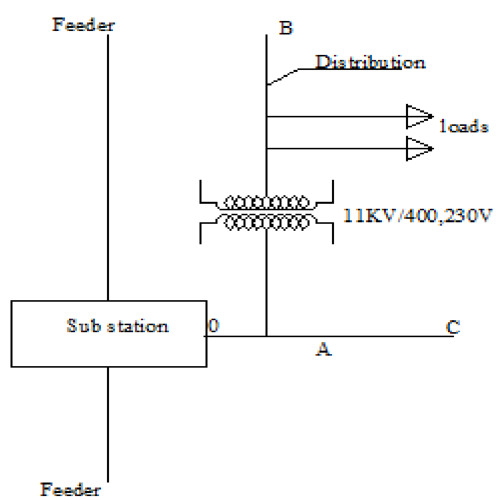
It consists of two outers and a middle or neutral wire which is earthed at the substation. The voltage between the outers is twice the voltage between either outer and neutral wire as shown in fig the principal advantage of this system is that it makes available two voltages at the consumer terminals V between any outer and the neutral and 2v between the outers. Loads requiring high voltage are connected across the outers whereas lamps and heating circuits requiring less voltage are connected between either outer and the neutral the methods of obtaining 3 wire system are discussed in the following article

1.19. Connection schemes of Distribution system

All distribution of electrical energy is done by constant voltage system in practice the following distribution circuits are generally used

a) Radial system

In this system separate feeders radiate from a single substation and feed the distributors at one end only. A single line diagram of a radial system for dc distribution where a feeder OC supplies a distributor AB at point A. Obviously the distributor is fed at one end only point A in this case show a single line diagram of



RADIAL SYSTEM

In Fig 1.10.Radial system for ac distribution the radial system is employed only when power is generated at low voltage and the substation is located at the center of the load

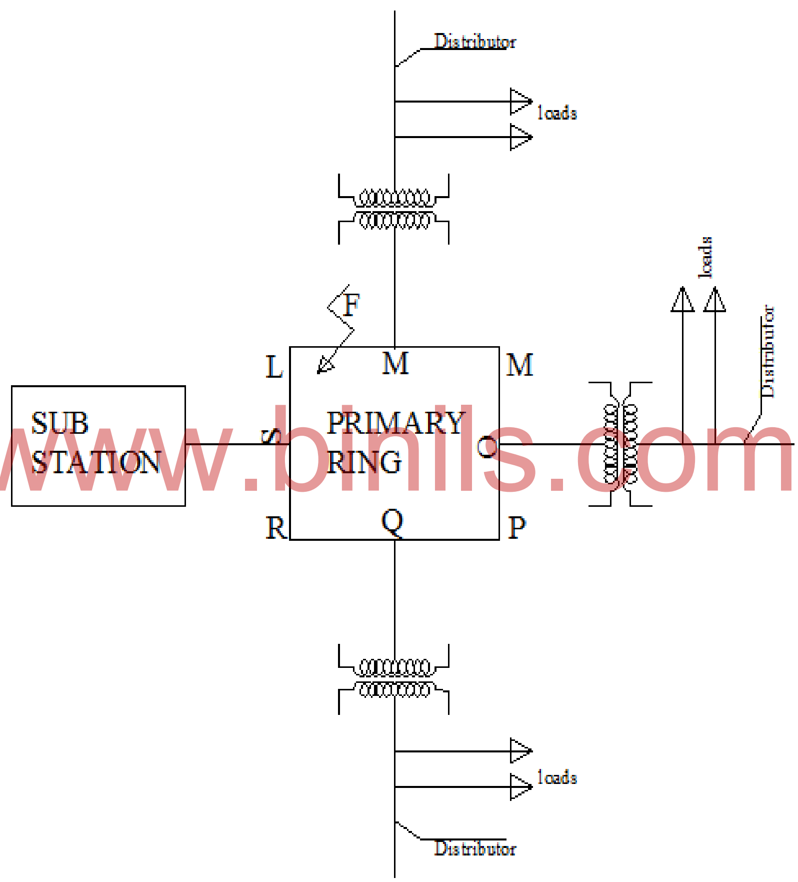
This is the simplest distribution circuit and has the lowest initial cost. However it suffers from the following draw backs

The end of the distributor nearest to the feeding point will be heavily loaded

The consumers are dependent on a single feeder and single distributor. Therefore any fault on the feeder or distributor cutoff supply to the consumers, who are on the side of the fault away from the substation.

The consumers at the distant end of the distributor would be subjected to serious voltage fluctuations, when the load on the distributor changes.

b) Ring main system (Fig.1.11)



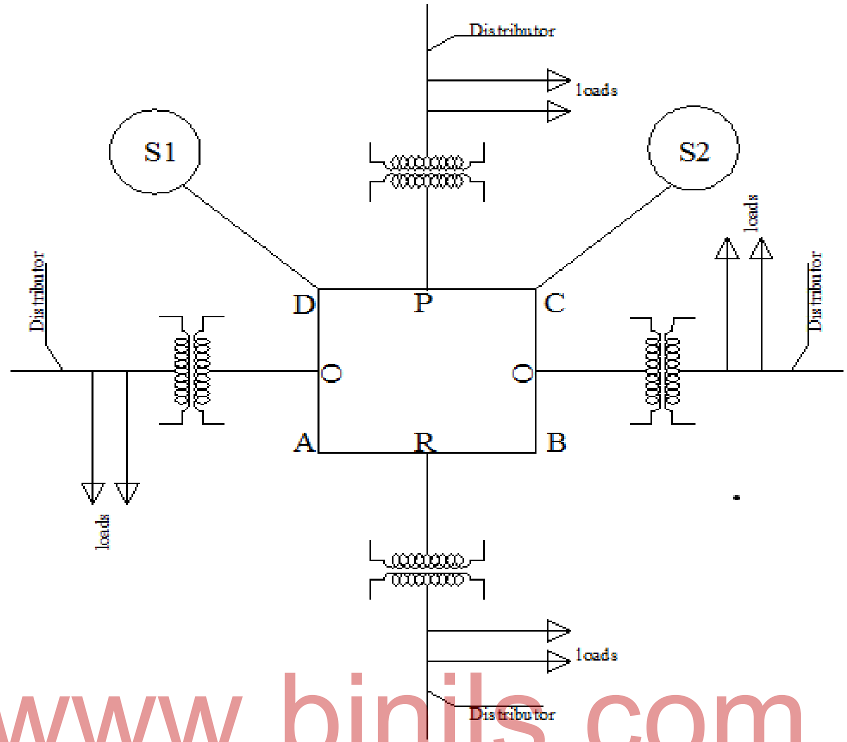
RING MAIN SYSTEM

In this system the primaries of distribution transformers form a loop. The loop circuit starts from the substation bus bars makes a loop through the area to be served and returns to the substation shown the single line diagram of ring main system for ac distribution, where substation supplied to the closed feeder LMNOPQRS. The distributors are tapped from different points MOQ of the feeder through distribution transformers. The ring main system has the following advantages

There are less voltage fluctuations at consumers' terminals.

The system is very reliable as each distributor is fed two feeders. In the event of fault on any section of the feeder. The continuity of supply is maintained for examples suppose that fault occurs at any point F of section SLM of the feeder. Then section SLM of the feeder can be isolated for repairs and at the same time continuity of supply is maintained to all the consumers' feeders SRQPONM

c) Interconnected system Fig (1.12)



INTER CONNECTED SYSTEM

When the feeder ring is energized by two or more than two generating stations or substations it is called inter connected system. Shows the single line diagram of interconnected system, where the closed feeder ring ABCD is supplied by two sub stations S1 and S2 at points D and Q respectively. Distributors are connected to points OPQ and R of the feeder ring through distribution transformers.

The interconnected system has the following advantages.

- It increases the service reliability
- Any area fed from one generating station during peak load hours can be fed from the other generating station. This reduces reserve power capacity and increases efficiency of the system.
- Requirements of a distribution system.
- A good distribution system should ensure that the voltage variations at consumers terminals are within permissible limits
- Availability of power demand.
- Power must be available to the consumers in any amount that they may require from time to time.
- Reliability.

1.20. Systems of A.C. Distribution

A.C. power transmission is always at high voltage and mostly by 3-phase system. The use of single-phase system is limited to single-phase electric railways. Single-phase power transmission is used only for short distances and for relatively low voltages. 3-phase power transmission requires less copper than either single-phase or 2-phase power transmission.

With respect to phases, the following systems are available for the distribution of a.c. power.

1. Single-phase, 2-wire system.
2. Single-phase, 3-wire system.
3. Two-phase, 3-wire system.
4. Two-phase, 4-wire system.
5. Three-phase, 3-wire system.
6. Three-phase, 4-wire system.

1.21. A.C distribution calculations

Methods of solving AC Distribution Problems:

In a.c distribution calculations, power factors of various load currents have to be considered, since currents in different sections of the distributor will be the vector sum of load currents and not the arithmetic sum. The power factors of load currents may be given i) w.r.t. to receiving or sending end voltage ii) w.r.t to load voltage itself.

i) Power factors referred to receiving end voltage:

Consider an ac distributor AB with concentrated loads of I_1 and I_2 tapped off at points C and B as shown in fig. Taking the receiving end voltage V_B as the reference vector, let lagging power factors at C and B $\cos\phi_1$ and $\cos\phi_2$ w.r.t. V_B.

Let R_1,X_1 and R_2,X_2 be the resistance and reactance of section AC and CB of the distributor

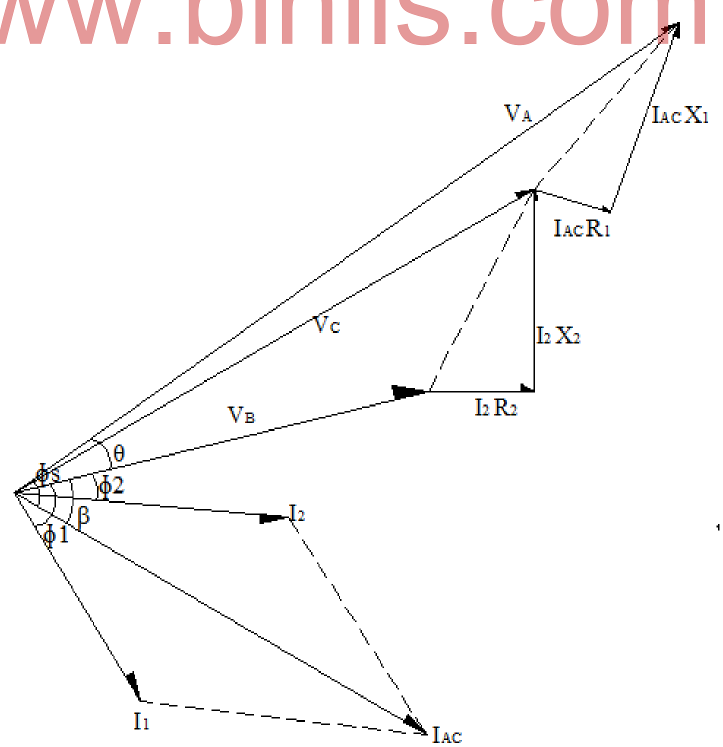


Fig 1.13 Power factors referred to receiving end voltage

Impedance of section AC

$\overrightarrow{ZAC}$=R_1+jX_1

Impedance of section CB

$\overrightarrow{ZCB}$=R2+jX2

Load current at point C

I_1=I_1(cosϕ_1-jsinϕ_1)

Load current at point B

I_2=I_2(cosϕ-jsinϕ_2)

Current in section CB

I_{CB}=I_2= I_2(cosϕ_2-jsinϕ_2)

Current in section AC

I_{AC}=I_1+I_2

I_{AC}= I_1(cosϕ_1-jsinϕ_1)+ I_2(cosϕ_2-jsinϕ_2)

Voltage drop in section CB

V_{CB}=$I_{CB}$$Z_{CB}$= I_2(cosϕ_2-jsinϕ_2) (R_2+jX_2)

Voltage drop in section AC

$\overrightarrow{VAC}$=$\overrightarrow{IAC, ZAC}$=[I_1(cosϕ_1-jsinϕ_1)+ I_2(cosϕ_2-jsinϕ_2)](R_1+jX_1)

Sending end voltage

$\overrightarrow{VA}$=$\overrightarrow{VB + VCB + VAC}$

Sending end current

$\overrightarrow{IA}$=$\overrightarrow{I1}$+$\overrightarrow{I2}$

The vector diagram of the ac distributor under these conditions is shown in fig. Here the receiving end voltage V_B is taken as the reference vector. As power factors of loads are given w.r.t. V_B therefore I_1 and I_2 lag behind V_B by ϕ_1 and ϕ_2 respectively.

ii) Power factors referred to respective load voltages:

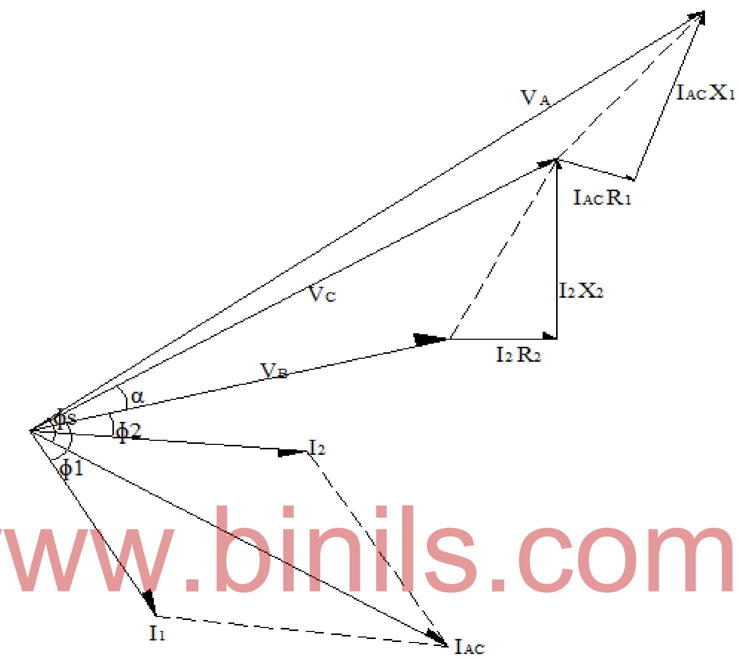


Fig 1.14. Power factors referred to respective load voltages

Suppose the power factor of loads in the previous are referred to their respective load voltages.thenϕ_1 is the phase angle between V_C and I_1 and ϕ_2 is the phase angle between V_B and I_2.The vector diagram under these conditions is shown

Voltage drop in section CB = $\vec{I}_2\vec{Z}_{CB}$ = $I_2\,(\cos\varphi_2 - j\sin\varphi_2)\,(R_2+jX_2)$

Voltage at point C=$\vec{V}_B$ + Drop in section CB

$=V_C \angle\alpha$

$I_1=I_1\angle-\varphi_1$ w.r.t voltage V_C

$I_1 = I_1\angle-(\varphi_1-\alpha)$ w.r.t voltage V_B

$I_1=I_1\,[\cos(\varphi_1-\alpha-j\sin(\varphi_1-\alpha)]$

$I_{AC}=I_1+I_2$

$=I_1\,[\cos(\varphi_1-\alpha)-j\sin(\varphi_1-\alpha)] + I_2(\cos\varphi_2-j\sin\varphi_2)$

Voltage drop in section in AC = $I_{AC}\ Z_{AC}$

Voltage at point A= V_B + Drop in CB + Drop in AC

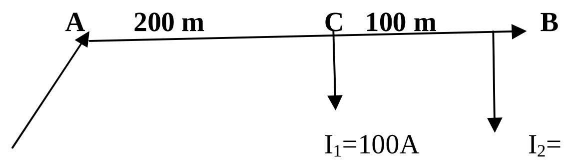
Problem 1.A single phase ac distributor AB 300 meters long is fed from end A and is loaded as under

i) 100 A at 0.707 pf lagging 200m from point A

ii)200A at 0.8 pf lagging 300m from point A

The total resistance and reactance of the distributor is 0,2 Ω and 0.1Ω per kilometer. Calculate the total voltage drop in the distributor. The load power refer to the voltage at the far end

Solution



The single line diagram of the distributor

Impedance of distributor/km=(0.2+j0.1)Ω

$\cos\varphi_1$ =0.707lag. $\cos\varphi_{2}$ = 0.8 lag

Impedance of section AC

$\vec{Z}_{AC}$=(0.2+J0.1)X200/1000=(0.04+j0.02)Ω

Impedance of section CB

$\vec{Z}_{CB}$=(0.2+j0.1)X100/1000=(0.02+j0.01)Ω

Taking voltage at the far end B as the reference vector we have

Load current at point B

$\bar{I}_2=I_2(\cos\varphi_2-j\sin\varphi_2)=200(0.8-j0.6)$

Load current at point C

$\bar{I}_1=I_1(\cos\varphi_1-j\sin\varphi1)=100(0.707-j0.707)=(70.7-j70.7)A$

Current in section CB

$\bar{I}_{CB}=\bar{I}_2=(160-j120)A$

Current in section AC

$\bar{I}_{AC}=\bar{I}_1+\bar{I}_2=(70.7-j70.7)+(160-j120)=(230.7-j190.7)A$

Voltage drop in section CB

$\vec{V}_{CB}=\bar{I}_{CB}\vec{Z}_{CB}=(160-j120)(0.02+j0.01)=(4.4-j0.8)$volts

Voltage drop in section AC

$\vec{V}_{AC}=\vec{I}_{AC}\vec{Z}_{AC}$=(230.7-j190.7)(0.04+j0.02)=(13.04-j3.01)volts

Voltage drop in the distributor

$=\vec{V}_{AC}+\vec{V}_{CB}$=(13.04-j3.01)+(4.4-j0.8)=**(17.44-j3.81)volts**

Magnitude of drop

$=\sqrt{(17.44)^2+(3.81)^2}$=**17.85V**

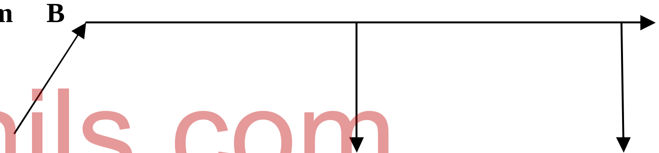
Problem2.A single phase distributor 2 kilometers long supplies a load of 120 A at 0.8pf lagging at its far end and a load of 80A at 0.9 pf lagging at its mid-point. Both power factors are referred to the voltage at the far end. The resistance and reactance per km (go and return) are 0.05Ω and 0.1Ω respectively. If the voltage at the far end is maintained at 230V.calculate

i)Voltage at the sending end

ii) Phase angle between voltage at the two ends

Solution:

A 1000m C 1000m B



The distributor AB with C as the mid – point

Impedance of distributor/km=(0.05+j0.1)Ω

I_1
I_2

Impedance of section AC

$\vec{Z}_{AC}$=(0.05+j0.1)X1000/1000=(0.05+j0.1)Ω

Impedance of section CB

$\vec{Z}_{CB}$=(0.05+j0.1)X1000/1000=(0.05+j0.1)Ω

Let the voltage VB at point B be taken as the reference vector

$\vec{V}_B$=230+j0

i)Load current at point B:

$\bar{I}_2$=120(0.8-j0.6)=96-j72

Load current at point C

$\bar{I}_1$=80(0.9-j0.436)=72-j34.88

Current in section CB

$\bar{I}_{CB}=I_2=96-j72$

$\bar{I}_{AC}=\bar{I}_1+\bar{I}_2=(72-j34.88)+(96-j72)=(168-j106.88)$

Drop in section CB

$\vec{V}_{CB}=\bar{I}_{CB}\vec{Z}_{CB}=(96-j72)(0.05+j0.1)=12+j0.6$

Drop in section AC

$\vec{V}_{AC}=\bar{I}_{AC}\vec{Z}_{AC}=(168-j106.88)(0.05+j0.1)=19.08+j11.45$

Sending end voltage

$\vec{V}_A=\vec{V}_B+\vec{V}_{CB}+\vec{V}_{AC}=(230+j0)+(12+j6)+(19.08+j11.45)=261.08+j17.45$

Its Magnitude is

$\sqrt{(261.08)^2+(17.45)^2}$=**261.67V**

The Phase difference θ between V_A and V_B is given by

$\tan\theta=\frac{17.45}{261.08}$=**0.0668**

$\theta=\tan^{-1}0.0668=$ **3°49'**

Problem3.A single phase distributor one km long has resistance and reactance per conductor of 0.1Ω and 0.15Ω respectively. At the far end the voltage $_{VB}$=200V and the current is 100A at a pf of 0.8 lagging. At the midpoint M of the distributor a current of 100A is tapped at a pf 0.6 lagging with reference to the voltage Vm at the midpoint calculate

i)Voltage at mid point

ii)Sending end voltage VA

iii) Phase angle between VA and VB

Solution:

Fig Shown the single line diagram of the distributor AB with M as the mid point

Total impedance of distributor=2(0.1+j0.15)=(0.2+j0.3)Ω

Impedance of section AM

$\vec{Z}_{AM}=(0.1+j0.15)\Omega$

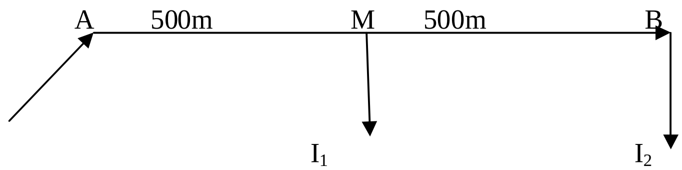
Impedance of section MB

$\vec{Z}_{MB}=(0.1+j0.15)\Omega$

Let the voltage V_B at point B be taken as the reference vector

Then $\vec{V}_B$=200+j0

i)Load current at point B



$\bar{I}_2$=100(0.8-j0.6)=80-j60

Current in section MB

$\bar{I}_{MB}$=I2=80-j60

Drop in section MB

$V_{MB}=I_{MB}\ Z_{MB}$=(80-j60)(0.1+j0.15)=17+j6

Voltage at point M

$V_M=V_B+V_{MB}$=(200+j0)+(17+j6)=217+j6

Its magnitude is =$\sqrt{(217)^2+(6)^2}$= **217.1V**

ii)Phase angle between V_M and V_B

$\alpha=\tan^{-1}\frac{6}{217}=\tan^{-1}0.0276$=**1°35'**

ii)The load current I_1 has a lagging p.f of 0.6 V_M.It lags behind V_M by an angle $\varphi_1=\cos^{-1}0.6$=53°7'

Phase angle between I_1 and V_B

$\Phi'_1=\varphi_1-\alpha$=53°7'-1°35'=51°32'

Load current at M

$\vec{I1}=I_1(\cos\varphi'_1-j\sin\varphi'_1)$ = 100(cos51°32'- jsin51°32') = 62.2- j78.3

Current in section AM

$I_{AM}=\bar{I}_1+\bar{I}_2$=(62.2-j78.3)+(80-j60)=142.2-j138.3

Drop in section AM

$\vec{V}_{AM}=\bar{I}_{AM}\bar{Z}_{AM}$=(142.2+j138.3)(0.1+j0.15)=34.96+j7.5

Sending end voltage

$\vec{V}_A=\vec{V}_M+\vec{V}_{AM}$=(217+j6)+(34.96+j7.5)=251.96+j13.5

Its magnitude is

=$\sqrt{(251.96)^2+(13.5)^2}$=**252.32V**

iii) The phase difference θ between V_A and V_B is given by

tanθ =13.5/251.96=0.05358

$\theta = \tan^{-1} 0.05358 = 3°4'$

Hence supply voltage is 252.32V and leads V_B by 3°4'

Problem 4. A single phase ring distributor ABC is fed at A. The loads at B and C are 20A at 0.8p.f lagging and 15A at 0.6 p.f lagging respectively both expressed with reference to the voltage at A. The total impedance of the three sections AB, BC and CA are (1+j1),(1+j2) and (1+j3) ohms respectively. Find the total current fed at A and the current in each section.

Solution

Shows the ring distributor ABC. Thevenins theorem will be used to solve this problem. To find the current in section BC, imagine that the section BC is removed as shown. The Thevenins equivalent circuit is shown

Current in section AB = 20 (0.8 – j0.6) = (16 – j12) A

Current in section AC = 15 (0.6 – j0.8) = (9 – j12) A

Voltage drop in section AB=I_{AB} Z_{AB} = (16-j12) (1+j1) = (28+j4) V

Voltage drop in section AC=I_{AC} Z_{AC} = (9-j12) (1+j3) = (45+j15) V

Voltage between BC = (45+j15)-(28+j4) = (17+j11) V

Thevenins equivalent circuit e.m.f. or open circuit voltage

V_o= (17+j11)V

Thevenins looking back impedance = Z_T

$Z_T = Z_{AB}+Z_{AC}$ = (1+j1)+(1+j3) = (2+j4)Ω

Current is section BC = $\frac{Vo}{ZT+ZBC} = \frac{17+j11}{(2+j4)+(1+j2)}$ = 2.60-j1.534 = 3.02

Since the voltage drop in section AC is high compared to V_{AB} the potential at B is higher than C. Hence current flows from B to C

Actual current in section AB ($\bar{I}_{AB}$) = $\bar{I}_1+\bar{I}_{BC}$-------(I_1 and I_{BC} current away from the junction B)

Actual current in section AB = (16-j12) + (2.60-j1.534) = (18.60-j13.534) = 23 $\angle$-36.04

Actual current in section AC ($\bar{I}_{AC}$) = $\bar{I}_2-\bar{I}_{BC}$

(I2 away from the junction C I_{BC} towards the junction C)

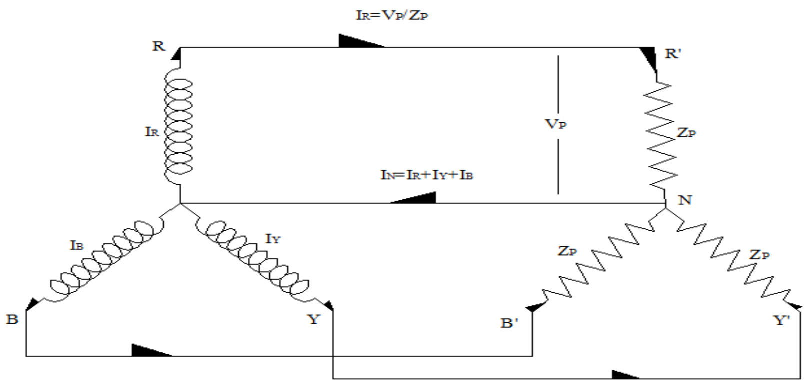
Actual current in section AC = (9-j12) -(2.60-j1.534) = (6.4-j10.466) =12.27 $\angle$-58.55

Current fed at A = (16-j12) + (9-j12) = (25-j24) = 34.65 $\angle$-43.83° A

1.22- THREE PHASE, 4-WIRE STAR CONNECTED UNBALANCED LOAD CIRCUITS

In 3-phase 4-wire star-connected load circuits the star points of load and the generator are tied together through neutral wire of zero impedance. Therefore the neutrals are at the same potential and voltage across each impedance is same and equal to phase voltage whether the circuit is balanced or unbalanced. The three phase currents or line currents can be determined by dividing the phase voltage by the impedance of the concerned phase.

$I_R=V_R/Z_R$; $I_Y=V_Y/Z_Y$; $I_B=V_B/Z_B$



STAR CONNECTED UNBALANCED CIRCUITS

Fig 1.15. Three phase, 4-wire star connected unbalanced load circuits

The current in neutral wire can be determined by applying Kirchhoff's first law at star point N. in Fig 1.15

According to which $\mathbf{I_R+I_Y+I_B+I_N=0}$ or current in neutral wire $\mathbf{I_N=-(I_R+I_Y+I_B)}$

In balanced load circuits the line currents are equal and have the same phase angles with their respective phase voltages so their vector sum is zero and current in neutral wire is zero. In unbalanced load circuits the neutral wire Carries currents.

Problem 5. In a 3-phase 4-wire system the line voltage is 400 volts and non inductive loads of 10, 8 and 5KW are connected between the three line conductors and the neutral .Calculate the current in each line and the current in the neutral conductor

Solution:

Phase voltage across each load,

$R_p = \frac{Vl}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 231\text{ V.}$

Current in R phase,

$$I_R = \frac{KW X 1000}{Vp cos\emptyset} = \frac{10 X 1000}{231 x 1} = 43.4\text{ A}$$

Current in Y phase,

$$I_Y = \frac{KW X 1000}{Vp cos\emptyset} = \frac{3 X 1000}{231 x 1} = 34.7\text{ A}$$

Current in B phase,

$$I_B = \frac{KW X 1000}{Vp cos\emptyset} = \frac{5 X 1000}{231 x 1} = 21.7\text{ A}$$

These currents are mutually 120° out of phase as the circuit is purely resistive. Taking IR as reference vector, line current may be given as

$$I_R = 43.4\,(1 + j0)$$

$$I_Y = 34.7\,(-0.5 - j0.866)$$

$$I_B = 21.7\,(-0.5 + j0.866)$$

b) Current in neutral wire,

$$I_N = -(I_R + I_Y + I_B)$$

$$= -[43.4\,(1 + j0) + 34.7\,(-0.5 - j0.866) + 21.7\,(-0.5 + j0.866)]$$

$$= -15.2 + j\,11.258$$

$$I_N = A = \sqrt{(-15.2)^2 + 11.258)^2} = 18.9\text{A}$$

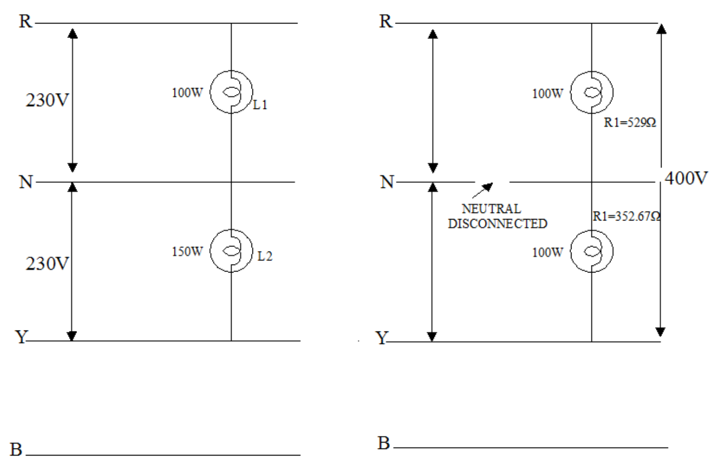
$$\Phi = \tan^{-1}\frac{11.258}{-15.2} = \mathbf{143.5^{\circ}\,A}$$

1.23. Consequence of disconnection of neutral in three phase four wire system

In a balanced three phased four wire system when the neutral is disconnected no change is produced but in case of unbalanced 3-phase 4-wire system when the neutral is disconnected the loads which are connected between any two conductors and the neutral are connected in series and potential difference across the combined load becomes equal to line voltage. The potential difference across each load is thus changed as per rating of the load. The effect of disconnecting the neutral in a 3- phase 4- wire unbalanced system will be clear from the following solved example.

Problem .6. In a 3-phase 4-wire 400/230 V system a lamp of 100 watts is connected to one phase and neutral and a lamp of 150watts is connected to the second phase and neutral. If the neutral wire is disconnected accidentally, what will be the voltage across each lamp?

The lamp L1 of 100 Watts is connected between phase R and neutral Lamp L2 of 150 watts is connected between phase Y and the neutral.



1.16. Consequence of disconnection of neutral in three phase four wire system

Resistance of lamp L_1, $R_1 = \frac{(230)2}{100} = 529\ \Omega$ i.e.$[R = \frac{V2}{P}]$

Resistance of Lamp L_2, $R_2 = \frac{(230)2}{150} = 352.67\ \Omega$

When the neutral wire is disconnected as shown infig the two lamps are connected in series. Therefore the potential difference across the combination becomes equal to the line voltage E_L(400V)

Now current through lamps, $I = \frac{EL}{R1+R2} = \frac{400}{529+352.67} = 0.454$ A

Voltage across lamp L1 = IR_1= 0.454 x 529 = 240.17 V

Voltage across lamp L2 = IR_2 = 0.454 x 352.67 = 160.11V

From the above the voltage across 100 watt lamp is increased to 24 V whereas voltage across 150 watt lamp is decreased to 160V. Therefore 100 W lamps become brighter and 150W becomes dim.

REVIEW QUESTIONS

Part A & B

1. What is the voltage rating of Distribution Substation?
2. Mention the types of Electrical power distribution System?
3. List the types of Bus Bar arrangements?
4. Draw & explain the parts of Typical distribution system?
5. List the advantages of Ring Main Distribution system?
6. Draw the Schematic Diagram of Radial Distribution System?
7. State the different types of Connection schemes of Distribution system?
8. What is meant by feeder and distributor in distribution system?
9. What is the purpose of using auxiliary bus bar in bus bar arrangement?
10. What is the Effect of unbalanced load in star connected System?
11. What is transformer Substation?
12. State the advantages of Outdoor substation Over Indoor Substation.
13. What is the use of Instrument transformer in Substation?
14. State the classification of substation.
15. What are the advantages of Inter connected system?
16. Draw the layout of 110/11kV substation.
17. Distinguish between primary and secondary distribution system.
18. Compare radial and ring distribution system.
19. What are the classifications of bus bar system.
20. Explain single bus bar system
21. Explain double bus bar system with diagram.
22. Name some of the substation equipment’s.
23. What are the advantages of GIS.
24. What are the disadvantages of GIS.
25. What are the features of GIS.

Part C

1. Discuss the different types of Bus bar arrangements.
2. Draw the layout of 11kv/400v Distribution substation and explain the necessity of each part.

3. Explain the methods of solving AC distribution calculation referring power factor.
4. List and explain various equipments used in substation.
5. Classify the distribution systems based on types of supply, character of service, type of construction and scheme of connections.
6. Explain the consequences of disconnection of neutral in 3phase 4wire AC distribution system.
7. Explain 3 phase, 4 wire star connected unbalanced load circuit in detail.
8. Classify the substation according to service and constructional features.
9. Explain various connection schemes of distribution system.
10. Explain the gas insulated substation in detail.
11. **A** single phase distributor one km long has resistance and reactance per conductor of 0.1Ω and 0.15Ω respectively. At the far end the voltage $_{VB}$=200V and the current is 100A at a pf of 0.8 lagging. At the midpoint M of the distributor a current of 100A is tapped at a pf 0.6 lagging with reference to the voltage Vm at the midpoint calculate i)Voltage at mid point ii)Sending end voltage VA iii)Phase angle between VA and VB.
12. A single phase distributor 2 kilometers long supplies a load of 120 A at 0.8pr lagging at its far end and a load of 80A at 0.9 pf lagging at its mid point. Both power factors are referred to the voltage at the far end. The resistance and reactance per km(go and return) are 0.05Ω and 0.1Ω respectively. If the voltage at the far end is maintained at 230V.calculatei)Voltage at the sending end.
    ii) Phase angle between voltage at the two ends.
13. Discuss the different types of Bus bar arrangements.
14. Draw the layout of 11kv/400v Distribution substation and explain the necessity of each part.
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    ii) Phase angle between voltage at the two ends.

UNIT II
INDUSTRIAL DRIVES

INTRODUCTION:

An industrial drive System basically consists of a mechanical working equipment or load which has to be kept in motion to turn out mechanical work equipment to do this job called the prime mover and a transmission to transfer energy from the prime mover to the mechanical load. Transmission equipment such as a gearing or belt may be used to match the speeds of the prime mover and the load. The transmission may also be required sometimes to convert rotator to linear motion and vice versa. Thus a combination of a prime mover transmission equipment and mechanical working load is called a drive.

2.1. Electric drive:

An electric drive can be defined as a drive using an electric motor as a prime mover and ultimately converting electrical energy to mechanical energy. The electric motors used may require some types of control equipment to achieve speed control and torque control. These controls make the motor work on a specific speed torque curve and may be operated using open loop or closed loop control

a) Advantages of Electric Drive

Almost all modern industrial and commercial undertakings employ electric drive in preference to mechanical drive because it possesses the following advantages:

1. It is simple in construction and has less maintenance cost

2. Its speed control is easy and smooth

3. It is neat, clean and free from any smoke or flue gases

4. It can be installed at any desired convenient place thus affording more flexibility in the layout

5. It can be remotely controlled

6. Being compact, it requires less space

7. It can be started immediately without any loss of time

8. It has comparatively longer life.

b) Disadvantages:

1. It comes to stop as soon as there is failure of electric supply and

2. It cannot be used at far off places which are not served by electric supply.

However, the above two disadvantages can be overcome by installing diesel-driven dc generators and turbine-driven 3-phase alternators which can be used either in the absence of or on the failure of normal electric supply.

2.2. Parts of drive:

The above discussion makes clear that an electric drive system basically consists of a mechanical load to which the required mechanical motion is imparted through a transmission drive usually equipped with gears or pulleys Gearless transmission is possible sometimes in which case there exists a direct coupling between the motor and load. The system also compresses certain controls for the motor for precise adjustment of the speed torque curve as demanded by the mechanical load. Electrical drive has three parts namely

1. Motors

2. Load

3. Control unit

1. Motor:

A motor and its controls have to be selected to suit the given power supply and drive the load. The motors may be selected as per the load requirements. Motors commonly used in electric drives are

1. D.C. moors – Shunt, Series motor, compound motor.

2. Induction motor – Squirrel cage, Slipring motor.

3. Synchronous motor.

4. Brushless D.C. motor, Stepper motor and reluctance motor.

2. Load

The load which is connected with the shaft of electric motor is called as mechanical load. The load may be connected with the motor shaft directly or by using belt, chain, gear drives. The mechanical load and its characteristics are normally specified by means of its load diagram and torque speed curve

3. Control unit

In modern electric drives, automatic operations are performed, i.e., starting, speed control of motors, braking, reversing. All these functions are performed by electronic circuit using programmable logic controllers, micro controller.

The function of the control equipment is to set the desired speed or torque precisely. Untill the advent of thyristors, and associate power converters the speed control of motors had been achieved by means of contactors and relays which include or cut off the resistors. The development of power converters has made the control of motors quite straightforward. With this help the speed of ac motors is also smoothly variable. The element of a drive system when converters are employed are shown

2.3. Transmission of Power

There are many ways of transmitting mechanical power developed by a motor to the driven machine.

1. **Direct Drive:** In this case, motor is coupled directly to the driven machine with the help of solid or flexible coupling. Flexible coupling helps in protecting the motor from sudden jerks. Direct drive is nearly 100% efficient and requires minimum space but is used only when speed of the driven machine equals the motor speed.

2. **Belt Drive**: Flat belts are extensively used for line-shaft drives and can transmit a maximum power of about 250 kW. Where possible, the minimum distance between the pulley centers should be 4 times the diameter of the larger pulley with a maximum ratio between pulley diameters of 6 : 1. The power transmitted by a flat belt increases in proportion to its width and varies greatly with its quality and thickness. There is a slip of 3 to 4 per cent in the belt drive.

3. **Rope Drive**: In this drive, a number of ropes are run in V-grooves over the pulleys. It has negligible slip and is used when the power to be transmit-ted is beyond the scope of belt drive.

4. **Chain Drive**: Though somewhat more expensive, it is more efficient and is capable of transmitting larger amounts of power. It is noiseless, slip less and smooth in operation.

5. **Gear Drive**: It is used when a high-speed motor is to drive a low-speed machine. The coupling between the two is through a suitable ratio gear box. In fact motors for low-speed drives are manufactured with the reduction gear. Geared Motor Unit incorporated in the unit itself. Fig. shows such a unit consisting of a flange motor bolted to a high-efficiency gear box which is usually equipped with feet, the motor being overhung.

2.4. Types of Electric Drives:

Electric drives may be grouped into three categories:
1. Group drive,
2. Individual drive and
3. Multi motor drive.

1. Group drive

In group drive, a single motor drives a number of machines through belts from a common shaft. It is also called line shaft drive.

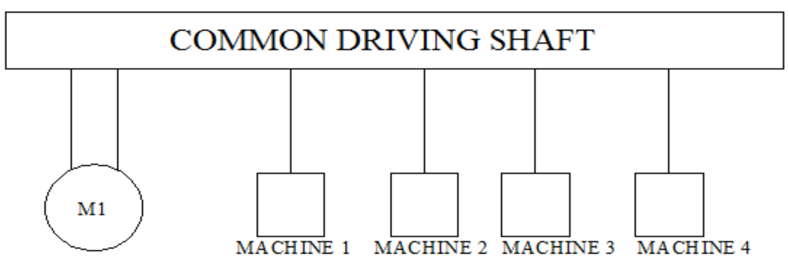


Fig 2.1.The group drive

Advantages:

1. It leads to saving in initial cost because one 150-kW motor costs much less than ten 15-kW motors needed for driving 10 separate machines.

2. Since all ten motors will seldomly be required to work simultaneously, a single motor of even 100-kW will be sufficient to drive the main shaft. This diversity in load reduces the initial cost still further.

3. Since a single large motor will always run at full-load, it will have higher efficiency and power factor in case it is an induction motor.

4. Group drive can be used with advantage in those industrial processes where there is a sequence of continuity in the operation and where it is desirable to stop these processes simultaneously as in a flour mill.

Disadvantages:

1. Any fault in the driving motor renders all the driven equipment idle. Hence, this system is unreliable

2. If all the machines driven by the line shaft do not work together, the main motor runs At reduced load. Consequently, it runs with low efficiency and with poor power factor.

3. Considerable amount of power is lost in the energy transmitting mechanism.

4. Flexibility of layout of different machines is lost since they have to be so located as to suit the position of the line shaft.

5. The use of line shaft, pulleys and belts etc. making the drive look quite untidy and less safe to operate.

6. It cannot be used where constant speed is required as in paper and textile industry.

7. Noise level at the worksite is quite high.

2. Individual drive

In the case of an individual drive, each machine is driven by its own separate motor with the help of gears, pulley etc.

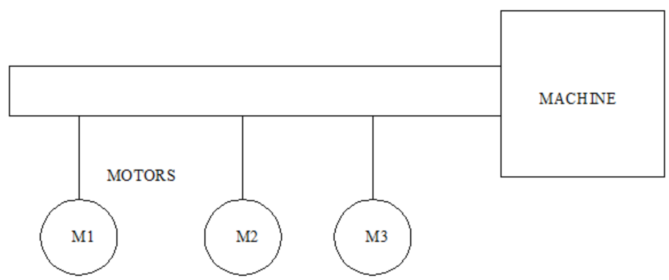


Fig 2.2. Individual Drive

Advantages

1. Since each machine is driven by a separate motor, it can be run and stopped as desired.
2. Machines not required can be shut down and also replaced with a minimum of dislocation.
3. There is flexibility in the installation of different machines.
4. In the case of motor fault, only its connected machine will stop whereas others will continue working undisturbed.
5. The absence of belts and line shafts greatly reduces the risk of accidents to the operating personnel.
6. Ach operator has full control of the machine which can be quickly stopped if an accident occurs.
7. Maintenance of line shafts, bearings, pulleys and belts etc. is eliminated. Similarly there is no danger of oil falling on articles being manufactured–something very important in textile industry.

The only disadvantage of individual drive is its initial high cost. However, the use of individual drives and multimotor drives has led to the introduction of automation in production processes which, apart from increasing the productivity of various undertakings, has increased the reliability and safety of operation

3. Multi motor drive.

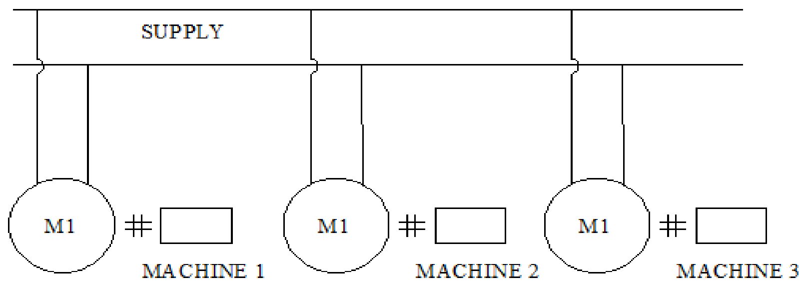


Fig 2.3 Multi motor drive

In multi-motor drives separate motors are provided for actuating different parts of the driven mechanism. For example, in travelling cranes, three motors are used: one for hoisting, another for long travel motion and the third for cross travel motion. Multimotor drives are commonly used in paper mills, rolling mills, rotary printing presses and metal working machines etc.

2.5. Factors governing the Selection of a Motor

The selection of a driving motor depends primarily on the conditions under which it has to operate and the type of load it has to handle. Main guiding factors for such a selection are as follows :

(*a*) Electrical characteristics

1. Running characteristics
2. Starting characteristics
3. Speed control
4. Braking

(*b*) Mechanical considerations

1. Types of enclosures
2. Transmission of drive
3. Type of cooling
4. Noise level
5. Type of bearing

(*c*) Size and rating of motors

1. Requirement for continuous, intermittent or variable load cycle
2. Overload capacity

(*d*) Cost

1. Capital cost2. Running cost

In addition to the above factors, one has to take into consideration the type of current available whether alternating or direct. However, the basic problem is one of matching the mechanical output of the motor with the load requirement *i.e.* to select a motor with the correct speed/torque characteristics as demanded by the load. In fact, the complete selection process requires the analysis and synthesis of not only the load and the proposed motor but the complete drive assembly and the control equipment which may include rectification or frequency changing.

I). Electrical characteristics

a) Running characteristics:

The Running characteristics of a motor include the speed- torque or the speed- current characteristics, Losses, magnetizing current, efficiency and power factor at various loads. The magnetizing current and power factor are to be considered in case of AC motors only.

b) Starting characteristics:

The starting torque developed by a motor should be sufficient to start and accelerate the motor at its load to the rated speed in a reasonable time. Some motors may have to start against full load torque example: motors driving grinding mills or oil expellers, traction work.

c) Speed control:

i) In a DC motor the speed can be controlled by the following methods:

1. Armature control method
2. Field control method

ii) In AC motor the speed can be controlled by the following methods

1. By changing the supply voltage
2. By changing the supply frequency
3. By changing the number of poles of motor
4. By injecting emf in the rotor circuit.
5. By cascading of motors.
6. By injecting resistance in the rotor circuit.

d) Braking

If the load is removed from an electric motor and even the supply is disconnected, the motor will run for some time due to its inertia. To avoid danger to the worker or to stop the motor immediately braking is applied. The braking should be reliable and quick in action. The braking torque is applied to stop the motor. There are two types of braking i0Mechanical Braking ii) Electrical braking.

(*II*) Mechanical characteristics

a)Types of Enclosures

The main function of an enclosure is to provide protection not only to the working personnel but also to the motor itself against the harmful ingress of dirt, abrasive dust, vapors and liquids and solid foreign bodies such as a spanner or screw driver etc. At the same time, it should not adversely affect the proper cooling of the motor. Hence, different types of enclosures are used for different motors depending upon the environmental conditions. Some of the commonly used motor enclosures are as under:

1. Open Type: In this case, the machine is open at both ends with its rotor being supported on pedestal bearings or end brackets. There is free ventilation, since the stator and rotor ends are in free contact with the surrounding air. Such, machines are housed in a separate neat and clean room. This type of enclosure is used for large machines such as d.c. motors and generators.

2. Screen Protected Type: In this case, the enclosure has large openings for free ventilation. However, these openings are fitted with screen covers, which safeguard against accidental contacts and rats entering the machine but afford no protection from dirt, dust and falling water. Screen-protected type motors are installed, where dry and neat conditions prevail without any gases or fumes.

3. Drip Proof Type: This enclosure is used in very damp conditions *i.e.* for pumping sets. Since motor openings are protected by over-hanging cowls, vertically falling water and dust are not able to enter the machine.

4. Splash-proof Type: In such machines, the ventilating openings are so designed that liquid or dust particles at an angle between vertical and 100° from it cannot enter the machine. Such type of motors can be safely used in rain.

5. Totally Enclosed (TE) Type: In this case, the motor is completely enclosed and no openings are left for ventilation. All the heat generated due to losses is dissipated from the outer surface which is finned to increase the cooling area. Such motors are used for dusty atmosphere *i.e.* sawmills, coal-handling plants and stone-crushing quarries etc.

6. Totally-enclosed Fan-cooled (TEFC) Type: In this case, a fan is mounted on the shaft external to the totally enclosed casing and air is blown over the ribbed outer surfaces of the stator and end shields (Fig. 44.1). Such motors are commonly used in flour mills, cement works and sawmills etc. They require little maintenance apart from lubrication and are capable of giving years of useful service without any interruption of production.

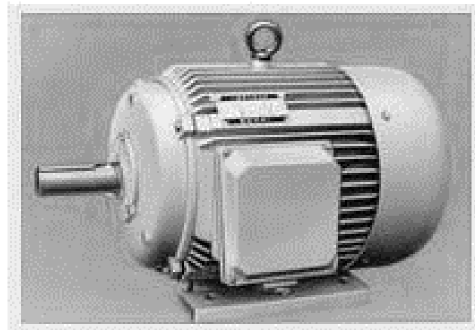


Fig. 44.1. A three-phase motor

7. Pipe-ventilated Type: Such an Enclosure is used for very dusty surroundings.

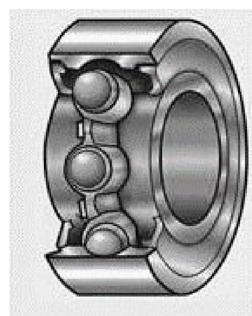
The motor is totally enclosed but it is cooled by neat and clean air brought through a separate pipe from outside the dust-laden area. The extra cost of the piping is offset by the use of a smaller size motor on account of better cooling.

8. Flame-proof (FLP) Type: Such motors are employed in atmospheres which contain in-flammable gases and vapors *i.e.* in coal mines and chemical plants. They are totally enclosed but their enclosures are so constructed that any explosion within the motor due to any spark does not ignite the gases outside. The maximum operating temperature at the surface of the motor is much less than the ignition temperature of the surrounding gases.

b) Bearings

These are used for supporting the rotating parts of the machines and are of two types:

1. Ball or roller bearings **2.** Sleeve or bush bearings



(*a*) Ball Bearings

Up to about 75kW motors, ball bearings are preferred to other bearings because of their following advantages:

1. They have low friction loss
2. They occupy less space
3. They require less maintenance
4. Their life is long.
5. Their use allows much smaller air-gap between the stator and rotor of an induction motor.

Their main disadvantages are with regard to cost and noise particularly at high motor speeds.

(*b*) Sleeve Bearings

These are in the form of self-aligning pourous bronze bushes for fractional kW motors and in the Form of journal bearings for larger motors. Since they run very silently, they are fitted on super-silent motors used for driving fans and lifts in offices or other applications where noise must be reduced to the absolute minimum.

(c) Noise

The noise produced by a motor could be magnetic noise, windage noise and mechanical noise. Noise level must be kept to the minimum in order to avoid fatigue to the workers in a workshop. Similarly, motors used for domestic, hospital appliances; offices and theatres must be almost noiseless. Transmission of noise from the building, where the motor is installed to another building can be reduced if motor foundation is flexible *i.e.* has rubber pads and spring.

2.6. Nature and classification of load torque

The mechanical system is coupled to the motor by means of a transmitting device. The motor has to develop a torque as required by the mechanical work to be carried out to drive the load and the mechanical losses occurring in the system. A mechanical system is specified by a speed torque curve. The motor while driving this mechanical load must provide enough torque to drive the load against losses like friction and to accelerate the load torque to the desired speed.

A) Windage torque

The torque required by the load when the air surrounding the rotating parts moves. It is normally proportional to the square of the speed. However at normal speeds of operation it may be considered equivalent to viscous friction and the value of B may be taken to contain both friction and windage.

The working mechanism must be accelerated and brought to the desired speed. The motor should provide a torque at the shaft capable of accelerating the rotating parts against their inertia. Inertia as seen by the motor shaft includes the inertia of the mechanism as well as of transmission.

Hence the load torque required by the load at the shaft has the following components.

- Torque component to overcome friction and windage which accompanies mechanical motion.T_{fw}
- Torque required to accelerate the load to the desired speed.T_a
- Torque required to do the prescribed mechanical work to run to the load at the desired speed.T_w

The load torque seen by the motor at the shaft.

$$T_L=T_{fw}+T_a+T_w$$

The friction existing in a mechanical system may be classified as follows

i) Viscous friction. In this type of friction the torque required is directly proportional to the speed of rotation.

$$T_B=Bw=B\frac{d\theta}{dt}$$

Where B is a constant of proportionally

ii) Colomb friction .The torque required is independent of speed in this type of friction. It acts as a load torque in either direction and is also called dry friction. Viscous friction changes to coulomb friction at very low speeds

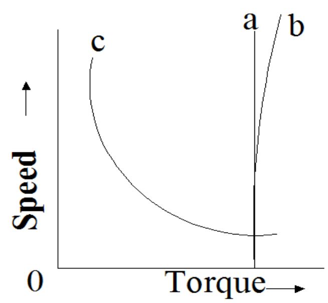
iii) Static friction or station Occurs due to the sticking nature of the surfaces. This is generally very small and can be neglected.

2.7. Matching of speed torque characteristics of load and motor.

The various types of load torques that occur in industrial practices are considered with matching the speed torque characteristics of load and motor for its specific applications.

The load torque may be constant at all speeds as shown curve in fig2.4 .curve a.This type of torque is represented by a compressor load.

The speed torque curve b is as shown is for unidirectional drives.



a. Constanr torque load b. Compressure load
c.Constant power load

Fig 2.4 Speed torque characteristics

The torque speed curve c is shown with certain types of loads like winch drives a constant torque is required when the mechanism is under standstill conditions. The direction of rotation may need to be reversed.These occur in ships when it is required to hold he ship in a particular location or to warp it through a lock gate.

Another type of load has its torque proportional to the square of the speed as in fig .The speed torque curve is found with pump or fan type loads.

$Tw=Kw^2$

The power developed at the motor shaft

$P=Kw^3$

This load is also unidirectional. It is required to run at constant speeds for a longer period of time or at several speed settings or over a range of speeds

Another type of mechanical load requires constant power at all speeds

$P_w=T_w\omega$

P constant at all w. The torque speed characteristic of such a load is a rectangular hyperbola. This load is found with steel rolling mills papers mills. It occurs in transportation also.

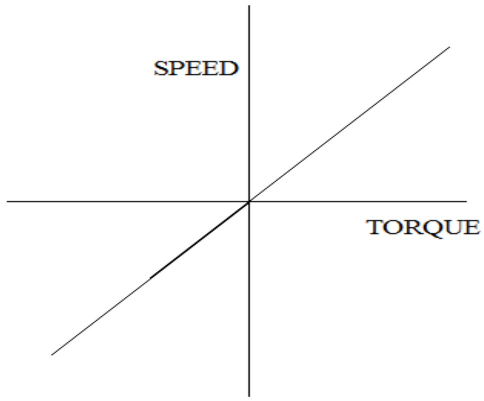


Fig 2.5 Load torque characteristics

From the above types of loads some operates only in one direction with no reversal of speed. In the speed – torque plane these are represented in the first quadrant. The forward driving of the mechanism corresponds to an operation in the first quadrant where motor draws electrical power to drive the mechanical load coupled to it.

The mechanical load sometimes requires braking to bring it to rest quickly. During braking, which torque is achieved either by electrical or mechanical method is applied in the negative direction. Electrical methods are dynamic braking, eddy current braking, regenerative braking and plugging.

2.8. Size and Rating of motor:

The factors which govern the size and rating of motor for any particular service are its maximum temperature rise under given load conditions and the maximum torque required. It is found that a motor which is satisfactory from the point of view of maximum temperature rise usually satisfies the requirement of maximum torque as well. For class-A insulation, maximum permissible temperature rise is 40°C whereas for class – B insulation, it is 50°C. This temperature rise depends on whether the motor has to run continuously, intermittently or on variable load.

Different ratings for electrical motors are as under:

1. Continuous Rating. It is based on the maximum load which a motor can deliver for an indefinite period without its temperature exceeding the specified limits and also possessing the ability to take 25% overload for a period of time not exceeding two hours under the same conditions.

For example, if a motor is rated continuous 10 KW, it means that it is capable of giving an output of 10 KW continuously for an indefinite period of time and 12.5 KW for a period of two hours without its temperature exceeding the specified limits.

2. Continuous Maximum Rating. It is the load capacity as given above but without overload capacity. Hence, these motors are a little bit inferior to the continuous-rated motors.

3. Intermittent Rating. It is based on the output which a motor can deliver for a specified period, say one hour or ½ hour or ¼ hour without exceeding the temperature rise. This rating indicates the maximum

load of the motor for the specified time followed by a no-load period during which the machine cools down to its original temperature.

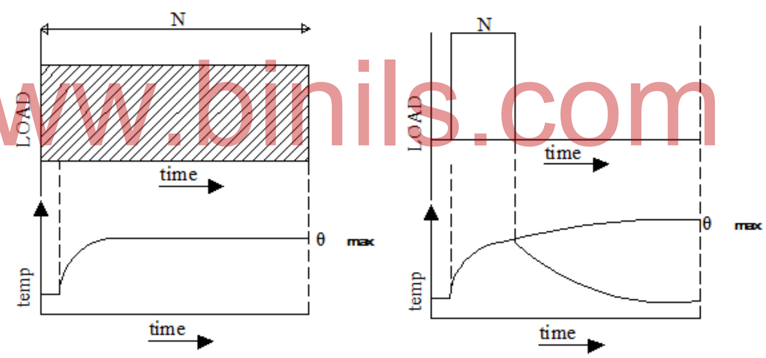
2.9 Classes of load duty cycles

The eight standard classes of duty cycles are
1. Continuous duty
2. Short time duty
3. Intermittent periodic duty
4. Intermittent periodic duty in the starting
5. Intermittent periodic duty with staring and braking
6. Continuous duty intermittent periodic loading
7. Continuous duty with staring and braking
8. Continuous duty with periodic speed changes.

2.10. Selection of motor for different duty cycles

1. Continuous duty (fig 2.6)

It denotes the motor operation at a constant load torque to reach steady state temperature. The load time and temperature time graph are shown. Paper mill drives compressors conveyers' centrifugal pumps and fans are some examples of continuous duty.



Continuous duty

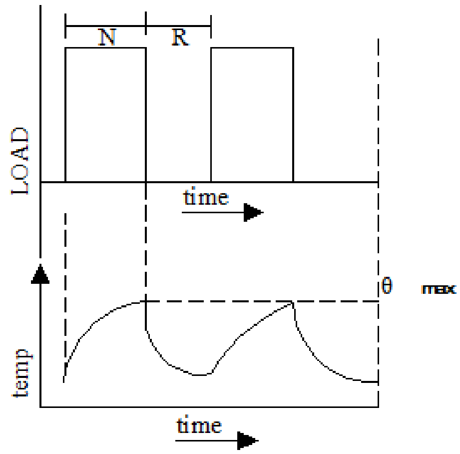
Short-time duty

2. Short time duty

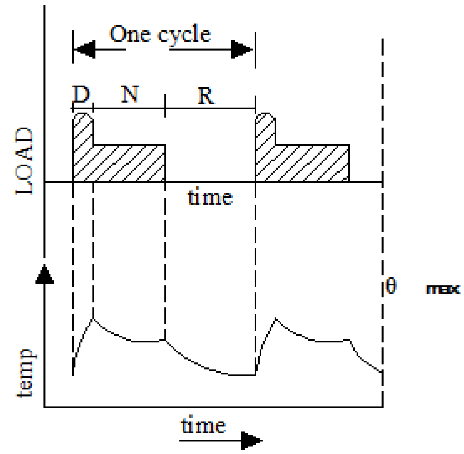
It denotes the operation of motor at constant load for short period followed by rest to cool down to the original starting temperature. Short time duty timings are generally 10, 30, 60 and 90 minutes. The load time and the temperature time graph are shown. Crane drivers for household appliances sluices gate drives valve drives and machine tool drives are some examples of short-time duty

3. Intermittent periodic duty (Fig 2.7)

It denotes the operation of motor a sequence of identical duty cycle each of constant load and rest period. In this duty heating of machine during starting and braking operation is negligible. The load time and temperature time graph. Pressing cutting and drilling machine drives are some examples of intermittent periodic duty.



Intermittent duty



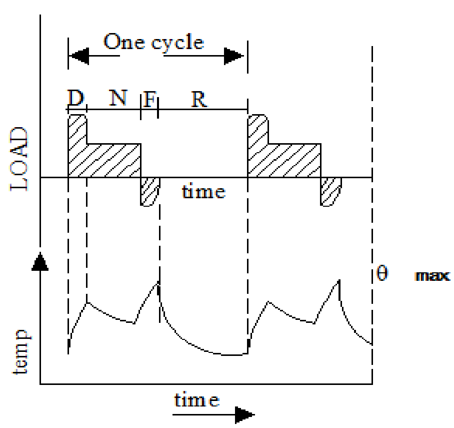
Intermittent duty with starting

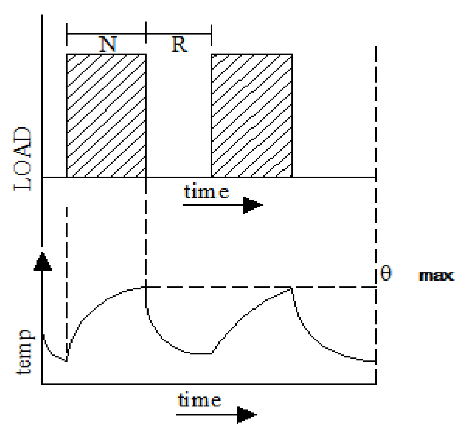
4. Intermittent period duty with starting

This is intermittent periodic duty where heat losses during starting cannot be neglected. Thus it consists of a period of starting a period of operation at a constant load and rest period. The operating and rest periods are too short to attain the steady state temperature in one duty cycle. Its characteristics are shown In this duty heating of machine during braking is considered to be negligible .Some examples are metal cutting drilling tool drives mine hoist drives for lift trucks.

5. Intermittent periodic duty with starting and braking (2.8)

This is the periodic duty where heat losses during starting and braking cannot be ignored. Thus it consists of a period of starting a period of operation with a constant load a braking period and a rest period. Thermal equilibrium is not reached in one duty cycle. Braking is done electrically and is quick. Its characteristics is Several machine tool drives, drives for electric suburban trains and mine hoist are some examples of this duty.

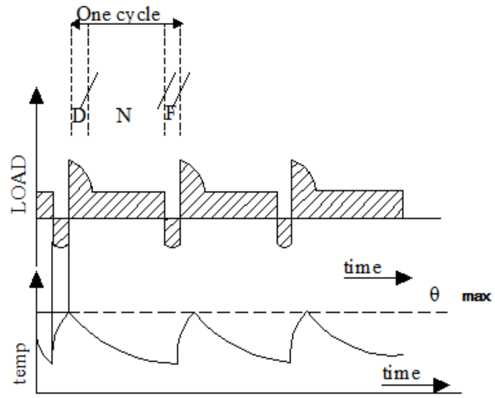


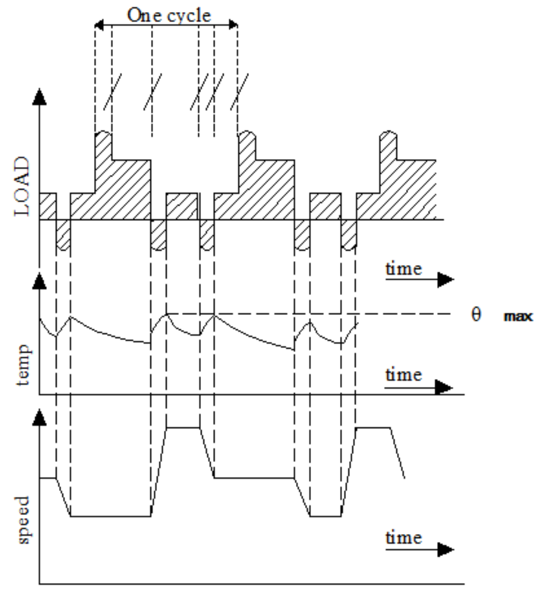


Intermittent duty

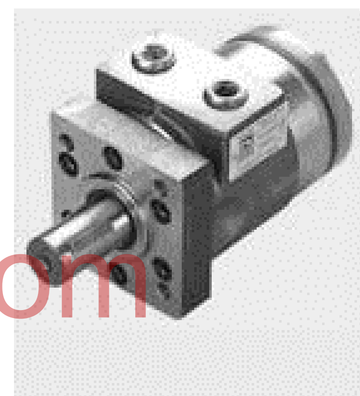
6. Continuous duty with intermittent periodic loading(Fig 2.9)

The operation of motor has a sequence of identical duty cycle each consisting of a period of operation and a period of operation on no load. Thermal equilibrium





2.11. Motors for Different Industrial Drives



1. **D.C. Series Motor:** Since it has high starting torque and variable speed, it is used for heavy duty applications such as electric locomotives, steel rolling mills, hoists, lifts and cranes.

2. **D.C. Shunt Motor**: It has medium starting torque and a nearly constant speed. Hence, it is used for driving constant-speed line shafts, lathes, vacuum cleaners, wood-working machines, laundry washing machines, elevators, conveyors, grinders and small printing presses etc.

3.**Cumulative Compound Motor**: It is a varying-speed motor with high starting torque and is used for driving compressors, variable-head centifugal pumps, rotary presses, circular saws, shearing machines, elevators and continuous conveyors etc.

4. **Three-phase Synchronous Motor**: Because its speed remains constant under varying loads, it is used for driving continuously-operating equipment at constant speed such as ammonia and air compressors, motor-generator sets, continuous rolling mills, paper and cement industries.

5. **Squirrel Cage Induction Motor**: This motor is quite simple but rugged and possesses high over-load capacity. It has a nearly constant speed and poor starting torque. Hence, it is used for low and medium power drives where speed control is not required as for water pumps, tube wells, lathes, drills, grinders, polishers, wood planers, fans, blowers, laundry washing machines and compressors etc.

6. **Double Squirrel Cage Motor**: It has high starting torque, large overload capacity and a nearly constant speed. Hence, it is used for driving loads which require high starting torque such as compressor pumps, reciprocating pumps, large refrigerators, crushers, boring mills, textile machinery, cranes, punches and lathes etc.

7. Slip-ring Induction Motor: It has high starting torque and large overload capacity. Its speed can be changed up to 50% of its normal speed. Hence, it is used for those industrial drives which require high starting torque and speed control such as lifts, pumps, winding machines, printing presses, line shafts, elevators and compressors etc.

8. Single-phase Synchronous Motor: Because of its constant speed, it is used in teleprinters, clocks, all kinds of timing devices, recording instruments, sound recording and reproducing systems.

9. Single-phase Series Motor: It possesses high starting torque and its speed can be controlled over a wide range. It is used for driving small domestic appliances like refrigerators and vacuum cleaners etc.

10. Repulsion Motor: It has high starting torque and is capable of wide speed control. More-over, it has high speed at high loads. Hence, it is used for drives which require large starting torque and adjustable but constant speed as in coil winding machines.

11. Capacitor-start Induction-run Motor:It has fairly constant speed and moderately high starting torque. Speed control is not possible. It is used for compressors, refrigerators and small portable hoists.

12. Capacitor-start-and-run Motor. Its operating characteristics are similar to the above motor except that it has better power factor and higher efficiency. Hence, it is used for drives requiring quiet operations

2.12. Electrical braking:

The stored energy of rotating parts is converted into electrical energy and dissipated in the resistance in the form of heat or returned to the supply in case of electrical braking. In electrical braking the driving motor operates as a generator during the period of braking and comes to standstill.

a)Advantages of Electrical Braking :

1. The electrical braking is more economical than mechanical braking.
2. Wear and tear of brake will not take place.
3. Mechanical braking produces metal dust, which can damage bearings. Electrical braking has no such high maintenance problems.
4. Comfort, easy speed control.
6. Electrical braking is smooth, fast and cheap.
7. In regenerative braking electrical energy can be returned back to the supply so running cost is less.
8. Noise produced is very low.
9. Capacity of the system can be increased.

b) Disadvantages:
1. It is ineffective in applying holding torque.
2. High initial cost.
3. Cannot be applied to all types of motors

2.13. Types of Electric Braking

There are three types of electric braking as applicable to electric motors in addition to eddy-current braking.

1. Plugging or reverse-current braking.

2. Rheostat or dynamic braking.

3. Regenerative braking.

In many cases, provision of an arrangement for stopping a motor and its driven load is as important as starting it. For example, a planner machine must be quickly stopped at the end of its stroke in order to achieve a high rate of production. In other cases, rapid stops are essential for preventing any danger to operator or damage to the product being manufactured. Similarly, in the case of lifts and hoists, effective braking must be provided for their proper functioning.

1. Plugging

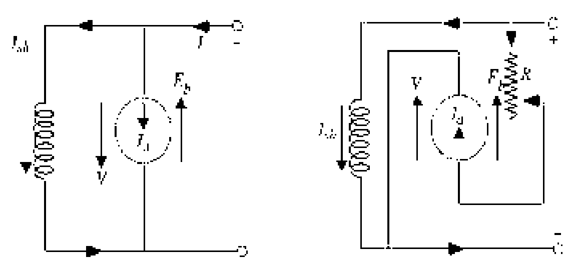
Plugging means phase reversal. It is a simple method of electrical braking. During the braking period reverse torque produces on the motor. A special device is required to cut off the supply as soon as the motor comes to rest. This method can be applied to both AC and DC motors.

a) Plugging Applied to D.C. Motors

With reversed armature connections, the motor develops torque in the ***opposite*** direction. So, armature connections are reversed whereas ***field winding connections remain unchanged***. When speed reduces to zero, motor will accelerate in the opposite direction. Hence, the arrangement is made to disconnect the motor from the supply as soon as it comes to rest.

b) Plugging Applied to D.C. Shunt Motors (Fig 2.11)

Fig. shows running and reversed connections for shunt motors. In this back emf (Eb) opposes the applied voltage (V). The armature current flows from A to B. When plugging is applied the armature connections are reversed as in fig. Since with reversed connection, *V* and E_b are in the same direction, voltage across the armature is almost double of its normal value. In order to avoid excessive current through the armature, additional resistance *R* is connected in series with armature



C)Plugging Applied to D.C. Series Motors(Fig 2.12)

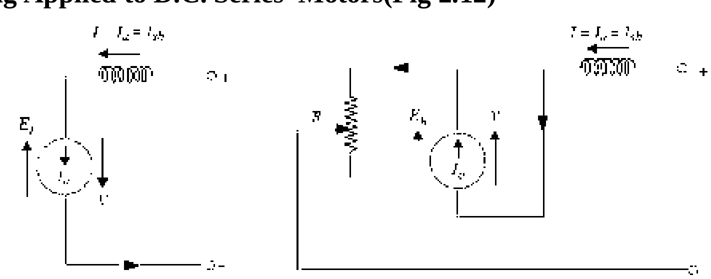
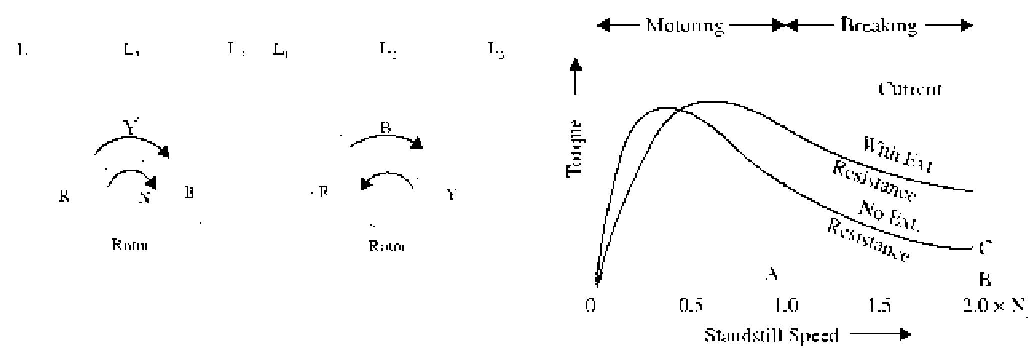


Fig. shows similar conditions for series motors. In DC series motor. In series motor while plugging the field current is also reversed. These results the production of the torque in the same as it is working normally. In order to develop torque in the reverse direction, the direction of field current should remain unchanged. At this time now a total voltage (V+Eb) is available across the armature terminals. It will be nearly twice of the supply voltage. It may causes high current to flow around the circuit. To limit this current additional resistance R is connected in series. This method is simple but power is wasted in the resistance.

d) Plugging Applied to Induction Motors

This method of braking is applied to an induction motor by transposing any of its two line leads as shown in Fig. It reverses the direction of rotation of the synchronously-rotating magnetic field which produces a torque in the reverse direction, thus applying braking on the motor. Hence, at the first instant after plugging, the rotor is running in a direction opposite to that of the stator field. At the instant of plugging the relative speed between the rotor conductors and the magnetic field will be twice the synchronous speed. So voltage induced in the rotor will be twice that of normal voltage. It means that speed of the rotor relative to the magnetic field is$(N_s + N) \cong 2N_s$ as shown in Fig.



In Fig.2.13. Plugging Applied to Induction Motors

Coordinate *BC* represents the braking torque at the instant of plugging. As seen, this torque gradually increases as motor approaches standstill condition after which motor is disconnected from the supply. Due to high voltage, abnormal current will flow so in order to protect the windings additional insulation to be provided. Hence high value of resistance may be inserted in the rotor or stator circuit.

e) Plugging Applied to Synchronous Motors

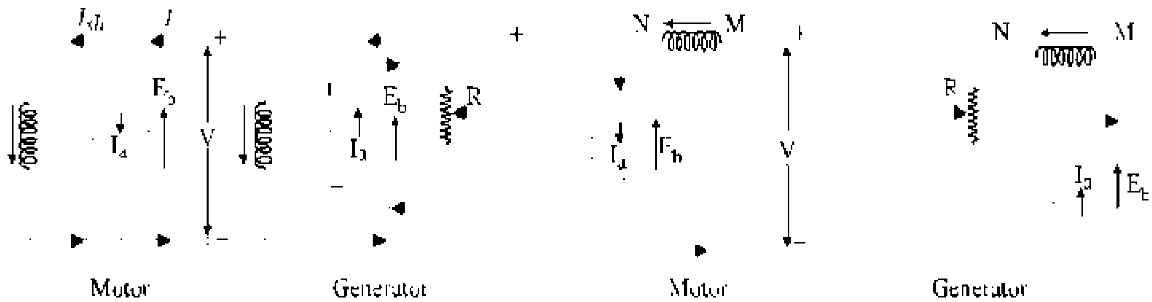
As compared to squirrel cage motors, slip-ring motors are more suitable for plugging because, in their case, external resistance can be added to get the desired braking torque. When three phase voltage is supplied to the stator of Synchronous Motors a rotating magnetic field is produced in the stator. D.C voltage is applied to the rotor field windings producing permanent magnetic field. If the direction of rotating magnetic field is reversed by interchanging the two phases of the stator then the braking torque is not produced. Therefore in case of plain Synchronous Motors plugging is not possible. But in case of self-started Synchronous Motors the braking effect will be produced due to eddy current induced in damper windings provided for starting purpose.

2. Dynamic or Rheostat Braking

This method has advantage over plugging because, in this case, no power is drawn from the supply during braking. In his method of braking, a motor is disconnected from the supply and operated as a generator driven by the kinetic energy of the rotor. The kinetic energy of rotation is converted in to electrical energy, in which the energy is dissipated in external resistor.*D.C.* and synchronous motors can be broken this way but induction motors require separate d.c.source for field excitation.

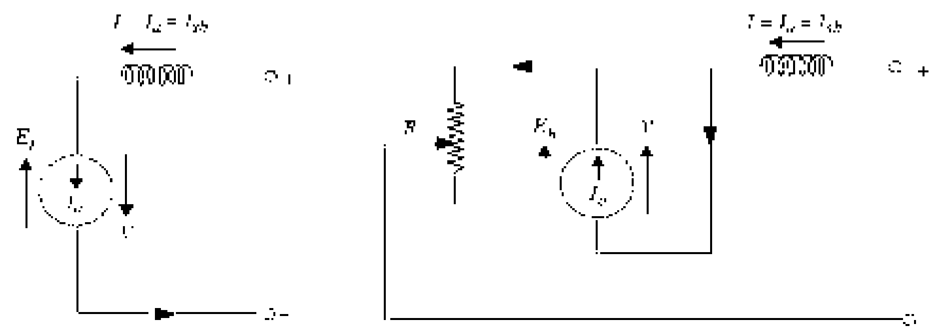
a) Dynamic or Rheostat Braking of D.C.shunt Motors

Fig2.14.a. shows connections for a D.C. shunt motor. For applying rheostat braking armature is disconnected from the supply and connected to a variable external resistance *R* while the field remains on the supply. The motor starts working as a generator whose induced emf E_b depends upon its speed. At the start of braking, when speed is high, E_b is large, hence I_a is large. As speed decreases, E_b decreases, hence I_a decreases. Since $T_b \alpha \Phi I_a$, it will be high at high speeds but low at low speeds. By gradually cutting out *R*, I_a and, hence, T_B can be kept constant throughout. Value of $I_a = E_b (R + R_a)$.



a) Dynamic or Rheostat Braking of D.C. series Motors

Fig2.14.b. shows running and braking conditions for a D.C. series motor. In this case also, for rheostat braking, the armature is disconnected from the supply and, at the same time, is connected across *R*. However, connections are so made that current keeps flowing through the series field ***in the same direction*** otherwise no braking torque would be produced. The motor starts working as a series generator provide Rheostat Braking Torque.



1. For D.C shunt motors and synchronous motor is constant hence $T_B = k_1 N$

2. In the case of series motors, flux depends on current. Hence, braking torque can be found from its magnetization curve.

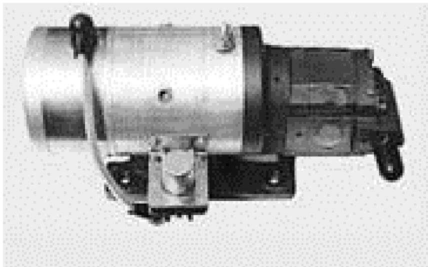
b) Dynamic or Rheostat Braking of Induction Motors

If an induction motor the stator is disconnected from the supply for rheostat braking, there would be no magnetic flux and, hence, no generated emf in the rotor and no braking torque. However, if after disconnection, direct current is passed through the stator; steady flux would be set up in the air-gap which will induce current, in the short-circuited rotor. This current which is proportional to the rotor speed, will produce the required braking torque whose value can be regulated by either controlling d.c. excitation or varying the rotor resistance.

C) Dynamic or Rheostat Braking of Synchronous Motors

In synchronous motor, the D.C excitation is maintained and the stator is disconnected from the supply. Then the stator is connected across three resistances in star or delta. Now the machine operates as an alternator and the kinetic energy is dissipated in the resistance and braking will occur.

3. Regenerative Braking



In this method of braking, motor is not disconnected from the supply but is made to run as a generator by utilizing the Kinetic energy .Electrical energy is fed back to the supply. The magnetic drag produced on account of generator action offers the braking torque. It is the most efficient method of braking.

a) Regenerative Braking applied to D.C.shunt motor

Take the case of a shunt motor. It will run as a generator whenever its E_b be-comes greater than V. Now, E_b can exceed V in two ways:

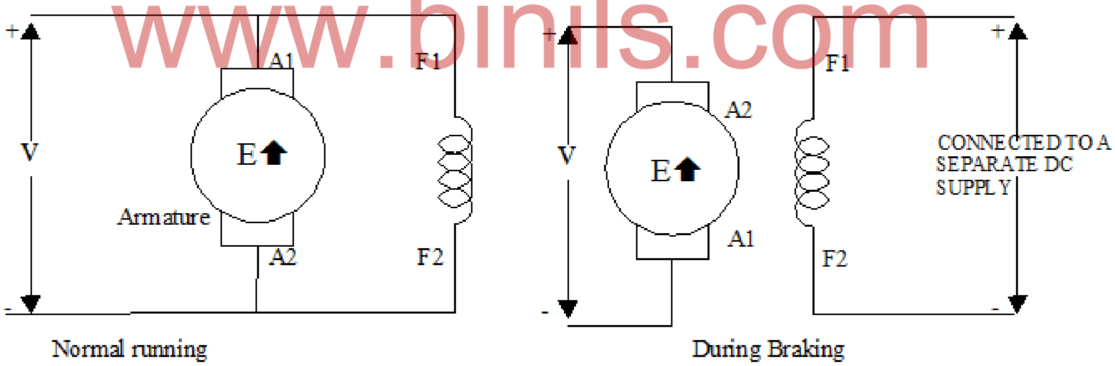


Fig 2.15.Regenerative Braking applied to D.C.shunt motor

1. By increasing field excitation
2. By increasing motor speed beyond its nor-mal value, field current remaining the same. It happens when load on the motor has overhauling characteristics as in the lowering of the cage or a hoist or the down-gradient movement of an electric train. Regenerative braking can be easily applied to D.C. shunt motors though not down to very low speeds because it is not possible to increase field current sufficiently.

b) Regenerative Braking applied to D.C.series motor

In the case of D.C. series motors, reversal of current necessary to produce regeneration would cause reversal of the field and hence of E_b. Consequently, modifications are necessary if regenerative braking is to be employed with D.C. series motors. It may, however, be clearly understood that regenerative braking cannot be used for stopping a motor. Its main advantages are ***(i)*** reduced energy consumption ***(ii)*** reduced wear of brake shoes and wheel ***(iii)*** lower maintenance cost.

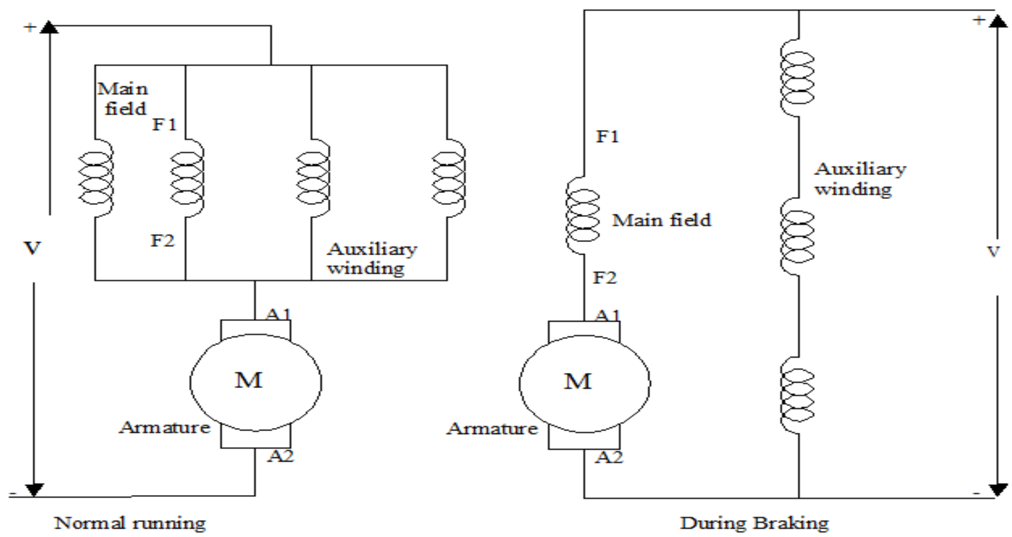


Fig 2.16.Regenerative Braking applied to D.C.series motor

Fig shows the connection of a D.C. series motor for Regenerative Braking using French method. It is provided with a main series winding and auxiliary field winding connected in parallel with the main series winding in a D.C series motor. During braking period, the auxiliary windings are put in series with each other and switched across the supply as in fig. the motor acts as a differentially compound generator.

c) Regenerative Braking applied to induction motor

When an induction motor runs above synchronous speed the emf induced in the rotor is greater than the supply voltage. Hence the motor works acts as an induction generator and feed power back to the supply line. No extras auxiliaries are needed for this purpose. Its application is very useful to lift and hoist for a descending load at a speed slightly above synchronous speed.

REVIEW QUESTIONS
Part-A& Part-B

1. Mention any one application area of group drive system?
2. What is Short time duty cycle?
3. What are the important parts of electric drives?
4. What is meant by Regenerative braking?
5. What is mean by Individual Drive system?
6. What is mean by rating of motor?
7. List the motors used for mining.
8. Why DC Series motor is used in Crane Drive?
9. What are the factors to be taken in to consideration while selecting a motor for industrial applications?
10. What is plugging?
11. Write a Note on nature and Classification of load Torque?
12. What do you mean by group drive & individual drive .Give examples?
13. What are the factors to take into account for selection of driving motor?
14. Name the types of enclosures of Electric drives.

15. Name the types of Transmission of drive.
16. What is the effect of Noise? How it can be Limited?
17. How regenerative braking is achieved in AC Drive?
18. Bring out the difference between Regenerative Braking & Plugging.
19. List out the classification of duty cycles & explain.
20. State the advantages and Disadvantages of Electric Braking compare to Mechanical braking?
21. What is meant by continuous rating?

Part-C

22. Explain how regenerative braking is applied to DC shunt and DC series motor?
23. Explain the different types of electric drives used in industrial loads?
24. Give the choice of motors for the following giving Proper reasons
25. Lathe, Cement Kiln, Hoist, Textile mill, Paper Mill, Electric crane, Centrifugal Pump.
26. Explain Load duty cycles and how a motor is selected from a given duty cycles?
27. Explain Plugging and how it is carried out in a 3-pahse induction motor?
28. Explain dynamic braking is applied to DC shunt motor and 3-phase induction motor?
29. Explain the factors governing the selection of motors in detail.

UNIT III

ELECTRIC TRACTION

INTRODUCTION

The electric traction is meant locomotion in which the driving (or attractive) force is obtained from electric motors. It is used in electric trains, tramcars, trolley buses and diesel-electric vehicles etc. Electric traction has many advantages as compared to other non-electrical systems of traction including steam traction

3.1Traction Systems.

Traction systems can broadly speaking be classified as those which do not involve use of electrical energy at any stage, such as steam engine drive and internal combustion engine drive and those traction systems which involve use of electrical energy at some stage or the other, such as diesel electric drive battery electric drive and straight electric drive.

Broadly speaking, all traction systems may be classified into two categories:

(*a*) Non-Electric traction systems

They do not involve the use of electrical energy at ***any stage***. Examples are : steam engine drive used in railways and internal-combustion-engine drive used for road transport

(*b*) Electric traction systems

They involve the use of electric energy at some stage or the other. They may be further sub-divided into two groups:

1. First group consists of self-contained vehicles or locomotives. Examples are : batteryelectric drive and diesel-electric drive etc.

2. Second group consists of vehicles which receive electric power from a distribution network fed at suitable points from either central power stations or suitably-spaced sub-stations.

Examples are: railway electric locomotive fed from overhead ac supply and tramways and trolly buses supplied with dc supply

3.2. Electric Drive:

Drives using by means of electric motors which are fed from over head distribution system are known as electric drives.

3.3. Advantages and disadvantages of electric drive are:

a)Advantages

1. Cleanliness

As it has no smoke electric traction is most suited for the underground and tube railways. Because of absence of smoke and spark there is not only greater safety in the drive but damage to buildings and apparatus by corrosive fumes is not caused.

2. High starting torque

Due to high starting torque developed it is possible to achieve high acceleration rates of 1.5 to 2.5 Kmphs as against 0.6 to 0.8 Kmphs in case of steam engine drive as a result of this we are able to achieve following

a) High schedule speed

Traffic handling capacity of electric traction is over double that of steam traction

b) Due to high Schedule speed and high traffic handling capacity less terminal space is required. This is an important factor in urban areas.

3. Cleanliness:

Owing to cleaner quicker and more comfortable passenger travel and increased transport of goods it leads to greater traffic density and greater industrialization

4. Power requirement:

Power requirement for railway electrification has been of the order of 50KW/track Km. This is sizeable load which tends to increase power development schemes. Traction load has high load factor of the order of 60 to 70%. Electric traction therefore provides a most important base load. This therefore enables the use of large generator units having high thermal efficiency possible in thermal stations. High base load also affords economic development of hydro electric potential

5. Rural electrification:

Railway electrification encourages rural electrification as no special transmission lines have to be run for this purpose

6. On account of release of wagons for the transport of coal for steam, locomotives greater availability of rolling stock is obtained with railway electrification

7. Flexibility of operation

Traction system operating in urban and sub-urban areas, experiences heavy rush in the morning and evening. At mid day the traffic is light. It is possible with motor coaches to run shorter trains.

8. Maintenance

Not only electric locomotive maintenance cost is about 50% of that of steam locomotive but it requires much less maintenance time also.

9. It has very low starting time.

10 Easy to control the speed, braking..

11. Saving in high grade coals.

b) Disadvantages

1. Most vital factor against electric traction is high capital outlay on overhead supply system.

2. Power failure for few minutes can cause dislocation of traffic for hours

3. Communication lines which also run along with power lines experience interference.

4. Traction is tied up to electrified routes only.

SYSTEM OF TRACK ELECTRIFICATION

3.4. METHODS OF SUPPLYING POWER

There are two methods of supplying power to electric train

1. Rail conductor system.

2. Over head line system.

1. Rail Conductor system

Early day's electric traction employed conductor rail system of supply of electric power to the traction units. This was founded on the difficulties experienced in maintaining contact wire in level. This system of supply has been used in many countries mainly for high density suburban traffic.

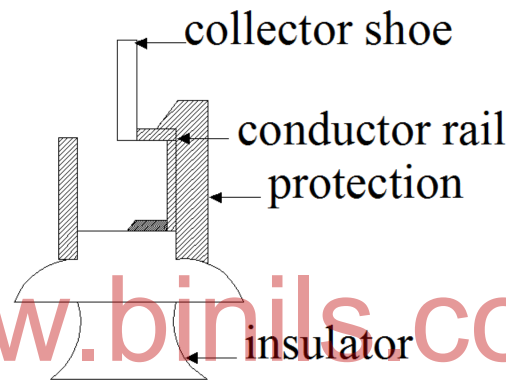


Fig 3.1**Conductor rail system**

In this system electric supply is collected from an insulated rail running parallel to the track at a distance of 0.3 to 0.4m from the running rails .However in underground system of traction in large cities insulated return rail is used to eliminate any electrolytic action due to return currents on other public services buried in the vicinity of the railway tunnels.

In majority of conductor rail systems, current collection is from the top surface of the rail but in certain systems current collection is from sides or underside of conductor. Fail latter systems are supposed to be more protective against accidental contact. Conductor rails are supposed to have low resistance and not as much hardness as track rails as such these are of low carbon .05% and low manganese .02% content. To reduce the voltage drop at joints conductor rails are bonded together by copper conductors riveted or welded to the rails. Current is collected by steel shoes necessary contact pressure being obtained by gravity in the case of top contact and by means of springs in case of side and under side contacts. At points and crossings there is bound to be discontinuity in the conductor rail. Two collection brushes prevent any interruption in the supply to the train. For this purpose conductor rail alternates between one side of the track and the other. This also events out the wear on the collector shoes. In certain situations due to complicated track work or due to safety reasons no conductor rails can be provided one such example is the level crossing with public roadways.

2. Overhead line system:

In overhead line conductor system the track rail is used as the return path of the current. The current from the overhead network is collected by using sliding contact collectors. There are two types of current collecting equipments

3.5. Overhead Equipment (OHE)

1. Catenary and droppers

The first and foremost function in electric traction is to keep the traction unit fed with the energy that it needs. For this purpose broadly speaking there are two systems of current collection namely from third rail and from overhead wire. Current collection from overhead wire is far superior to that from the third rail this is because both theoretically and experimentally current collection is more difficult from a rigid body than from an elastic one.

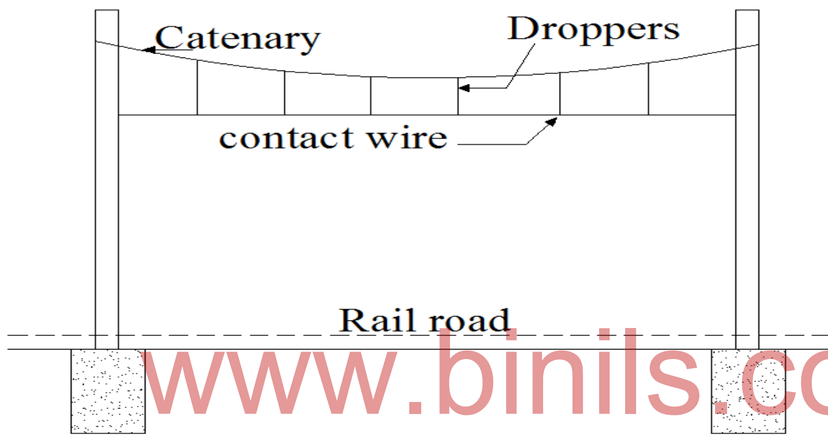


Fig 3.2.Catenary and droppers

The maximum distance between the two consecutive supports with this system is restricted to 30m.Because there is appreciable sag of wire between supports this limits the speed up to maximum of 30kmph.

The contact wire must be suspended with the minimum of sag so that it remains practically horizontal to have a contact with the collector. This is achieved by centenary and droppers. In this system the contact wire is suspended by the centenary wire by means of droppers. The droppers are fixed on contact wire and centenary wire at equal distances. The length of the span for the centenary wire on a single route varies with 45m to 90m. The distance between the droppers should be 3m to 5m. The sag in the catenaries' wire varies from 1m to 2m.this centenary wire provides a continuous contact with the conductor.

2. Current Collection Systems-Current Collection Gear for OHE

Main requirement of a collection gear is that it should, under no circumstances leave the contact of OHE. Contact wire in all practical installation is never perfectly horizontal. It rises and falls depending upon the weight of the contact wire and distance between droppers. Depending upon the speed of the electric vehicle collection gear has to rise and fall in order to main train the contact with OHE. The various types of current collection gears are Bow collector, Pantograph collectors, Pole collector, Cable collector…

a) Pole Collector

For tramways grooved gun metal wheel trolley collector of grooved slider shoe with carbon insert attached to the end of long pole provided on the top of the car is used. Collector is held in contact with the wire by means of spring the force of contact being 10kg.for wheel collector 17kg for carbon insert slider. The pole can swivel about its support so that it is not necessary for trolley wire to run exactly in the centre of the track. It is universally used for trolley buses to enable them to maneuver in traffic up to a distance of 4 to 5 meters from the contact wire. Trolley collector has to operate in trailing position. Main drawback of trolley collector is that it has to be rotated by 180°before tramcar can have motion in the reverse direction. Trolley collector is suitable for low speeds up to 22 to 30kmph beyond which it runs the risk of jumping off the contact wire. Another drawback particularly with trolley wheel pole collector is that there is poor contact between the wheel and trolley wire. This gives rise to high current density which results in heavy arcing. Its use is therefore prohibited in gassy mines where pole collector with grooved slider shoe is preferred.

b)Bow Collector

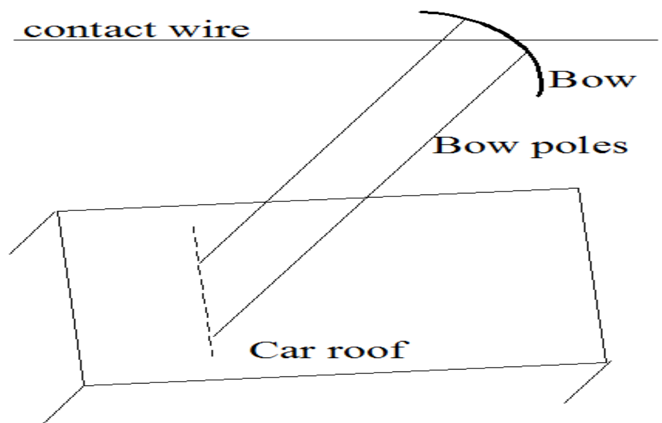


Fig 3.3.Bow Collector

Main advantage of bow collector is that it can be used for higher speeds. Bow collector consists of two trolley collector poles at the end of which is placed a light metal strip up to one meter long for current collection. Although provision of metal strip enables the contact of trolley wire its maneuverability is lost. It is as such not suitable for trolley buses. On tramway services trolley wire is hung at the center line of the track with about 15cm.stagger to hive uniform wear of the strips and prevent formation of groove on it. Collection strip is of soft material such as copper aluminum or carbon so that it should wear instead of trolley wire as it is easy to replace wrong out collection strip than trolley wire. Bow collector has always to run trailing just like trolley collector. It therefore requires either provision of duplicate bows or an arrangement of reversing the bows for motion in the reverse direction.

Disadvantages:

- Poor current collecting capacity
- Irreversible operation is not possible

c) Pantograph collector:

The disadvantages of bow collectors are overcome by this type of collectors. Pantograph collectors always maintain the link between the overhead lines.

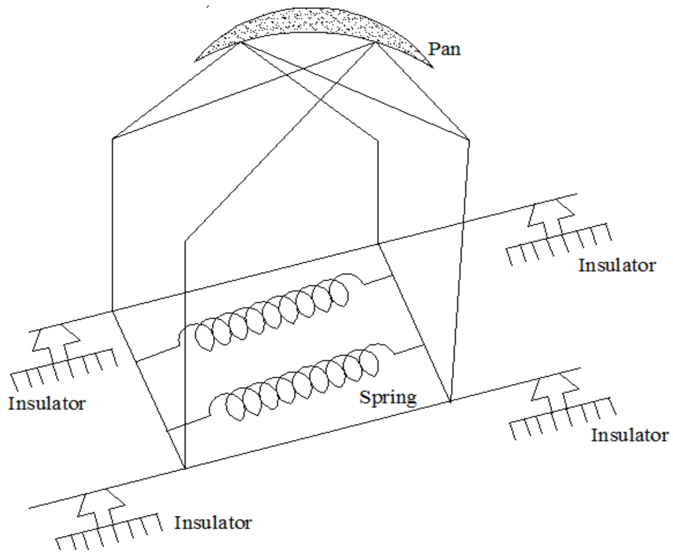


Fig 3.4. Pantograph collector:

Its function is to maintain link between overhead contact wire and power circuit of the electric locomotive at different speeds under all wind conditions and stiffness of OHE. It means that positive pressure has to be maintained at all times to avoid loss of contact and sparking but the pressure must be as low as possible in order to minimize wear of OH contact wire.

A 'diamond' type single-pan pantograph is shown in Fig. It consists of a pentagonal framework of high-tensile alloy-steel tubing. It has a copper strip which acts as contact surface. The contact portion consists of a pressed steel pan fitted with renewable copper wearing strips which are forced against the OH contact wire by the upward action of pantograph springs. The pantograph can be raised or lowered from cabin by air cylinders. It is used in the vehicles run at high speeds and current to be collected is 2000 to 3000 A.

Advantages:

1. It can operate in either direction of motion.

2. Risk of jumping off the collector is minimum

3. Erection of overhead network is simple.

4. Its height can be increased or decreased by simple operations from the drivers' cabin.

3.6. Systems of Railway Electrification

Presently, following four types of track electrification systems are available:

1. Direct current system—600 V, 750 V, 1500 V, 3000 V

2. Single-phase ac system—15-25 kV, 16 $^{2/}{}_{3}$, 25 and 50 Hz

3. Three-phase ac system—3000-3500 V at 16 $^{2/3}$ Hz

4. Composite system—involving conversion of single-phase ac into 3-phase ac or dc.

1. Single-Phase Low-frequency 25 Hz AC System

In this system, ac voltages from 11 to 15 kV at 16 $^{2/}{}_{3}$ or 25 Hz are used. If supply is from a generating station exclusively meant for the traction system, there is no difficulty in getting the electric supply of 16 $^{2/}{}_{3}$

or 25 Hz. If, however, electric supply is taken from the high voltage transmission lines at 50 Hz, then in addition to step-down transformer, the substation is provided with a frequency converter. The frequency converter equipment consists of a 3-phase synchronous motor which drives a 1-phase alternator having or 25 Hz frequency.‾

The 15 kV 16 $^{2}/_{3}$ or 25 Hz supply is fed to the electric locomotors via a single over-head wire (running rail providing the return path).

A step-down transformer carried by the locomotive reduces the 15-kV voltage to 300-400 V for feeding the ac series motors. Speed regulation of ac series motors is achieved by applying variable voltage from the tapped secondary of the above transformer.

Low-frequency ac supply is used because apart from improving the commutation properties of ac motors, it increases their efficiency and power factor. Moreover, at low frequency, line reactance is less so that line impedance drop and hence line voltage drop is reduced. Because of this reduced line drop, it is feasible to space the substations 50 to 80 km apart. Another advantage of employing low frequency is that it reduces telephonic interference

2. Advantages of 25-kV, 50-Hz AC System

Advantages of this system of track electrification over other systems particularly the dc systems are as under:

a) Light Overhead Catenary

Since voltage is high (25 kV), line current for a given traction demand is less. Hence, cross-section of the overhead conductors is reduced. Since these small-sized conductors are light, supporting structures and foundations are also light and simple. Of course, high voltage needs higher insulation which increases the cost of overhead equipment (OHE) but the reduction in the size of conductors has an overriding effect.

b) Less Number of Substations

Since in the 25-kV system, line current is less, line voltage drop which is mainly due to the resistance of the line is correspondingly less. It improves the voltage regulation of the line which fact makes larger spacing of 50-80 km between sub-stations possible as against 5-15 km with 1500 V dc system and 15-30 km with 3000 V dc system. Since the required number of substations along the track is considerably reduced, it leads to substantial saving in the capital expenditure on track electrification.

c) Flexibility in the Location of Substations

Larger spacing of substations leads to greater flexibility in the selection of site for their proper location. These substations can be located near the national high-voltage grid which, in our country, fortunately runs close to the main railway routes. The substations are fed from this grid thereby saving the railway administration lot of expenditure for erecting special transmission lines for their substations. On the other hand, in view of closer spacing of dc substations and their far away location, railway administration has to erect its own transmission lines for taking feed from the national grid to the substations which consequently increases the initial cost of electrification.

d) Simplicity of Substation Design

In ac systems, the substations are simple in design and layout because they do not have to install and maintain rotary converters or rectifiers as in dc systems. They only consist of static transformers along with their associated switchgear and take their power directly from the high-voltage national grid running over the length and breadth of our country. Since such sub-stations are remotely con-trolled, they have few attending personnel or even may be unattended.

e) Lower Cost of Fixed Installations

The cost of fixed installations is much less for 25 kV ac systems as compared to dc system. In fact, cost is in ascending order for 25 kV ac, 3000 V dc and 1500 V dc systems. Consequently, traffic densities for which these systems are economical are also in the ascending order.

f) Higher Coefficient of Adhesion

The straight dc locomotive has a coefficient of adhesion of about 27% whereas its value for ac rectifier locomotive is nearly 45%. For this reason, a lighter ac locomotive can haul the same load as a heavier straight dc locomotive. Consequently, ac locomotives are capable of achieving higher speeds in coping with heavier traffic.

g) Higher Starting Efficiency

An ac locomotive has higher starting efficiency than a straight dc locomotive. In dc locomotive supply voltage at starting is reduced by means of ohmic resistors but by on-load primary or secondary tap-changer in ac locomotives.

3. Disadvantages of 25-kV AC System

1. Single-phase ac system produces both current and voltage unbalancing effect on the supply.

2. It produces interference in telecommunication circuits. Fortunately, it is possible at least to minimize both these undesirable effects.

3.7. Block Diagram of an AC Locomotive

The various components of an ac locomotive running on single-phase 25-kV, 50-Hz ac supply are numbered in Fig.

1. OH contact wire
2. pantograph
3. Circuit breakers
4. on-load tap-changers
5. transformer
6. rectifier
7. smoothing choke
8. Dc traction motors.

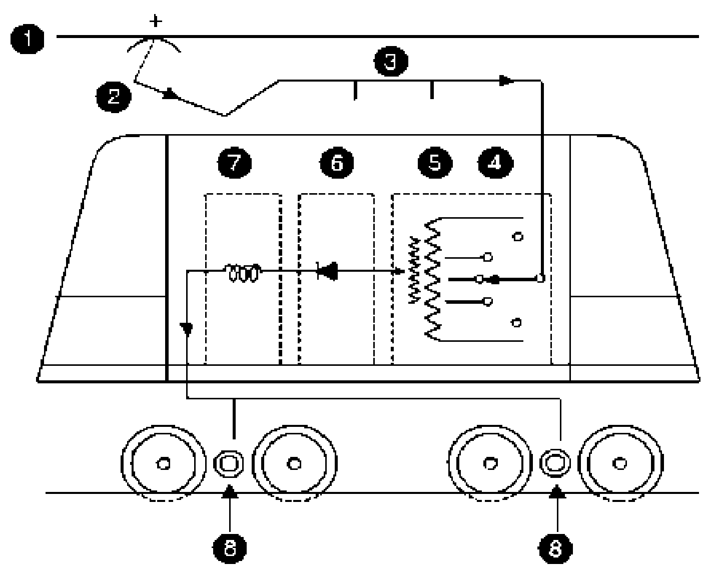


Fig 3.5.Block Diagram of an AC Locomotive

As seen, power at 25 kV is taken via a pantograph from the overhead contact wire and fed to the step-down transformer in the loco-motive. The low ac voltage so obtained is converted into pulsating dc voltage by means of the rectifier. The pulsations in the dc voltage are then removed by the smoothing choke be-fore it is fed to dc series traction motors which are mounted between the wheels.

Electric locomotive as collects current from over head equipment OHE through sliding contact with it by means of pantograph air circuit breaker is provided on the roof of the locomotive and its main function is to disconnect the locomotive from high voltage supply, by means of on load tap changer we can vary the output voltage supply, by means of on load tap changer we can vary the output voltage for speed control of traction motors by means of transformer high voltage of OHE is reduced to the utilization level by means of rectifier as is rectified to dc smoothing choke reduces the magnitude of the undesirable effects on the proper working of traction motor such as commutation and heating.

The function of circuit breakers is to immediately disconnect the locomotive from the overhead supply in case of any fault in its electrical system. The on-load tap-changer is used to change the voltage across the motors and hence regulate their speed.

a) Feeding post

Layout of feeding post is shown in normally there are two feeders running in between substation and feeding posts. Each feeder has two conductors. One insulated for 25KV for connection to the bus bar and the other for 3KV for connection to the track for return current. Cross section of the conductors is 20sq mm of copper or 400 sq.mm of ACSR. These feeders are connected to two sets of bus bars of feeding post through two oil circuit breakers. These two sets of bus bars are connected together through bus couplers which along with input circuit breakers enable OHE to be fed even if one of the feeders is out of action for maintenance purpose or due to fault. Feeding posts are located as close to the substation as possible maximum distance being 2 km. usually 25KV circuit breakers of feeding post are controlled from a remote control center of the railway. Interlocked double pole isolating switches are provided on both sides of every circuit breaker to enable its complete isolation and to ensure full safety for maintenance staff. In the case of two track lines there are four interrupters two for each feeder and supplying two tracks on one side of feeding post only. Interrupters are single pole low oil content outdoor type oil switches meant to connect different sections of OHE to feeding post. Interrupter is supposed to close or open for normal load conditions only. Since it is not equipped with any protective relays to trip it automatically in the event of fault as in the case of circuit breaker it is not meant for automatic braking of fault currents. Interrupters are normally arranged for remote control operation but they have provision for manual operation if required

b) Feeding and Sectioning Arrangements

Power generation and transmission system of supply authorities are of 3 phase type. Electric traction on the other hand needs single phase supply. If all the traction load is put on one phase only. It would bring about unbalanced conditions. This besides causing inconvenience to other consumers due to phase shift is very harmful to the alternator as it produces lot of rotor heating due to double frequency currents induced in the rotor by rotating magnetic field produced by negative phase sequence currents. As such unbalanced conditions beyond certain limit are not permitted to exist. Effort is therefore made to supply power to the consecutive substation from difference phases in rotation. Zones fed by adjacent substations will therefore be across different phases each acting as a separate independent unit and never working in parallel This is quite contrary to the dc system where all the substations feed OHE in parallel. In order therefore to separate the two sections of OHE fed from two adjacent substations .The purpose of providing neutral section is to separate the zones fed by two adjacent substations so that it is not possible for a pantograph of electric train to bridge two different live phases of 25kv supply while passing from the zone fed from preceding substations to the zone fed by next substation. Since neutral section is dead it becomes necessary for the driver of an electric train to switch off power before approaching neutral section and coast through it to the other zone. For these warning boards are provided to draw the attention of driver.

3.8. Booster transformer – Necessity

In a.c. traction system, return current which flows from the locomotive to the track soon leaks to the ground with in short distance and returns to the substation through its earth.

These ground current causes heavy interference with the communication lines. His current can be minimized by using booster transformers. It consists of two windings of1: 1 ratio. The primary winding is connected in series with contact wire. Any amount of current flowing through primary requires to be balanced by equal current in secondary and so the tendency of current flowing through stray path is reduced. There are two methods of connecting booster transformer.

1. Rail connected booster transformer.

2. Booster transformer with return feeder.

1. Rail connected booster transformer.

As in fig primary is connected in series with the contact line and secondary in series with rails. Induced voltage in the secondary constraints the return current to flow through rails. This method of connecting booster transformer has the following drawbacks.

1. Need insulated rail joint with small neutral sectioning.

2. Insulation puncture between rails of insulated joins may cause short circuiting the secondary and make the booster transformer ineffective.

3. Voltage rises of 200v between rails and 100v between rail and earth may cause danger.

4. Requires close spacing of booster transformer.

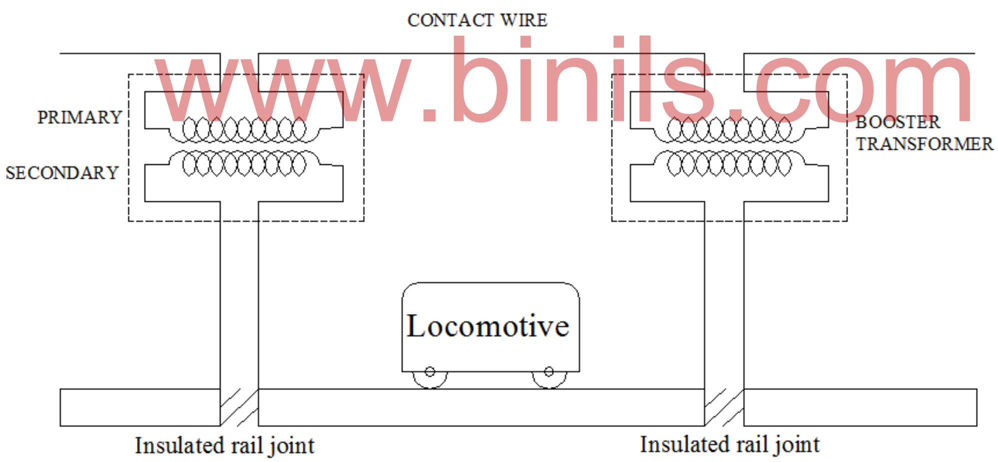


Fig 3.6. Rail connected booster transformer.

2. Booster transformer with return feeder

This method is more effective than others. Fig shows the connection of booster transformer with return feeder. In this system rails are connected midway between booster transformers. The return current now flows through the return feeder back to substation. Running the return feeder very close to the contact wire reduces the tendency of magnetic coupling between power line and telecommunication line. The turns of the booster transformer should be 1:1 so as to enables the secondary to suck out the current from rails equal in magnitude to that flows in primary

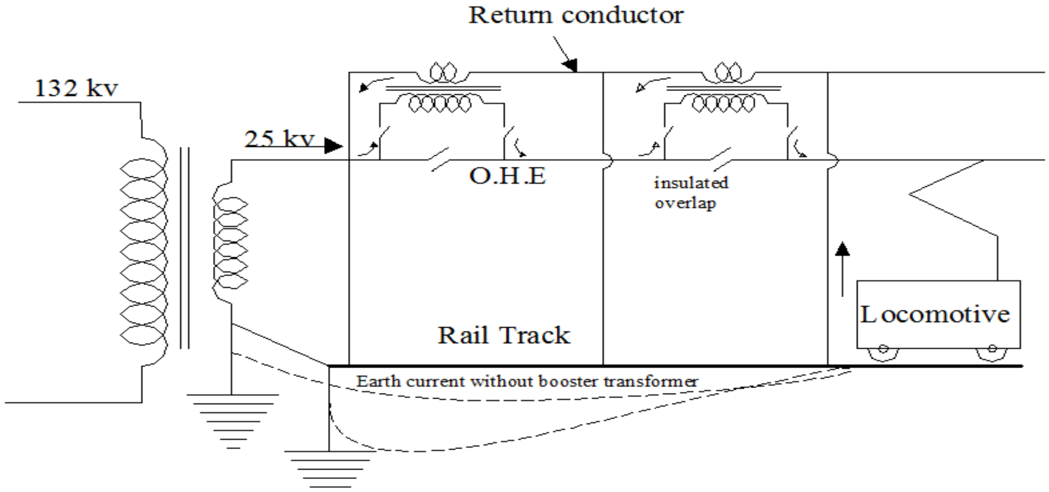


Fig 3.7.Booster transformer with return feeder

3.9. Neutral sectioning

Power generation and transmission systems of supply are three phase system. For traction it needs single phase system. If all he traction loads are put on one phase alone, it will causes unbalancing in three phase system. For this the adjacent substations tap different phases of three phases in order to achieve even loading of the lines. For that it must have boundary of supply between two substations which have insulated over lap. Therefore Momentary passing of pantograph under insulated overlap will cause short circuit between two phases, thereby damaging the OHE equipments. In order to prevent bridging of two different phases a small insulation called neutral section is provided. It is insulated from both sides and is not connected to any source of supply. Its main function is to permit physically smooth and electrically sparkless passage of pantograph from one section to and the other. Neutral sections are indicated in displays for the drivers of an electric train to switch off before approaching neutral section and coast it to other zone. For these warning boards are placed to draw the attention of the driver.

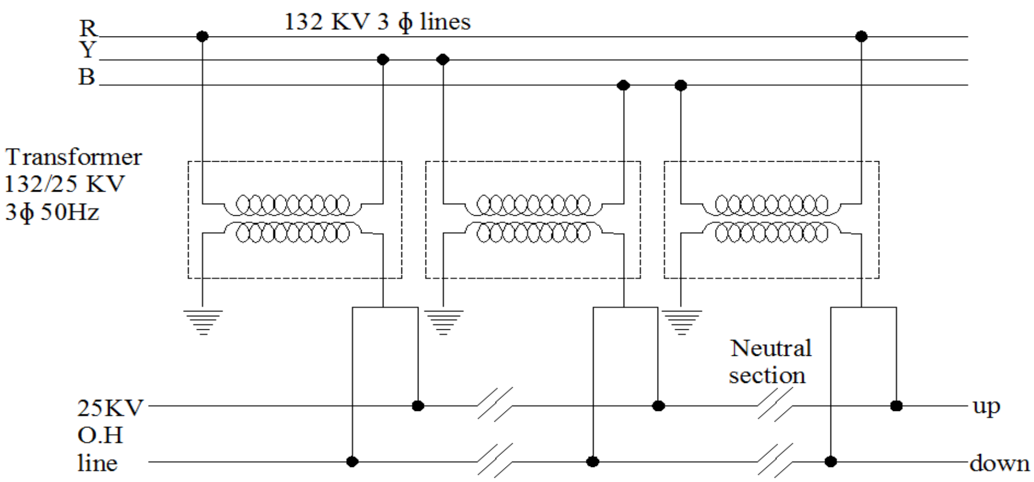


Fig 3.8.Neutral sectioning

3.10Traction Mechanics

2.1) Units and notations

In describing various quantities involved in the mechanics of train movement, only the latest SI system will be used. Since SI system is an ‘absolute system’, only absolute units will be used while gravitational units (used hitherto) will be discarded.

1. Mass: Its unit is kilogram (kg). Commonly used bigger units is tone (t),

Where 1 ton=1000 kg

2. Force: It is measured in Newton (N)

3. Work: Its unit is the same as that of energy.

4. Power: Its unit is watt (W) which equals 1 J/s. also Kilowatt (kW)

5. Distance: Its unit is meter. Other unit often used is kilometer (km).

6. Velocity: Its absolute unit is meter per second (m/s).

7. Acceleration: Its unit is meter/second^2 (m/s^2). Acceleration is given in km/h/s

3.10.1. Types of Railway Services

There are three types of passenger services which traction system has to cater for namely Urban Sub-urban and Main line services. In urban and sub-urban service the distance between the stops are small. On main line service distance between stations is long

1. **City or Urban Service.** In this case, there are frequent stops, the distance between stops being nearly 1 km or less. Hence, high acceleration and retardation are essential to achieve moderately high schedule speed between the stations.
2. **Suburban Service.** In this case, the distance between stops averages from 3 to 5 km over a distance of 25 to 30 km from the city terminus. Here, also, high rates of acceleration and retardation are necessary.
3. **Main Line Service.** It involves operation over long routes where stops are infrequent. Here, operating speed is high and accelerating and braking periods are relatively unimportant.

On goods traffic side also, there are three types of services ***(i)*** main-line freight service ***(ii)*** local or pick-up freight service and ***(iii)*** shunting service

3.10.2. Speed Time Curve

It is the curve showing instantaneous speed of train in kilometers per hour along ordinate and time in seconds along abscissa. Area in between the curve and abscissa gives the distance travelled during given time interval. Slope at any point on the curve towards abscissa gives the acceleration of retardation at that instant.

a) Typical Speed/Time Curve

Typical speed/time curve for electric trains operating on passenger services is shown in Fig. It may be divided into the following **five** parts:

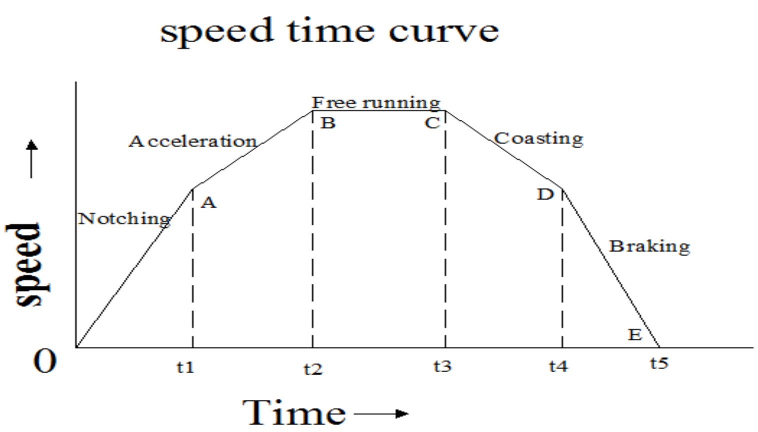


Fig 3.9.speed time curve

1. Constant Acceleration Period (0 to t_1) Notching up period

It is also called notching-up or starting period because during this period, starting resistance of the motors is gradually cut out so that the motor current (and hence, attractive effort) is maintained nearly constant which produces constant acceleration alternatively called 'rheostat acceleration' or 'acceleration while notching'. To cut the starting resistance handle has to be moved from one notch and hence the name given to this period. Attractive effort is defined as the force in newtons exerted by driving wheel on the rail to produce movement. Sum of the attractive efforts exerted by all the driving wheels of a locomotive is called gross attractive effort which is proportional to the combined torque exerted by the motors.

Motor current during notching up period fluctuates between certain maximum and minimum limits. Therefore torque developed by the motor and attractive effort also fluctuates. Speed time curve therefore is a straight line. Dotted speed time curve is obtained in case of series parallel starting

2. Acceleration on Speed Curve (t_1 to t_2)

This acceleration commences after the starting resistance has been all cut-out at point t_1 and full supply voltage has been applied to the motors. During this period, the motor current and torque de-crease as train speed increases. Hence, acceleration gradually ***decreases*** till torque developed by motors exactly balances that due to resistance to the train motion. When all the starting resistance has been cut out attractive effort exerted by the motor is more than the train resistance. As speed increases train resistance increases very much. This reduces the net attractive effort available for giving acceleration.

The speed of the train will continue to increase to a speed at which attractive effort is equal to the train resistance. Train will then continue to run at this maximum speed.

3. Free running period (t_2 to t_3) period

During this period train runs at constant speed attained at the end of speed curve running. During this period ie, **(t_2 to t_3)** the power supplied to the motor is full voltage and power drawn from the supply is also constant.

4. Coasting (t_3 to t_4) period

Power to the motors is cut off at point t_3 so that the train runs under its momentum, the speed gradually falling due to friction, windage etc. (portion *CD*). During this period, retardation remains practically constant. Coasting is desirable because it utilizes some of the kinetic energy of the train which would, otherwise, be wasted during braking. Hence, it helps to reduce the energy consumption of the train. At the end of free running period supply to motors is cut off and train is allowed to run under its own momentum. Due to train resistance speed of the train gradually decreases.

5. Braking (t_4 to t_5) or retardation period

At point t_4, brakes are applied and the train is brought to rest at point t_5.It may be noted that coasting and braking are governed by train resistance and allowable retardation respectively. At the end of coasting period brakes are applied to bring the train to stop.

3.4.Speed/Time Curves for Different Services

Fig. 3.10(a) is representative of city service where relative values of acceleration and retardation are high in order to achieve moderately high average speed between stops. Due to short distances between stops, there is no possibility of free-running period though a short coasting period is included to save on energy consumption.

In suburban services [Fig. (b)], again there is no free-running period but there is comparatively longer coasting period because of longer distances between stops. In this case also, relatively high values of acceleration and retardation are required in order to make the service as attractive as possible.

For main-line service [Fig. (c)], there are long periods of free-running at high speeds. The accelerating and retardation periods are relatively unimportant.

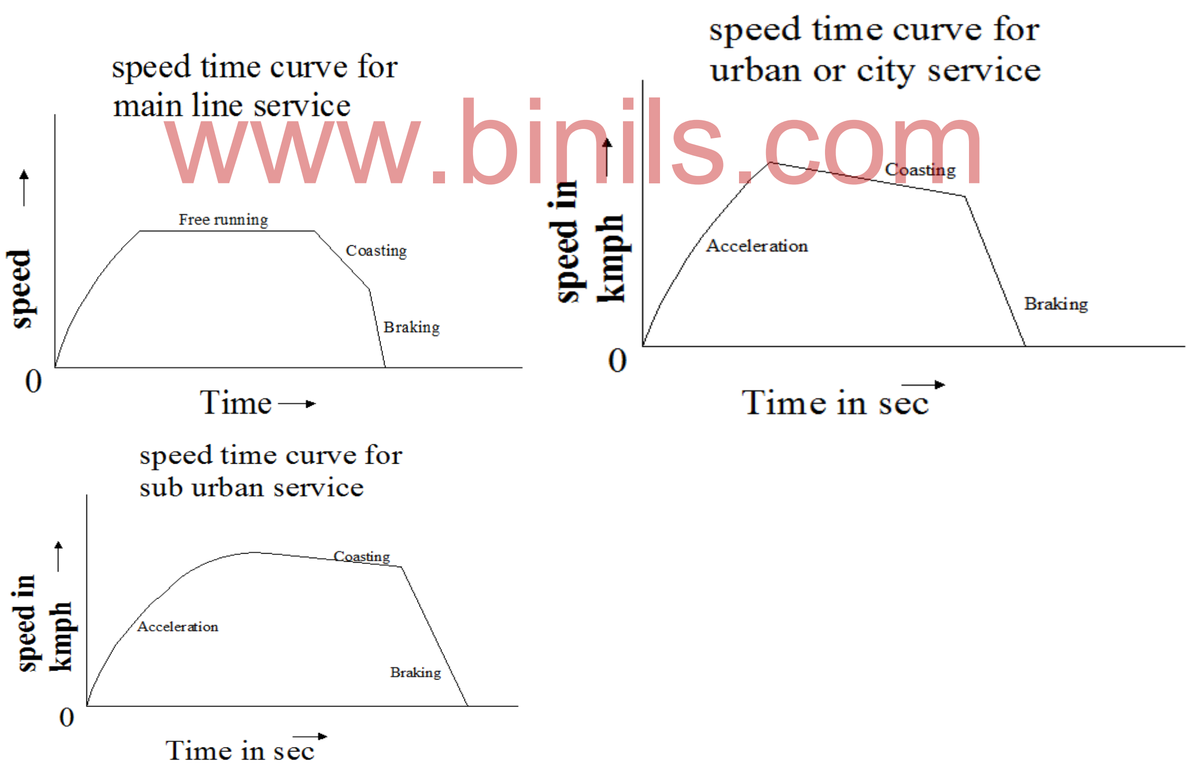


Fig 3.10.speed time curve for a) main line b) urban c) suburban.

3.11. Simplified Speed time curve

In order to make actual speed time diagram amenable to calculation simplified speed time curves are taken in such a way as to cause least error and at the same time calculations are made easy. OABC is the actual speed time curve. The basis of constructing simplified speed time curves to keep both acceleration and retardation values same and area under actual and simplifier curves also same. In case of simplified trapezoidal speed time curve OABC speed curve running and coasting periods are replaced by constant speed period. On the other hand in case of simplified quadrilateral speed time curve OABC speed curve running and coasting periods are extended. Trapezoidal speed time curve gives closer periods are extended. Trapezoidal speed-time curve gives closer approximation of the conditions of main line service where long distance involved and quadrilateral speed time curve for urban and suburban service.

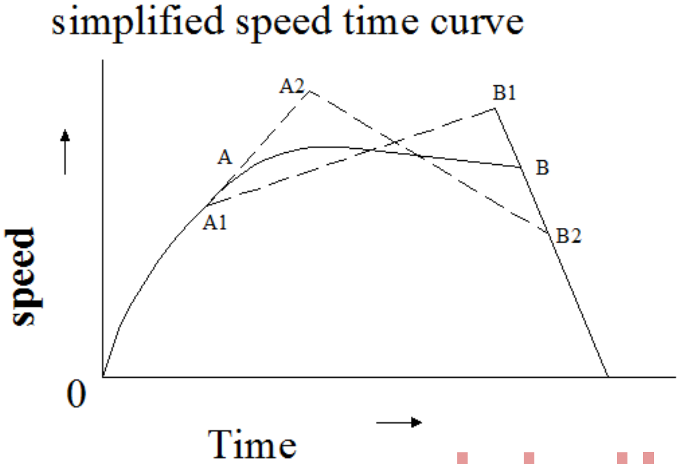


Fig 3.11.Simplified Speed time curve

(i) Trapezoidal shape OA_1B_1C of Fig. where speed-curve running and coasting periods of the actual speed/time curve have been replaced by a constant-speed period.

(ii) Quadrilateral shape OA_2B_2C where the same two periods are replaced by the extensions of initial constant acceleration and coasting periods.

It is found that trapezoidal diagram OA1B1C gives simpler relationships between the principal quantities involved in train movement and also gives closer approximation of actual energy consumed during main-line service on level track. On the other hand, quadrilateral diagram approximates more closely to the actual conditions in city and suburban services.

a) Derivation of maximum speed from trapezoidal speed- time curve

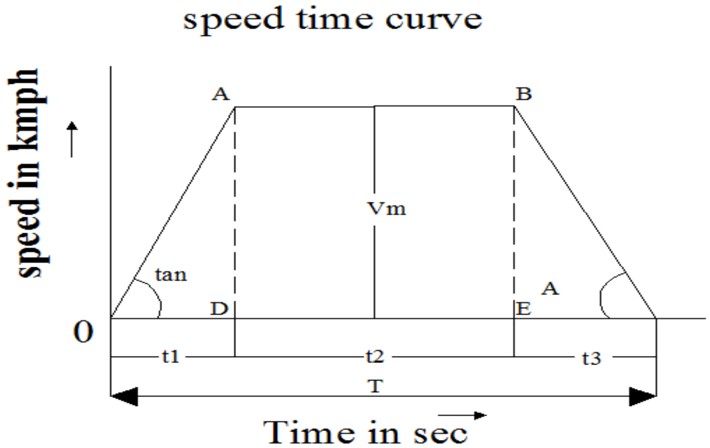


Fig 3.12.trapezoidal speed- time curve

Considering the trapezoidal speed time curve in fig:

Let S= Distance between stops in km.

T= Actual time of run between stops in sec.

α = Acceleration in km per hour per sec. (kmphps)

β = Retardation in km per hour per sec.

V_m=Maximum speed in km per hour.

t_1=Time for acceleration in sec = V_m/α

t_3=Time for retardation in sec = V_m/β

t_2= Time for free running in sec= T- (t_1+t_3) = T – $(V_m/\alpha + V_m/\beta)$

the area of the trapezoidal gives the total distance of run in km.

Total distance = Area of trapezoid OABC

S = Area of triangle OAD + Area of rectangle ABED + Area of triangle BCE

$$=\frac{1}{2} + \frac{t1}{3600}V_m + \frac{t2}{3600}V_m + = \frac{1}{2}\frac{t3}{3600}V_m$$

$$= \frac{Vm}{3600}[\frac{1}{2}t_1 + t_2 + \frac{1}{2}t_3]$$

$$= \frac{Vm}{3600}[\frac{1}{2}(t_1 + t_3) + t_2]$$

$$= \frac{Vm}{3600}[\frac{1}{2}(t_1 + t_3) + T - (t_1 + t_3)]$$

$$= \frac{Vm}{3600}[(t_1 + t_3)(\frac{1}{2} - 1) + T]$$

$$= \frac{Vm}{3600}[T - \frac{1}{2}(t_1 + t_3)]$$

$$= \frac{Vm}{3600}[T - \frac{1}{2}(\frac{Vm}{\alpha} + \frac{Vm}{\beta})]$$

$$S = \frac{Vm}{3600}[T - \frac{1}{2}V_m(\frac{1}{\alpha} + \frac{1}{\beta})]$$

$$3600\ S = TV_m - \frac{1}{2}V_m^2(\frac{1}{\alpha} + \frac{1}{\beta})$$

$$\frac{1}{2}(\frac{1}{\alpha} + \frac{1}{\beta})V_m^2 - TV_m + 3600\ S = 0$$

This is a quadratic equation

Put $\frac{1}{2}\left(\frac{1}{\alpha}+\frac{1}{\beta}\right) = K$

Then the equation becomes

$$KV_m^2 - T\,V_m + 3600\,S = 0$$

Solving the equation , we get

$$Vm = \frac{T \pm \sqrt{T^2 - 4K \times 3600S}}{2K}$$

The positive sign gives very much high value of Vm which is not possible in practice, hence negative sign is adopted.

Therefore

$$Vm = \frac{T - \sqrt{T^2 - 4K \times 3600S}}{2K}$$

Average speed and schedule speed

While considering train movement, the following three speeds are of importance :

1. Crest Speed=It is the maximum speed (V_m) attained by a train during the run

2. Average speed = $\frac{\text{Distance between the stops}}{\text{Actual time of run}}$

3. Schedule speed = $\frac{\text{Distance between the stops}}{\text{Actual time of run+stop time}}$

3.12. Factor affecting schedule speed

Following are the factors which affect the schedule speed of a train engaged in a given service.

(i)Value of α and β (ii) Duration of stop

3.13. Tractive Effort.

Tractive effort is the force developed by the traction unit at the wheel rims for moving the traction unit and its train. Thus the tractive effort by the force required to move the traction unit. Tractive effort exerted by the traction unit has to perform the following functions

- To give necessary linear and angular acceleration to the train mass
- To overcome the gravity component of the weight of the train
- To overcome the wind and frictional resistance of the train
- To overcome curve resistance

1. Tractive effort for acceleration:

Force is required to give linear acceleration to the train and is given by (F_a)

Let M is the dead mass or stationary mass of the train in tones.

Dead mass of train = M tones

Since 1 tonne =1000kg

Acceleration = α km/hr/sec^2

(F_a) = $\frac{\alpha \times 1000}{3600}$ **= 277.8 W**α Newtons or m/sec^2

When the speed of the train is being changed it behaves as a mass greater than its dead weight. This is due to angular speed variation of its rotating parts. If linear acceleration is f meter/sec^2 angular acceleration of rotating parts having radius of gyration r meters' will be f/r radians/sec^2.

Generally the effective mass is 10% more than the dead mass.

ie, M_e=1.1 M

Let the effective mass of the rain =M_e ton =1000$M_e$kg

Therefore Force required for acceleration = Mass x acceleration

ie, F_a= M_e x a

=1000 M_e x α 1000/3600

F_a **= 277.8. M_e α newtons.**

2. Tractive effort to overcome the train resistance:

Train resistance consists of all the forces which oppose the motion of the train on level track. This force can be classified as those forces which are internal to the rolling stock such as friction at journals axis guides bogie pivots buffers and those forces which are external to the rolling stock such as friction between wheels and rails. Track resistance depends upon the strength of the track and nature of the ballets. Wind resistance due to the length of train is due to air friction on sides and to underside of the train. This is sometimes termed as skin friction.

Therefore tractive effort to overcome the train resistance

F_r =M x r Newton's

Where M = mass of train in tones

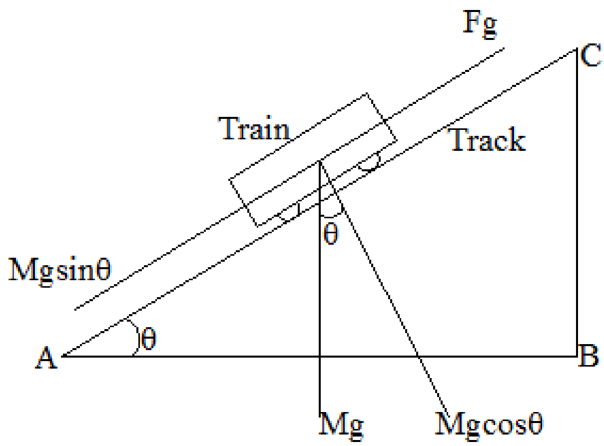
r = train resistance in newtons/tone

Now if I is the moment of insert of rotating masses and F the force in newtons applied at the rim the wheel then torque applied (F,r)will be given by

Magnitude of force as per equation will be in addition to the forced required to give linear acceleration and equivalent additional mass of rotating masses of rotating masses is $I/r^2 Km$.This additional mass is best expressed as a percentage of the dead weight of train the value of effective weight of the train We which takes in to account not only motion of translation of train but also the motion of rotation of wheels axis armatures of motors and gears Equation now becomes

3. Tractive effort required to balance the gravitational pull (F_g)

When train is on an up-gradient gravity component of dead weight of train parallel to the track will be responsible for the train to come down In order to prevent this tractive effort has to be applied in upwards direction whose magnitude is give by



F_g= Mg sinθ tonne m/sec^2

= 1000 Mg sinθ kg m/sec^{2}ie,(1 tonne=1000kg)

=1000Mg sinθ Newton

Where g is the acceleration due to gravity

= 9.81 m/sec^2

θ is the angle of scope

F_g =1000Mx9.81 sinθ Newton--------------(1)

In railway practice gradient is expressed in terms of rise or fall in a track distance of 1000 meters and is denoted by letter G% Location of gradient has important effort on the over loading that can be permitted on the traction motors. For instance if does not create any problem as momentum of the train takes it up the steep gradient. On the other hand if ruling gradient happens to be in the middle of a rising gradient the length of gradient becomes very important in determining the temperature

Gradient $G = \frac{BC}{\left(\frac{AC}{100}\right)} = \frac{BC}{AC} \times 100$

G = 100 Sin θ

Sin θ = G/ 100---------------------(2)

Putting the value of **Sin** θ in equation (1)

$$F_g = 1000M \times 9.81 \times \frac{G}{100} \text{ Newton}$$

$$F_g = \pm 98.1MG \text{ Newton}$$

Positive sign is to be used for up gradation and negative sign for down gradient

Therefore, total tractive effort $F_t = F_a + F_r + F_g$

$$= 277.8.\ M_e\alpha + Mr + \pm 98.1MG$$

3.9. Power required:

a)Power P= Rate of work $= \frac{FORCE\ X\ DISTANCE}{TIME}$

$$= \frac{TRACTIVE\ EFFORT\ X\ DISTANCE}{TIME}$$

=tractive effort x speed =F_t x V

Where V is in km/hr = $\frac{1000}{3600}$ m/sec

Therefore P = $F_t \times \frac{1000}{3600}$ **N-m/sec or watts.**

b) Specific Energy output

It is the energy given in watt hours per ton of train. The energy output of driving wheels. When this is divided by mass of transmission gear and distance, we will get specific energy output.

Specific energy output$= \frac{\text{total energy output at driving wheels (E)}}{\text{mass of train in tonne (M) x distance of run in km (S)}}$

$$= \frac{Ea+Er+Eg}{MxS}$$

Where are

E =Ea+Er+Eg

E = Total energy output of driving axis

Ea = Energy output of driving axis to acceleration the train

Er = Energy output of driving axis to overcome friction

Eg = Energy output of driving axis to overcome gradient

c) Specific Energy Consumption

It is the energy consumed in watt hours per ton of train. The specific energy output of driving wheels, when this is divided by overall efficiency of transmission gear and motor we will get specific energy consumption

$$\textbf{Specific energy consumption} == \frac{\text{Specific energy output at driving wheels}}{\text{Overall efficiency of transmission gear and motor}}$$

d) Factors Affective Specific energy Consumption:

The factors affecting specific energy consumption as follows

a. Distance between stops
b. Acceleration and retardation
c. Gradient
d. Train resistance
e. Type of train equipment

3.14. TRACTION MOTOR AND CONTROL:

a) Desirable characteristics of traction motors

i) Electrical characteristics

1. The motor should have high starting torque

2. The speed of the motor should fall with the increases in load.

3. Speed control of the motor should be simple.

4. It should be possible to employ dynamic or regenerative braking.

5. The motor must able to withstand sudden voltage fluctuations

6. The motor should have high efficiency.

7. The motor should be suitable for series parallel control.

ii) Mechanical characteristics

1. A traction motor must be robust and capable to withstand continuous vibrations.

2. The motor must be small in over all dimensions.

3. The motor should have minimum possible weight.

4. The motor should be totally enclosed type to provide protection against different types of weather and dirt, dust, water, mud…

b) Motors used for traction purpose.

The following motors are used for traction purposes:

1. D.C. Series motor

2. A.C.Series motor

3. Repulsion motors.

4. Three phase induction motor.

5. Linear induction motor.

3.15. Control of DC Traction motors

The magnitude of the current taken by a dc motor is given by equation

$$I = \frac{V - EB}{R}$$

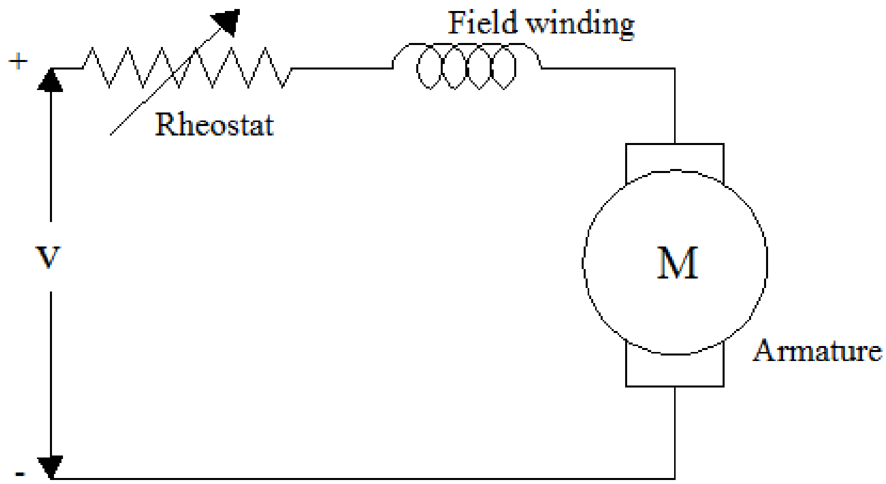
At starting the magnitude of the back emf Eb is zero obviously if the motor is switched on directly to the supply it will take very heavy current because the motor resistance is very small Excessive current would cause serve mechanical damage to the equipment and therefore its magnitude has to be restricted by adopting suitable measures. This is achieved by either applying reduced voltage to the motor or by artificially increasing the resistance in the motor circuit. In ac traction practice it is usually the first method which is adopted.

It is normal practice except in the case of small train car controllers to design the resistance as capable of carting only starting currents and is not in a position to carry motor currents continuously. The motor can therefore have only one speed characteristic besides this disadvantage considerable amount of energy is wasted in the starting resistances. Both of these disadvantages are overcome in series parallel and buck and boost control of traction motors described hereafter

3.16.Methods of starting D.C. traction motors

1. Plain Rheostatic starting
2. Series – parallel starting
3. Metadyne control

1. Plain Rheostatic starting (3.13)



In this method, the voltage across the motor armature is increased gradually from zero o full voltage. This is obtained by connecting an external series resistance as shown in fig. This external resistance helps to limit the starting current and suitable of the DC motors.

When the supply is switched ON, the back emf is zero. As the motor accelerates and speed increases, motor current will go on reducing with the development of back emf in the motor armature. When certain values of minimum motor current are reached, a portion of external resistance is cut out. As a result of this motor current again reaches its maximum value.

Energy saving with rheostatic starting

Let, I= current
V= supply voltage
T = starting period in sec.

Energy last in external resistance= Average voltage drop at external resistance x current x time

$= \frac{V+0}{2} \times I \times T$

$= \frac{VIT}{2}$ watt-sec

Energy utilized by the motor = average voltage drop across motor x time

$= \frac{0+V}{2} \times I \times T$

$= \frac{VIT}{2}$ watt-sec

Therefore energy drawn from drum supply= energy lost in resistance +energy utilized in motor

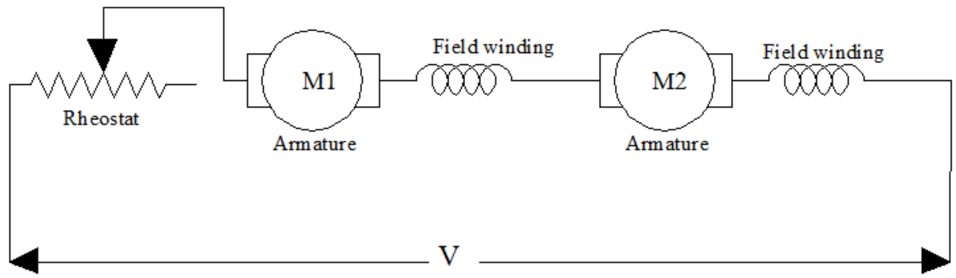
$$= \frac{VIT}{2} + \frac{VIT}{2} = VIT \text{ watt-sec}$$

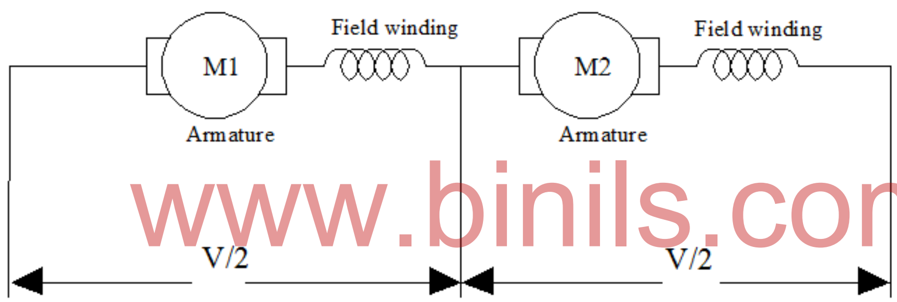
Total energy input = VIT watt-sec

Starting efficiency = $\frac{energy utilised}{energy input}$ x 100%

Starting efficiency =$\frac{VIT/2}{2}$ $x100$ =50%

2. Series Parallel Control (fig 3.14)

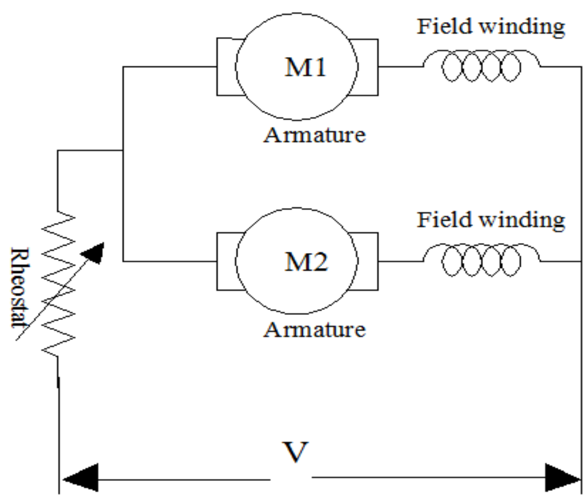




It is usual to have at a time more than one traction motor. In that case it is economical to have combined rheostatic and series parallel control of traction motors. Accordingly two traction motors are connected in series and supply to them is given through the starting resistance in series which is progressively cut out until only two motors remain in series when the motors are left running in this position voltage across each will be nearly half of the supply voltage and motors will be running nearly at half the full speed. For full speed motors are disconnected and then reconnected in parallel again supplied through starting resistance. This resistance is then progressively cut out leaving motors in parallel running condition.

Both series motors are connected in series through full starting resistance across supply. Starting resistance is gradually cut out step by step till both series motors are in series across supply it should be noted here that the starting resistance always divided into two separate sections each connected motor. This makes it possible to employ same resistance in both series and parallel for either connection. Both the motors are put in parallel along with their respective external resistances across supply

External resistance is gradually cut out till both the motors are left in parallel across supply. Various steps involved in between connections shown in are separately shown. In fig 3.15



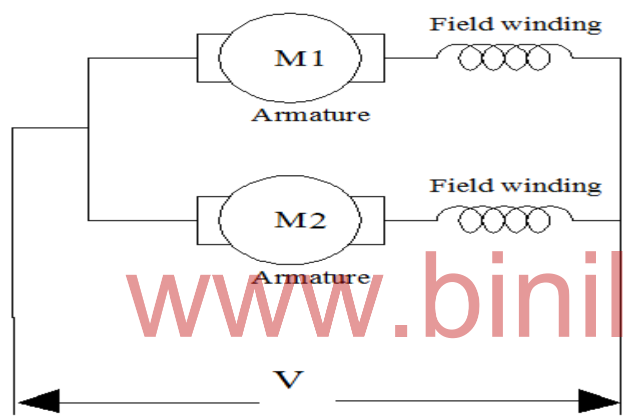


Fig When motors are in series across supply as voltage across each motor is half the supply voltage and will be running nearly at half the speed when they are put in parallel across supply as

Energy saving with series parallel control

Let, I= current

V= supply voltage

T = starting period in sec.

When the motors are in series, the voltage raises from 0 to V/2 volts. Let the time required be half of total accelerating period ie, T/2 sec.

Energy utilized by each motor= Average voltage x current x time

$= \frac{0+V/2}{2}$x I xT/2

$=\frac{VIT}{8}$watt-sec

Energy utilized by two motor = $\frac{VIT}{8}$x 2 watt-sec $=\frac{VIT}{4}$ watt-sec

Energy drawn from the line during this period= V x I x T/2

$=\frac{VIT}{2}$ watt-sec

When the connection is changed from series to parallel the voltage is increased from V/2 to V volts.

Energy utilized by two motor= 2 x Average voltage x current x time

$$= 2 \times \frac{\left(\frac{V}{2}\right)+V}{2} \times I \times T/2 = \frac{3VIT}{4} \text{watt-sec}$$

The current drawn from the line during this period = 2 xI

Energy drawn by the two motors =Vx2IxT/2

= VIT watt-sec

Therefore ,total energy utilized during both series and parallel connections

$$= \frac{VIT}{4} + \frac{3VIT}{4} = \textbf{VIT watt-sec}$$

Total energy drawn during series and parallel connections = $\frac{VIT}{2}$+ VIT

$= \frac{3VIT}{2}$ **watt-sec**

Starting efficiency = $\frac{energy utilised}{energy input}$x 100%

Starting efficiency = $\frac{VIT}{\frac{3}{2}(VIT)}$ $\mathbf{= 66.67\%}$

Therefore the starting efficiency is increased from 50% to 66.67% with series parallel method. By adopting four motors, starting efficiency is increased up to 72.72% and higher number of motors the efficiency goes up.

Advantages of Series Parallel Starting

- It has higher efficiency than plain rheostatic method of starting as proved above
- We get more than one economical speeds which are possible in plain rheostatic method only wasting energy in the rheostat.
- Due to low energy loss in the starting resistances they are not of cumbersome size
- Connecting the motor to supply without taking excessive current at starting
- Providing smooth acceleration without sudden shock to avoid damage to couplings
- Adjusting the speed according to the type of services and route conditions
- In this chapter we will take up various control method for motors supplied from straight dc supply rectified ac supply and pure ac supply

3. Metadyne control

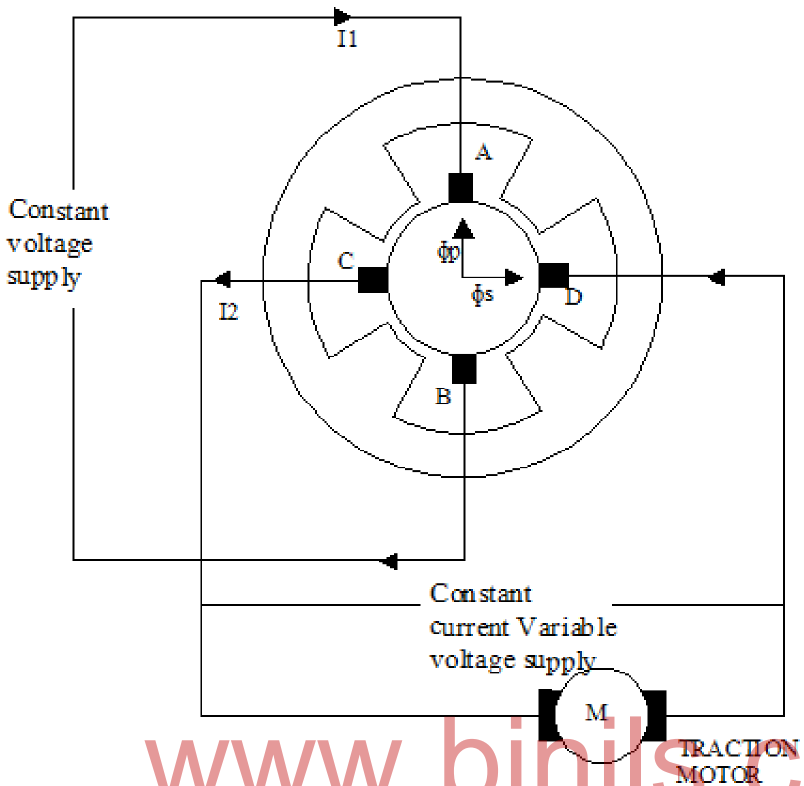


Fig 3.16.Metadyne control

Metadyne converter is a machine which takes power at constant voltage and variable current and delivers at constant current and variable voltage. The main advantages of this is that the loss is much, lower than resistance starting method. Since the current throughout the starting period is maintained constant, uniform tractive effort is produced and so jerks are avoided.

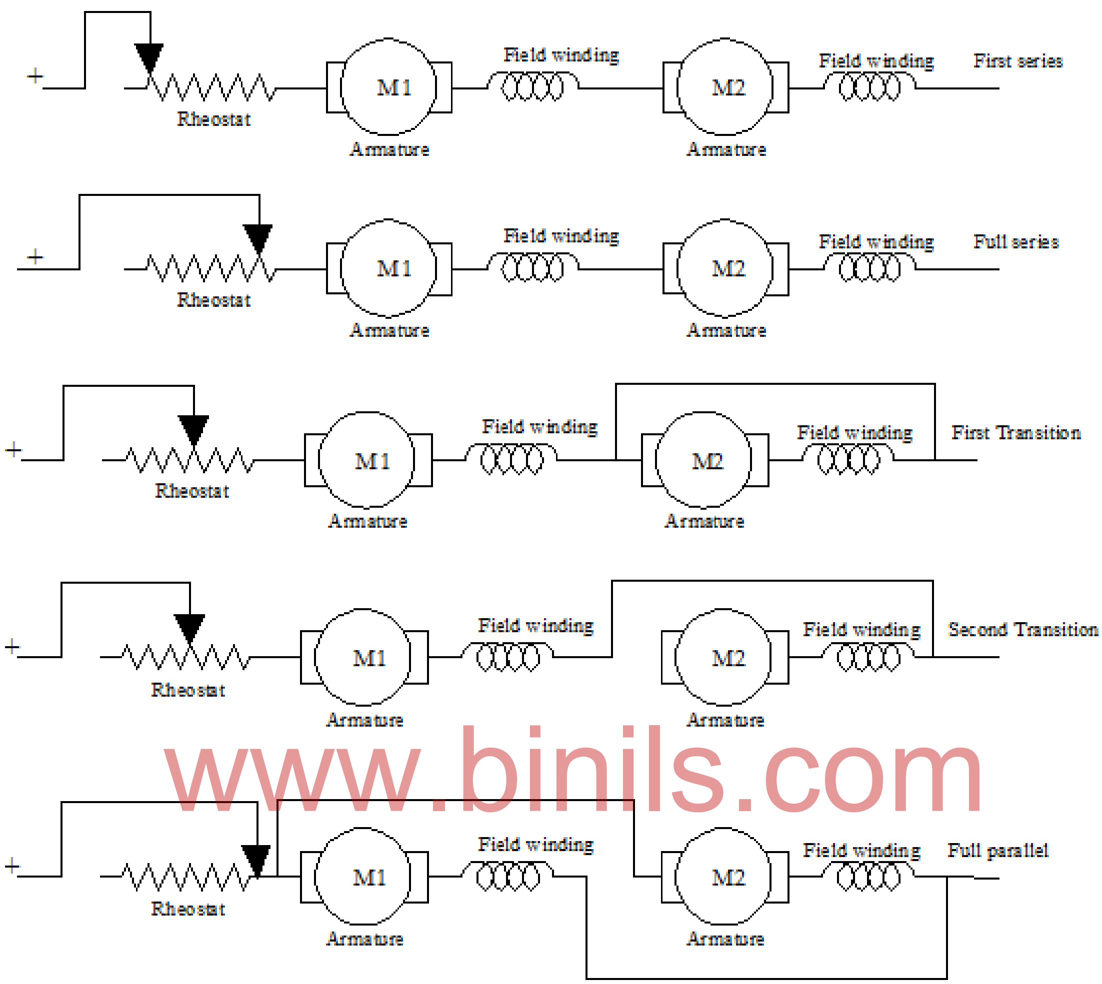
This type of control gives very smooth drive and high coefficient of adhesion. The metadyne consists of a d.c. armature wound for two poles, and provided with two pairs of brushes and a 4 –pole field magnet as shown in fig.

One pair of brushes A,B is connected across a constant voltage d.c. supply whereas the other pair C,D is connected to load ie series traction motor. The metadyne converts constant voltage supply in to a constant current, variable voltage supply for feeding the load. The machine acts as a motor as far as brushes AB are concerned and as a generator as far as brushes CD are concerned. With metadyne converter, a regenerative braking can be obtained by reversing the field of traction motor and also the magnitude of regenerative braking can be controlled by controlling the magnitude of reverse excitation.

2.13. Methods of series parallel connection

Series parallel method of starting can be achieved by using the following two methods.

1. Shunt Transition fig 3.17



According to this method transmission from connections shown is carried out in four steps as shown fig.a,b,c,d.

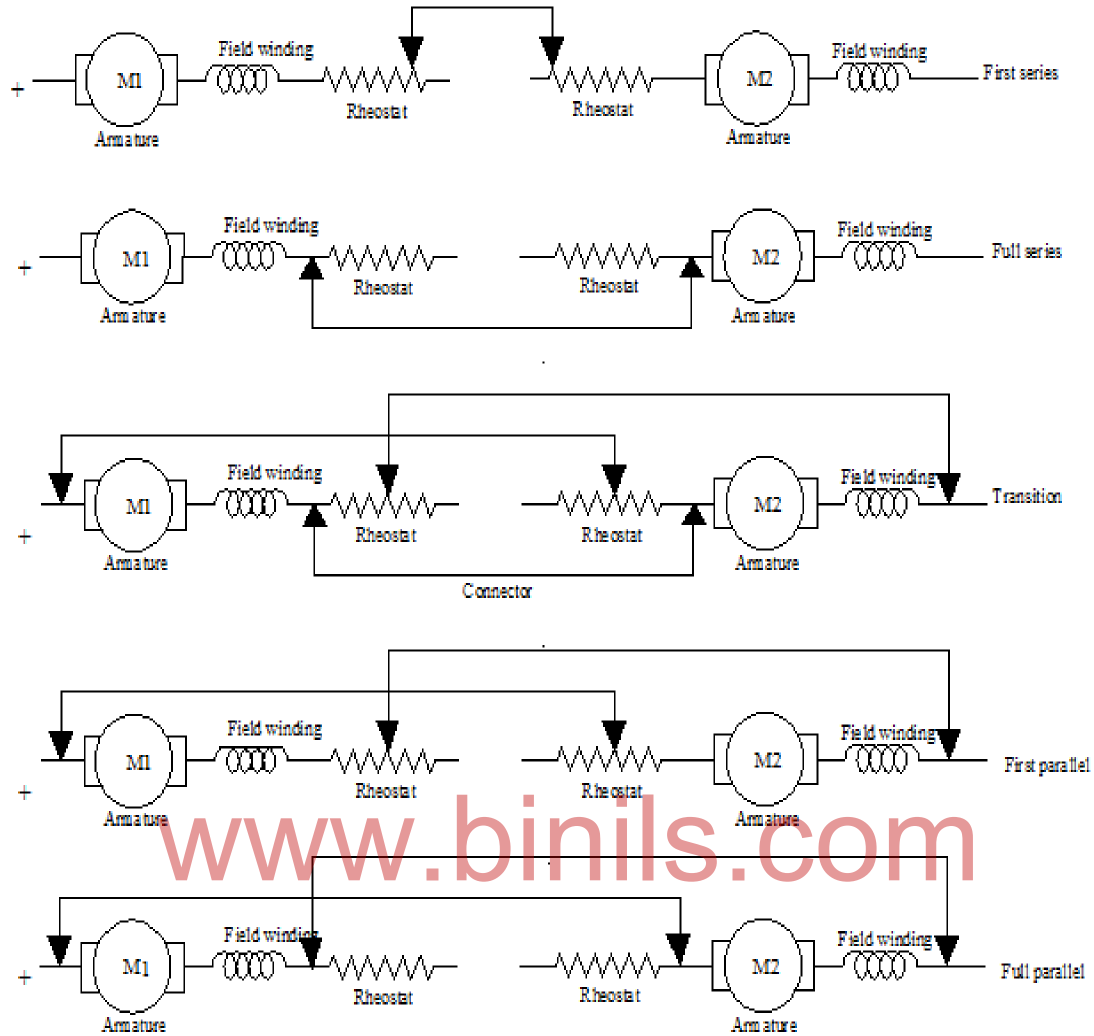
1) In first step the motors run with full resistance in series as in fig a and this is known as **First Series** After whole of the external resistance has been cut out as shown in fig b, now motors are now in series without resistance. This is known as **Full Series**.

2) Second step is to short circuit one motor as in fig c. This is known as **First Transition**

3) Third step is open one end of the short circuit motor as shown fig d. This is known as **Second Transition** and some of the resistance is connected and also known as **First Parallel.**

4) Fourth step is to connect this open end of the motor with corresponding terminal of the other motor. This is shown fig e and the external resistance is gradually reduced and now the motor runs at **Full Parallel.** It will be observed that during shunt transition steps from 1 to 4 one motor is actually short circuited and then disconnected from supply and afterwards reconnected in parallel. This therefore results in the loss of tractive effort during this period till motor is reconnected in parallel.

2.BridgeTransitionfig3.18



Main advantage of bridge transition method is that none of the motors is disconnected in the process of transition from series connection to parallel connection.

Various steps involved are:

In the first step individual resistances are shorted out as shown fig a. which is equivalent to motors are now in **First Series**

In the second step bridge link is so moved that motors are put in series by reducing the resistances and now the motor is at **Full Series**. As in fig b.

In the third step during **transition** a portion of starting resistance is connected in parallel with each motor and formed as bridges as in fig.c.

In the fourth step bridge link is removed. Now motors are in parallel with individual resistance inserted in each motor as shown in fig d. now the motors are in **First Parallel**

Finally the resistance is reduced and now the motor is in **Full Parallel** as in fig e.

Bridge transition method is very much suitable for operation under predetermined conditions of current and load such as those obtained in multiple unit trains

2.14 .A. Multiple unit control

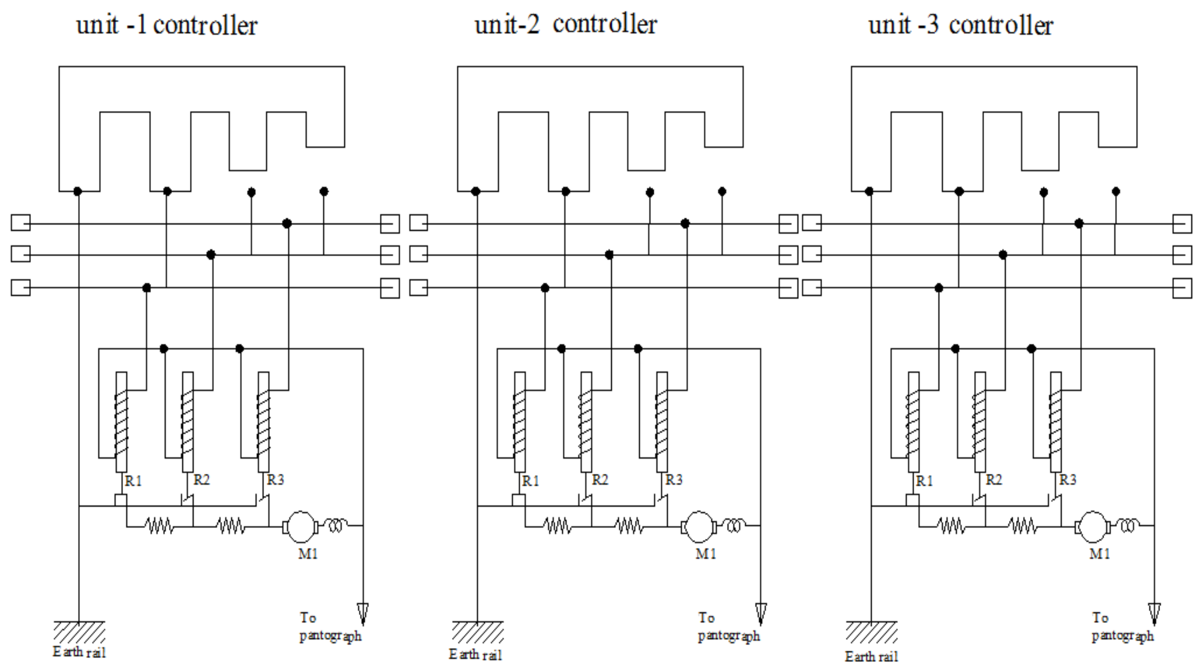


Fig 3.19.**Multiple unit control**

The coaches where electric motors are installed are known as motor coaches. For city and suburban services, It is usual to use motor coaches. Multiple unit trains are better suited for high speed running. Main advantage of this is the flexibility of operation.

Multiple unit train comprises the number of units. Each unit consists of a motor coach and number of trailing coaches for passengers. Depending upon the traffic requirement, a suitable number of motor and trailer coaches are added.

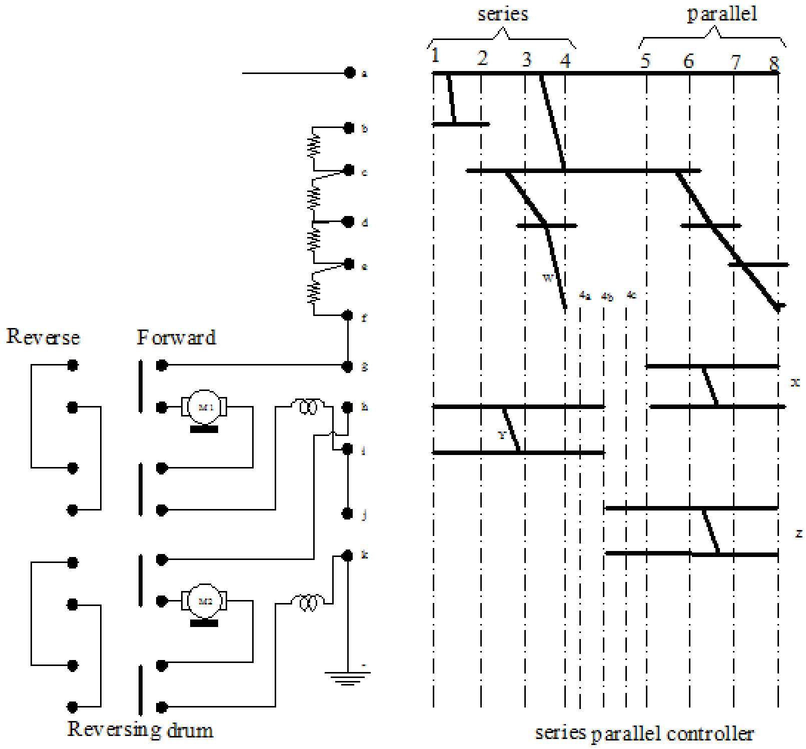
Each motor coach has two or four motors. It is possible to control the operation of all the motors in train from single point. This controlling system is known as **multiple unit control.**

The motor coaches of each unit consists of group of traction motor, series parallel controller, reverser, accelerating relay, motor generator set, coupler, over current relay, cutout switch, fuse…

The complete circuit of each unit connected in parallel with the help of coupling cable as shown in fig. is known as master controller. If the system has more than one controller, it is necessary to have an interlocking system.

If we considered the control point is unit no.1. ie, master controller, and the train is to be started from this unit. The contacts 0 and 1 of this controller unit are closed which will close down the contacts 0 and 1 of other units. At the same time the relay R_1 of all the units are closed and full starting resistance include with the motor. By this way traction motors in all units are started using multiple unit control. Next step the closing contacts 0 and 2 will energies the relay R_2 of all units. This reduces the starting resistance. Similarly in next step R_3 energies and cut down the total resistance in all units. Likewise starting, stopping and reversing operations are carried out by a single master unit control unit.

2.14. B. Drum Controller Employing Shunt Transition (fig 3.20)



Drum controller consists of rectangular interconnected but insulated strips carried on the cylinder. When the drum is moved through certain angles these strips make contact with appropriate contacts called fingers to which are connected rheostatic resistances, motor and supply terminals.

One such drum controller employing shunt transition from series to parallel connections of motors is shown in fig. For convenience sake cylindrical surface of drum controller is opened and layouts of segments shown by thick rectangular strips fingers are shown by vertical row of dots.

Vertical chain dotted lines show the operating positions called notches and coincide with the centered line of the fingers.

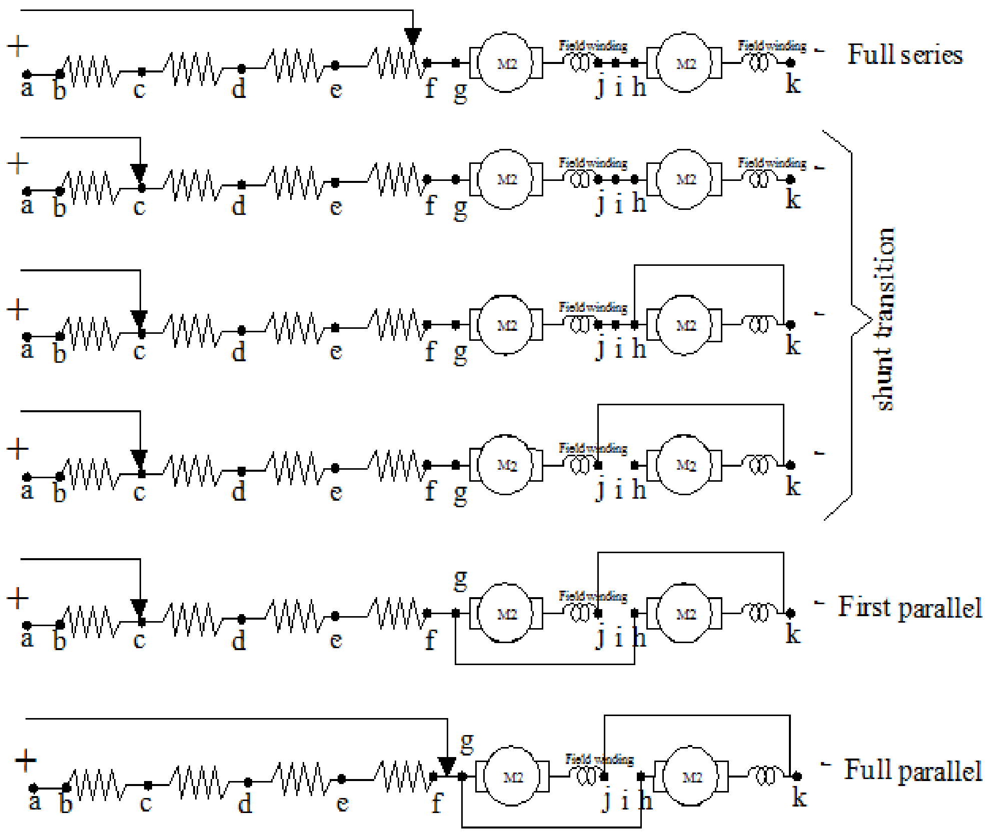


Fig 3.21.shunt transition.

a) On first notch fingers a and b are connected together and so also h and i. This puts the motors in **First Series** with full resistance assign fig a.

b) With controller moved from notch 1 to 4 external resistance is gradually cut out till at notch 4 we get motors connected at **Full series**. In fig b.

c)For various operations of **shunt transition** taking place in between notch 4 and 5 various sub notch position are indicated.

1. At sub notch position strip w leaves contact of finger f this inserts resistance between fingers c and f. Therefore notch 4a position corresponds to fig c.

2.At 4 b position while segments y have contact with finger h and i, segments z also establish contact with fingers j and k. This short circuits fingers h and k thereby short circuiting motor 2.This short position is corresponding to fig d.

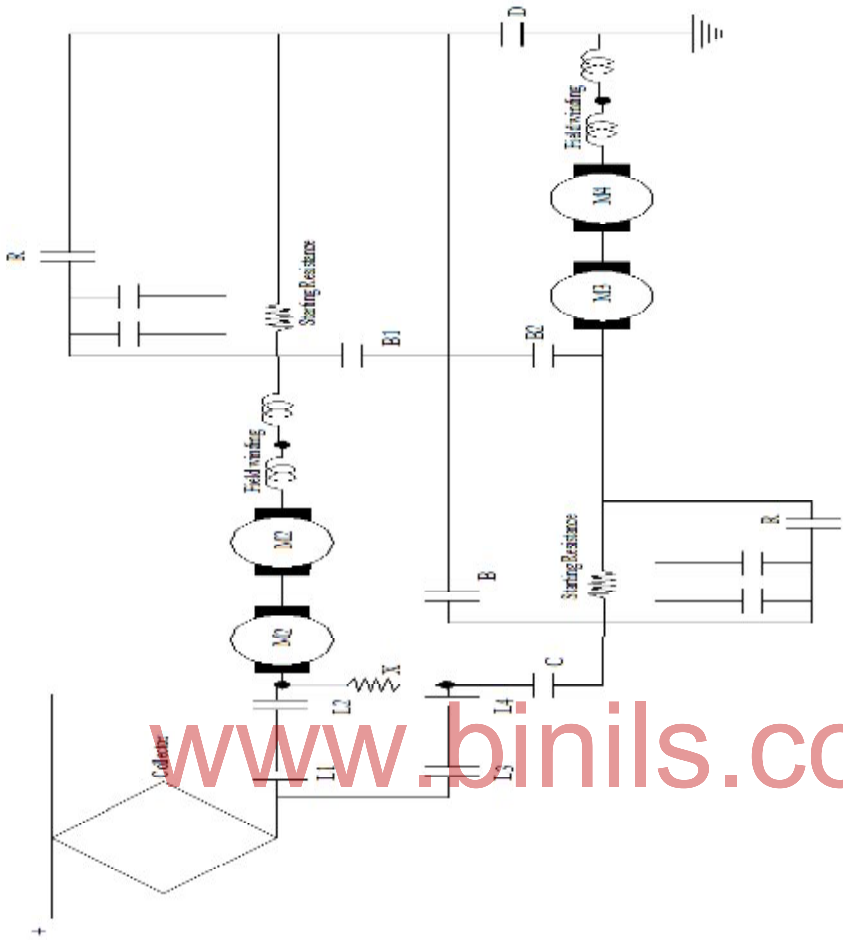
3. At sub notch position 4c segments Y loose contact with fingers h and i.

d) At notch 5 segment x establishes contact with fingers g and h. This position is corresponding to fig .f. and now the position is **First parallel**

e) At this positions 6 and 7 gradually reduces the resistance till notch position 8 corresponds to fig.g and now the position is **Full parallel**

In reverse drum controller direction of motor is changed by changing the direction of current flow through armature.

2.14.C .Contactor Type Bridge Transition Controller fig 3.22.



Power circuit of two motor traction unit using bridge transition is shown sequence of contactor operation at various notches. This unit consists of

i) Overload relay OLR is connected in series with each traction motor circuit

ii) Reverser is used to reverse the connections of the traction motor field for changing the direction of rotation

iii) Motor cut out switches and links are used to isolate any of the defective traction motor and provide a bypass to complete the circuit

iv) Auxiliary contacts are provided in addition to main contacts on overload relay reverser and motor cut out whose function is explained as follows

The connection diagram is having motors M1 and M2 are connected in series with three switches L1, L2 and D. Motors M3 and M4 is connected with switches L3 , L4 and C.

Bridging contacts B1 and B2 have full line voltage across them, when the motors are in parallel. Resistance X is used to protect the system.

In the starting position line switches L3, L4 and bridge contact B close and D, C, L3, L4 are open. Now all the motors are in first series as the connections are:

1. **First series through- L1, L2, M1, M2, STARTINGRESISTANCE,**

CONTACT B, STARTING RESISTANCE, M3and M4.

Now contactor R operates and cut down the resistance in step and now current flow through

2. Full series through - L1, L2, M1, M2, R, CONTACT B, R, M3 and M4.

Now contacts B1, B2 closes and B opens, but still the motors operates in series

Current flow through – L1, L2, M1, M2, B1, B2, M3, M4.

Now the contacts R open, C, D closes, B1, B2 open

3. First parallel through --L1, L2, M1, M2, STARTINGRESISTANCE, D and

L3, L4, C, STARTING RESISTANCE, M3 and M4.

Now contactor R operates and cut down the resistance in step and now current flow through

4. Full parallel through --L1, L2, M1, M2, R,D and

L3, L4, C, R, M3 and M4.

Auxiliary contacts on motor cut out switch confine the circuit operation to the series connections when one motor is isolated and short circuited.

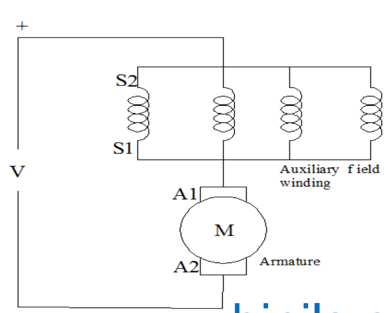
2.15. Braking in Traction

Both electrical and mechanical braking is used. Mechanical braking provides holding torque. Electric Braking reduces wear on mechanical brakes, provides higher retardation, thus bringing a vehicle quickly to rest. Different types of electrical braking used in traction are **Plugging, Rheostatic, Regenerative braking..**

Regenerative Braking with D.C. Motors

In order to achieve the regenerative braking, it is essential that ***(i)*** the voltage generated by the machine should exceed the supply voltage and ***(ii)*** the voltage should be kept at this value, irrespective of machine speed.

During electrical regenerative braking, traction motors are made to work as generators, utilizing kinetic energy of the moving train to run the generators. Electrical energy is fed back to supply line.



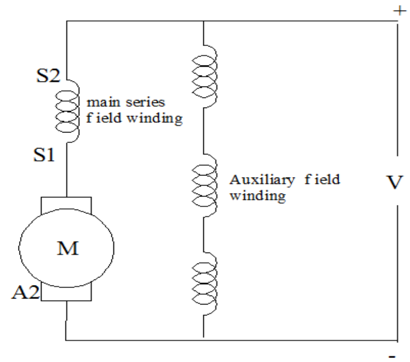


Fig.3.23. (*a*) shows the case of 4 series motors connected in parallel during normal running *i.e.* motoring.

One method of connection during regenerative braking is to arrange the machines as shunt machines, with series fields of 3 machines connected across the supply in series with suitable resistance. One of the field winding is still kept in series across the 4 parallel armatures as shown in figure (*b*).

The machine acts as a compound generator. (With slight differential compounding) Such an arrangement is quiet stable; any change in line voltage produces a change in excitation which produces corresponding change in e.m.f. of motors, so that inherent compensation is provided *e.g.* let the line voltage tends to increase beyond the e.m.f. of generators. The increased voltage across the shunt circuit increases the excitation thereby increasing the generated voltage. Vice-versa is also true. The arrangement is therefore self compensating

D.C. series motor can't be used for regenerative braking without modification for obvious reasons. During regeneration current through armature reverses; and excitation has to be maintained. Hence field connection must be reversed.

3.17.MAGNETIC LEVITATION(MEGLEV)

In levitation system, ordinary electromagnets are used .These magnets produce an attractive force and levitate the vehicle i.e., to rise and float the vehicle in the air with no physical support. The electromagnets are attached to the car. These magnets are placed such that they are facing the underside of the rail as shown in fig.3.26.They produce an attractive force and levitate the car. The attractive force is controlled by a gap sensor. The gap sensor measures the distance between the rails and electromagnets. A control circuit continuously regulates the gap at a fixed distance of about 8mm.If the gap increases beyond 8mm,the current to the electromagnet is increased, to create more attraction(i.e., Now the gap is reduced).If the gap become less than 8mm,the current is decreased, to create less attraction(i.e., Now the gap is increased).

The levitation magnets are 'U' shaped and the rails are inverted 'U' shaped as shown in fig. In this system the electromagnetic attractive forces levitates and guide the car.

In this system linear induction motor is used. The linear induction motor is just like ordinary induction motor, but it has been split open and flattened. The primary side coils of the motor are attached to the car body. The secondary side reaction plates are installed along the guide way of the rail as shown in fig. The secondary plate is made of aluminum or copper plate.

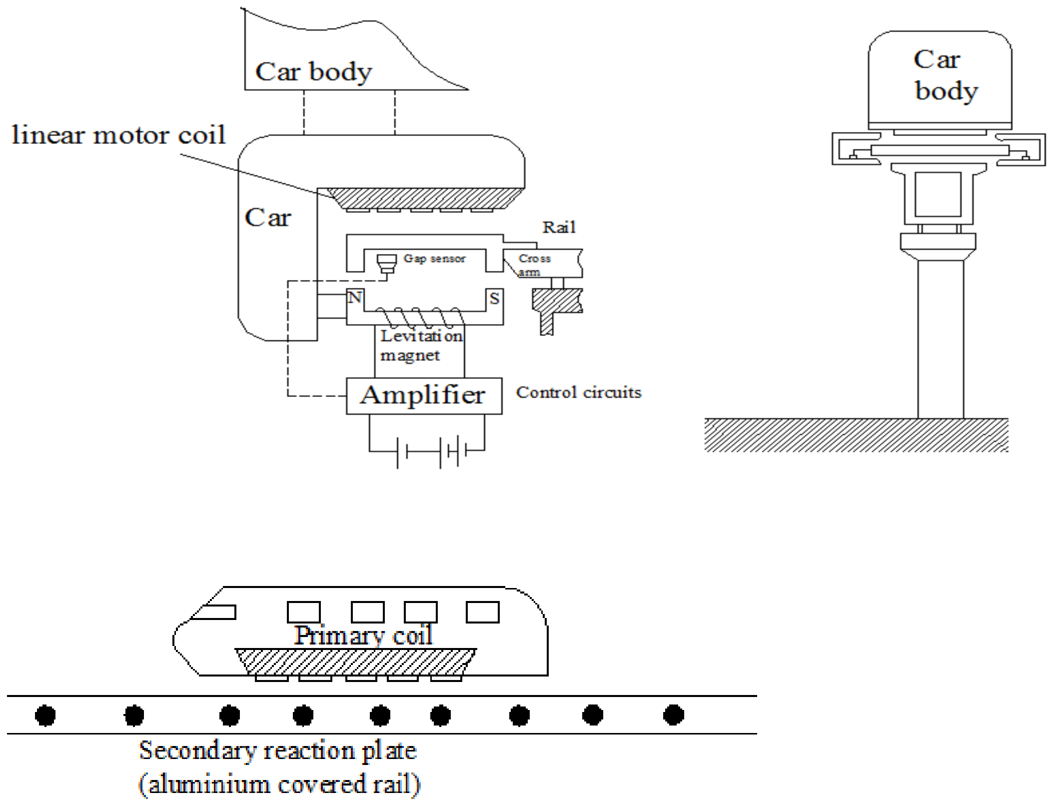


Fig 3.24.MAGNETIC LEVITATION (MEGLEV)

Advantages

1. The vehicle is designed so that it interlocks with the guide way. So there is no risk of derailment.

2. When the vehicle is running, there is no physical contact between the carriages and guide way which minimize the noise and vibration.

3. There are less moving and rolling parts. So wear and tearis less. Hence low maintenance is required.

SUSPENSION SYSTEMS

Primary and secondary suspension system

In suspension arrangement the locomotive (train engine) is carried by two bogies. The bogies are coupled by two or more axles. As the locomotive moves on the track, shocks are delivered to the wheels and axles due to irregular tracks. The purpose of suspension arrangement is to minimize the transmission of these shocks to the locomotive body with the help of springs and dampers. The set of springs and dampers are interposed in between axles and bogie. This arrangement is called primary suspension.

Generally up to 80 Kmph speed, railway vehicles do not produce any special vibration. At higher speeds vibration becomes more. Therefore for high speed vehicles, a second set of spring of low stiffness is provided in between the bogie and the body. These set of springing arrangement is called secondary suspension.

Review questions

Part A& B

1. Mention the methods of Feeding power to locomotive?
2. Define Average speed of Electric Train?
3. Mention the methods of Starting DC Traction motors?
4. Write the Frequency Adopted in single phase low frequency AC system of Track Electrification?
5. What is the purpose of Providing Neutral section in Track Electrification?
6. What are the different types of Electrical transmission in Diesel electric Traction?
7. Name the Motors used for traction purpose?
8. State the types of Traction Systems?
9. Define Co-effect ion of adhesion.
10. Define Average Speed.
11. What is mean by transition in Series-Parallel control connection?
12. List the advantages and Disadvantages of Diesel Electric traction System?
13. What are the advantages of electric traction?
14. What is the purpose of using Catenary and Droppers in electrical traction?
15. What is Neutral sectioning?
16. List the factors affecting schedule Speed.
17. What are the necessity of Booster Transformer?
18. List the desired Electrical and Mechanical Characteristics of traction Motors.
19. Compare overhead system and conductor Rail system.
20. Define Tractive Effort.
21. State the types of Traction Services.
22. Explain the operation of pantographs collectors.
23. Explain the over head equipments.
24. Define specific energy consumption and energy output.
25. Explain the regenerative braking in traction?
26. What are the types of braking methods?
27. What is primary and secondary suspension system in traction?

PART C

1. Explain different current collectors used in electric traction?
2. Explain contactor type Bridge Transition controller?
3. Write short notes on Booster transformer connection in Electric Traction and Neutral sectioning.
4. Draw the Typical Speed time Curve and explain each Constituent of it?
5. Derive the basic principles for the crest speed using Trapezoidal speed time curve. State all your assumption clearly with relevant units.
6. Draw the layout diagram of typical 25KV traction substation and explain the same.
7. Derive the tractive effort of a traction system.
8. Explain in detail different starting methods of traction motors
9. Explain in detail plain rheostatic control in detail
10. Explain in detail series parallel method of starting of traction motors
11. Explain in detail shunt and bridge Transition controller?
12. Explain in detail multiple unit controller?
13. Explain briefly the Magnetic Levitation.

UNIT IV

ILLUMINATION

4.1. INTRODUCTION

Illumination as a body is gradually heated above room temperature; it begins to radiate energy in the surrounding medium in the form of electromagnetic waves of various wavelengths. The nature of this radiant energy depends on the temperature of the hot body.

The usual method of producing artificial light consists in raising a solid body or vapour to incandescence by applying heat to it. It is found that as body is gradually heated above room temperature, it begins to radiate energy in the surrounding medium in the form of electromagnetic waves of various wavelengths. The nature of this radiant energy depends on the temperature of the hot body. Thus, when the temperature is low, the radiated energy is in the form of heat waves only, but when a certain temperature is reached, light waves are also radiated out in addition to heat waves and the body becomes luminous. Further increase in the temperature produces an increase in the amount of both kinds of radiations but the cplour of light or visual radiations change from bright red to orange, to yellow and finally, if the temperature is high enough, to white. As the temperature is increased, the wavelength of visible radiation goes on becoming shorter. It should be noted that heat waves are identical to light waves except that they are of longer wavelength and hence produce no impression on retina. Obviously, from the point of view of light emission, heat energy represents wasted energy.

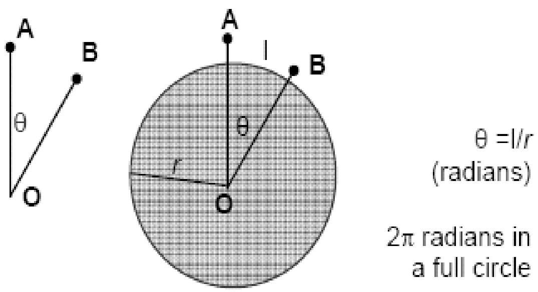
Radiant efficiency of the luminous source is defined as the ratio of "energy radiated in the form of light" to "total energy radiated out of the hot body" and it depends on the temperature of the source. As the temperature is increased beyond that at which the light waves were first given off, the Radiant efficiency increases, because the light energy will increase in greater proportion than the total radiated energy. When emitted light becomes white, i.e. it includes all the visible wavelengths, from extreme red to extreme violate, then a further increase in temperature produces radiations which are of wavelengths smaller than that of violate radiations. Such radiations are invisible and are known as ultra-violate radiations. It is found that maximum radiant efficiency would occur at about 6200^0 C and even then the value of this maximum efficiency would be 20%. Since this temperature is far above the highest that has yet been obtained in practice, it is obvious that the actual efficiency of all artificial sources of light i. e. those depending on temperature incandescence, is low.

Light is thus a part of radiant energy that propagates as a wave motion. Approx. velocity being 3x108 m/sec. The wavelengths which can produce sensation of sight have a range from $4x10^{-5}$ cm to $7.5x10^{-5}$ cm. For expressing wavelength of light, another unit called Angstrom Unit (1 A.U. = 10^{-8} cm= 10^{-10} m) is used. Thus the visible radiation lies between 4000 AU to 7500 AU. Typically a wavelength of 6000 AU produce yellow cplour and 4000 AU produces violate cplour.

4.2. IMPORTANT TERMS USED IN ILLUMINATION

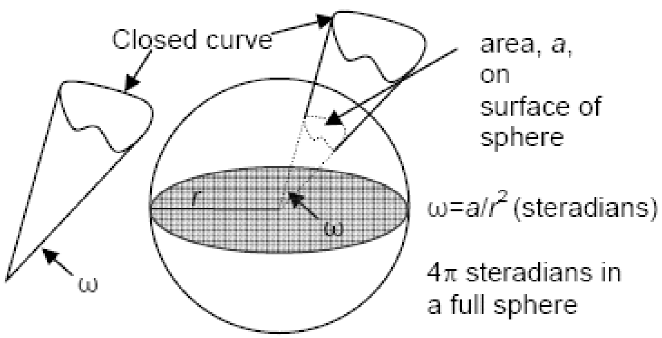
i)PLANE ANGLE

A plane angle, θ, made up of the lines from two points meeting at a vertex, is defined by the arc length of a circle subtended by the lines and by the radius of that circle, as shown below. The dimensionless unit of plane angle is the radian, with 2π radians in a full circle.



ii)SOLID ANGLE

A solid angle, ω, made up of all the lines from a closed curve meeting at a vertex, is defined by the surface area of a sphere subtended by the lines and by the radius of that sphere, as shown below. The dimensionless unit of solid angle is the steradian, with 4π steradians in a full sphere.



iii) LUMINOUS FLUX:

Luminous flux is the rate of energy radiation in the form of light waves. The unit is **lumen**.

It is thus the rate of energy radiation in the form of light. It is energy per second (and hence comparable to Power).

Approximate relation between lumen and electric unit of power i.e. watt is given as:

1 lumen=0.0016 watt (approx) or 1 watt=625 lumen (approx)

iv) LUMINOUS INTENSITY:

Luminous intensity in a given direction is the quotient of the luminous flux emitted by a source (or by an element of a source), in an infinitesimal cone containing the given direction by the solid angle of that cone. Hence it is the luminous flux / unit solid angle.

v) LUMINOUS EFFICACY

Efficacy is the ratio of light output from a lamp to the electric power it consumes and is measured in **lumens per watt** (LPW).

vi) CANDLEPOWER:

Candlepower is the capacity of a source to radiate light and is equal to the number of lumens emitted in a unit solid angle by a source of light in a direction. **Its unit is Candela (cd) or lumens per steradian.**

A source of one candela emits one lumen per steradian. Hence total flux emitted by it all-round is 4πx1=4π lumen.

vii) LUMEN:

Lumen is the unit of luminous flux. It represents the flux emitted in unit solid angle of one steradian by a point source having a uniform intensity of one candela. Thus a uniform point source of one candle power emits 4π lumens.

Lumens = Candle power x Solid angle.

viii) **ILLUMINATION:**

The luminous flux reaching a surface, per unit area of that surface. One lumen per square meter is termed as one lux. Also

Illumination = Flux / Area = Lumens / Area= (Candle power x Solid angle) / Area

ix) MEAN HORIZONTAL CANDLE POWER (MHCP):

It is the mean of the candle powers in all directions in the horizontal plane containing the source of light.

x) MEAN SPHERICAL CANDLE POWER (MSCP):

Generally, the luminous intensity or candle power of a source is different in different directions. The average candle-power of a source is the average value of its candle power in all the directions. Obviously, it is given by flux (in lumen) emitted in all directions in all planes divided by 4π. **This average candle-power is also known as mean spherical candle-power (MSCP).**

$$MSCP = \frac{total\ flux\ in\ lumens}{4\pi}$$

xi) MEAN SEMI-SPHERICAL CANDLE POWER (MHSCP):

It is the mean or average of the candle powers in all directions below the horizontal.

It is given by the total flux emitted in a hemisphere (usually the lower one) divided by the solid angle subtended at the point source by the hemisphere.

$$MHSCP = \frac{flux\ emitted\ in\ a\ hemisphere}{2\pi}$$

xii) REDUCTION FACTOR

The ratio of the mean spherical luminous intensity of a light source to its mean horizontal luminousintensity.

xiii) LUMINANCE

Luminance is the luminous intensity in a given direction of an element of a surface, per unit projected area of that surface.

xiv) GLARE

Glare may be defined as the brightness within the field of vision of such a character as to cause annoyance, discomfort, interference with vision or eye fatigue.

xv) LIGHT EFFICIENCY

The ratio of total luminous flux over total power input, expressed in **lumens per watt**.

For ex: An electric lamp.

Xvi)SPACE HEIGHT RATIO

Spacing Height Ratio is defined as the ratio of the distance between adjacent luminaries (center to center) to their height above the working plane.

SHR (Nominal) = (1/Hm) x (Square root (Area/N))

Where Hm is mounting height, N is number of luminaries.

xvii) WASTE-LIGHT FACTOR

A factor used in the design of floodlighting installations to allow for the light which, although emitted along the beam from the projector, does not fall on the area to be illuminated.

xviii)DEPRECIATIONFACTOR

Depreciation factor is merely the inverse of the maintenance factor and is defined as the ratio of initial meter-candles to the ultimate maintained meter-candles on the working plane. It is always more than unity.

xiv) UTILIZATION FACTOR

Utilization factor or coefficient of utilization is defined as the ratio of total lumens reaching the working plane to the total lumens given out by the lamp.

Xv) ABSORPTION FACTOR

The ratio of the total absorbed radiant or luminous flux to the incident flux is called **absorptance** (formerly also **absorption factor**).

Xvi) REFLECTION FACTOR

A measure of the ability of a surface to reflect light or other electromagnetic radiation, equal to the ratio of the reflected flux to the incident flux.

4.3.REQUIREMENT OF GOOD LIGHTING SYSTEM:

1. Illuminating source should have sufficient light.

2. It should not strike the eyes.

3. It should have suitable shades and reflectors.

4. It should be installed at such a place so as to give uniform light.

4.4. LAWS OF ILLUMINATION

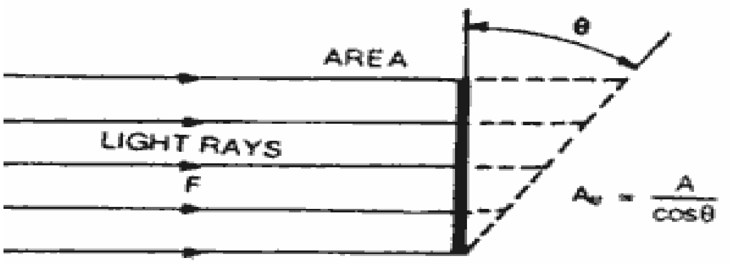
A) COSINE LAW:

The illumination received on a surface is proportional to the cosine of the angle between the direction of the incident light rays and the normal to the surface at the point of incidence. This is mainly due to the reduction of the projected area as the angle of incidence increases. Thus

$E_h= E_n \cos\theta \, (I \cos\theta) / D^2$

Where

E_h = illumination on a horizontal plane,
E_n = illumination due to light normally incident,
θ = the angle of incidence,
D = distance from the source.



B) INVERSE SQUARE LAW:

The illumination upon a surface varies inversely as the square of the distance of the surface from the source. Thus if the illumination at a surface one meter from the source is X units, then the illumination at 2 meters will be X/4 at 3 meters will be X/9 and so on.

Strictly the inverse square law operates only when the light rays are from a point source and are incident normally upon the surface.

Thus illumination in lamberts/metre^2 on a normal place= **Candle power / (Distance in meters)^2**

4.5. FACTORS CONSIDER WHILE DESIGNING GOOD LIGHTING SYSTEM

•Look good!
•Provide the proper amount of light in every room.
•Be built and constructed within budget, code, and other constraints.
•Be environmentally responsible.
•Respond to the Architecture and Interior Design
•Produce good cplour
•Achieve the desired moods of each space
•Be able to control the lights.

4.6. SOURCES OF LIGHT

The lighting industry makes millions of electric light sources, called lamps. Those used for providing illumination can be divided into three general classes:

- Incandescent,
- Discharge,
- Solid-state lamps.

- Incandescent lamps produce light by heating a filament until it glows.
- Discharge lamps produce light by ionizing a gas through electric discharge inside the lamp.
- Solid-state lamps use a phenomenon called electroluminescence to convert electrical energy directly to light.

In addition to manufactured light sources, daylight — sunlight received on the Earth, either directly from the sun, scattered and reflected by the atmosphere, or reflected by the moon — provides illumination. The prime characteristic of daylight is its variability. Daylight varies in magnitude, spectral content, and distribution with different meteorological conditions, at different times of the day and year, and at different latitudes. The illuminances on the Earth's surface produced by daylight can cover a large range, from 150,000 lx on a sunny summer's day to 1000 lx on a heavily overcast day in winter. The spectral composition of daylight also varies with the nature of the atmosphere and the path length through it.

Type of light source	Typical Luminous Efficiency (lm/W)
Incandescent bulb	8-18
Fluorescent Lamp	46-60
Mercury Vapour Lamp	44-57
CFL	40-70
Sodium Vapour Lamp (Low Pressure or LPSV)	101-175
Sodium Vapour Lamp (High Pressure or HPSV)	67-121
Metal Hallide	60-80
LED	30-50
Best LED	105

4.7. Lighting Schemes

Different lighting schemes may be classified as

(*i*) Direct lighting

(*ii*) Indirect lighting and

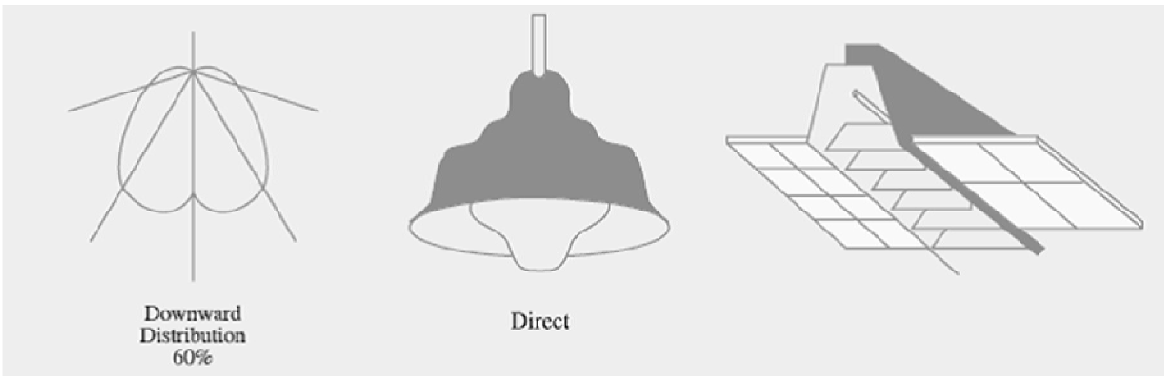
(*iii*) Semi-direct lighting

(*iv*) Semi-indirect lighting and

(*v*) General diffusing systems.

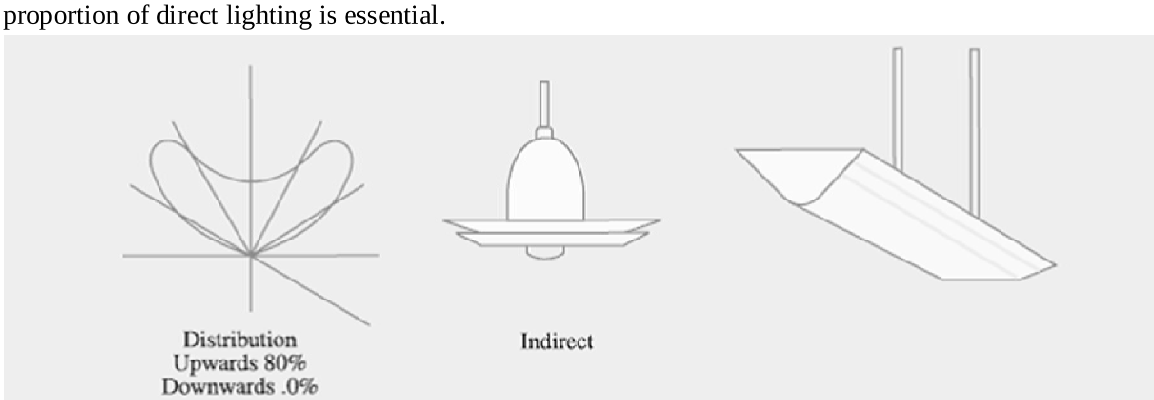
(*i*) Direct Lighting

As the name indicates, in the form of lighting, the light from the source falls directly on the object or the surface to be illuminated. With the help of shades and globes and reflectors of various types as discussed, most of the light is directed in the lower hemisphere and also the brilliant source of light is kept out of the direct line of vision. Direct illumination by lamps in suitable reflectors can be supplemented by standard or bracket lamps on desk or by additional pendant fittings over counters. The fundamental point worth remembering is planning any lighting installation is that sufficient and sufficiently uniform lighting is to be provided at the working or reading plane. For this purpose, lamps of suitable size have to be so located and furnished with such fittings as to give correct degree and distribution of illumination at the required place. Moreover, it is important to keep the lamps and fittings clean otherwise the decrease in effective illumination due to dirty bulbs or reflectors may amount to 15 to 25% in offices and domestic lighting and more in industrial areas as a result of a few weeks neglect. Direct lighting, though most efficient, is liable to cause glare and hard shadows.



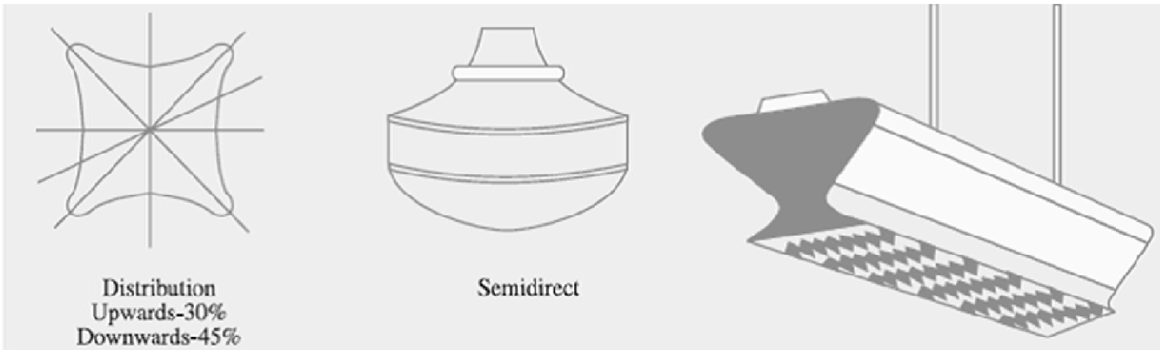
(*ii*) Indirect Lighting

In this form of lighting, light does not reach the surface directly from the source but indirectly by diffuse reflection. The lamps are either placed behind a cornice or in suspended ***opaque*** bowls. In both cases, a silvered reflector which is corrugated for eliminating striations is placed beneath the lamp. In this way, maximum light is thrown upwards on the ceiling from which it is distributed all over the room by diffuse reflection. Even gradation of light on the ceiling is secured by careful adjustment of the position and the number of lamps. In the cornice and bowl system of lighting, bowl fittings are generally suspended about three-fourths the height of the room and in the case of cornice lighting, a frieze of curved profile aids in throwing the light out into the room to be illuminated. Since in indirect lighting whole of the light on the working plane is received by diffuse reflection, it is important to keep the fittings clean. One of the main characteristics of indirect lighting is that it provides shadow less illumination which is very useful for drawing offices, composing rooms and in workshops especially where large machines and other obstructions would cast troublesome shadows if direct lighting were used. However, many people find purely indirect lighting flat and monotonous and even depressive. Most of the users demand 50 to 100% more light at their working plane by indirect lighting than with direct lighting. However, for appreciating relief, a certain proportion of direct lighting is essential.



(*iii*) Semi-direct System

This system utilizes luminaries which send most of the light downwards directly on the working plane but a considerable amount reaches the ceilings and walls also The division is usually 30% upwards and 45% downwards. Such a system is best suited to rooms with high ceilings where a high level of uniformly-distributed illumination is desirable. Glare in such units is avoided by using diffusing globes which not only improve the brightness towards the eye level but improve the efficiency of the system with reference to the working plane.

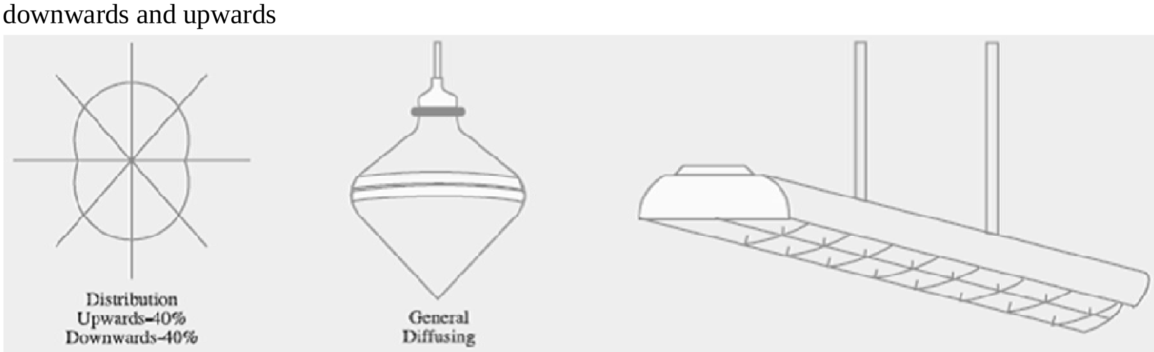


(*iv*) Semi-indirect Lighting

In this system which is, in fact, a compromise between the first two systems, the light is partly received by diffuse reflection and partly direct from the source . Such a system, therefore, eliminates the objections of indirect lighting mentioned above. Instead of using opaque bowls with reflectors, translucent bowls without reflector are used. Most of the light is, as before, directed upwards to the ceiling for diffuse reflection and the rest reaches the working plane directly except for some absorption by the bowl.

(*v*) General Diffusing System

In this system, luminaries are employed which have almost equal light distribution downwards and upwards



4.8. Design of Lighting Schemes and Lay-outs

A well-designed lighting scheme is one which

(*i*) Provides adequate illumination

(*ii*) Avoids glare and hard shadows

(*iii*) Provides sufficiently uniform distribution of light all over the working plane.

Consider the following two factors which are of importance in determining the number, size and proper arrangement of lamps in order to produce a given uniform illumination calculations.

a)Utilization Factor or Coefficient of Utilization (η)

It is the ratio of the lumens actually received by a particular surface to the total lumens emitted by a luminous source.

$$\eta = \frac{\text{lumens actually received on working plane}}{\text{lumens emitted by the light source}}$$

The value of this factor varies widely and depends on the following factors:

1. The type of lighting system, whether direct or indirect etc.
2. The type and mounting height of the fittings
3. The cplour and surface of walls and ceilings and
4. To some extent on the shape and dimensions of the room.

For example, for direct lighting, the value of η varies between 0.4 and 0.6 and mainly depends on the shape of the room and the type and mounting height of fittings but very little on the colour of walls and ceiling. For indirect lighting, its value lies between 0.1 and 0.35 and the effect of walls and ceiling, from which light is reflected on the working plane, is much greater. Exact determination of the value of utilization factor is complicated especially in small rooms where light undergoes multiple reflections.

Since the light leaving the lamp in different directions is subjected to different degrees of absorption, the initial polar curve of distribution has also to be taken into account. Even though manufacturers of lighting fittings supply tables giving utilization factors for each type of fitting under specified conditions yet, since such tables apply only to the fittings for which they have been compiled, a good deal of judgment is necessary while using them.

b) **Depreciation Factor (*p*)**

This factor allows for the fact that effective candle power of all lamps or luminous sources deteriorates owing to blackening and/or accumulation of dust or dirt on the globes and reflectors etc. Similarly, walls and ceilings etc., also do not reflect as much light as when they are clean. The value of this factor may be taken as 1/1.3 if the lamp fittings are likely to be cleaned regularly or 1/1.5 if there is much dust etc.

c) Illumination under actual conditions

$$\Phi = \frac{E.A}{\eta . p}$$

Since illumination is specified in lm/m^2, the area in square meter multiplied by the illumination required in lm/m^2 gives the total useful luminous flux that must reach the working plane. Taking into consideration the utilization and depreciation or maintenance factors, the expression for the gross lumens required is

Where E = desired illumination in lm/m^2; A = area of working plane to be illuminated in m^2 , p = depreciation or maintenance factor ;η= utilization factor.

The size of the lamp depends on the number of fittings which, if uniform distribution is required, should not be far apart. The actual spacing and arrangement is governed by space/height values and by the layout of ceiling beams or columns. Greater the height, wider the spacing that may be used, although the larger will be the unit required. Having settled the number of units required, the lumens per unit may be found from (total lumens/number of units) from which the size of lamp can be calculated

4.9. Lighting systems

1)Factory lighting

The factory lighting should be such so as to provide sufficient light without glare. If an adequate lighting is provided, it will increase the rate of production, improve the quality, accident.

The lighting scheme should provide required illumination level with uniform distribution. The fittings must be clean and should not provide glare.

The lamps should be mounted at sufficient height to provide even luminous intensity.

For some industries for machine operations, portable lights with reflectors may needed. Filament lamps and fluorescent tubes are usually employed.

2) Floodlighting

It means 'flooding' of large surfaces with the help of light from powerful projectors. Flooding is employed for the following purposes.

- For aesthetic purposes as for enhancing the beauties of building by night i.e. flood lighting of ancient monuments, religious buildings on important festive occasions etc.
- For advertising purposes i.e. flood lighting, huge hoardings and commercial buildings.
- For industrial and commercial purposes as in the case of railway yards, sports stadiums and quarries etc.

For flood lighting it is necessary to concentrate the light from the lamp into a relatively narrow beam. Lamp is accurately controlled and covered into a narrow beam by means of projector

However, in the case of flood-lighting, one more factor has to be taken into account. That factor is known as waste-light factor (W). It is so because when several projectors are used, there is bound to be a certain amount of overlap and also because some light would fall beyond the edges of the area to be illuminated. These two factors are taken into account by multiplying the theoretical value of the flux required by a waste-light factor which has a value of nearly 1.2 for regular surfaces and about 1.5 for irregular objects like statues etc. Hence, the formula for calculation of total flux required for floodlighting purposes

$$\Phi = \frac{EAW}{\eta p}$$

Where E = desired illumination in lm/m^2; A = area of working plane to be illuminated in m^2
p = depreciation or maintenance factor; η= utilization factor.

The size of the lamp depends on the number of fittings which, if uniform distribution is required, should not be far apart. The actual spacing and arrangement is governed by space/height values and by the layout of ceiling beams or columns. Greater the height, wider the spacing that may be used, although the larger will be the unit required. Having settled the number of units required, the lumens per unit may be found from (total lumens/number of units) from which the size of lamp can be calculated

3) Street lighting

The main purposes of street lighting are

i) To make the traffic and instructions on the road clearly visible.

ii) To make the street more attractive.

The principle behind street lighting is different from that of indoor lightning. There are no walls and ceiling which reflect or diffuse light. Hence only direct lighting scheme can be employed. Therefore it is not possible to avoid hard shadows and high contrast.

For economic reasons, very low value of illumination is used compared to indoor lighting since areas to be illuminated are usually large. For proper illumination of street the diffusion and specular principles are usually employed.

i) Diffusion principle

The lamps are fitted with suitable reflectors to spread the light as uniformly as possible over the road service. The reflectors are so shaped that the lamp filament is not visible except from underneath it. This avoid glare.

ii) Specular reflection

The reflector should be designed such that, the light falls on an object at a very large angle of incident and reflected correspondingly large angle.

But this produce glare and is only suitable for straight sections of the road.

All light fittings should be mounted solid so that they should not swing due to breeze. Lamp posts should always be fixed at the junction of two roads. Lamps near to large trees and shadows to be avoided.

Example 4.1. A room 8 m X 12 m is lighted by 15 lamps to a fairly uniform illumination of 100 lm/m2. Calculate the utilization coefficient of the room given that the output of each lamp is 1600 lumens.

Solution. Lumens emitted by the lamps = 15 **X**1600 = 24,000 lm

Lumens received by the working plane of the room =

=8 X 12 X 100 = 9600lm

Utilization coefficient = 9600/24,000 = **0.4 or 40%.**

Example 4.2 The illumination in a drawing office 30 mX10 m is to have a value of 250 luxand is to be provided by a number of 300-W filament lamps. If the coefficient of utilization is 0.4 and the depreciation factor 0.9, determine the number of lamps required. The luminous efficiency of each lamp is 14 lm/W.

Solution. $\Phi = E\,A/\eta p$; $E = 250\ \text{lm/m}^2$, $A = 30 \times 10 = 300\ \text{m}^2$; $\eta = 0.4$, $p = 0.9$

$$\Phi = \frac{E.A}{\eta . p}$$

$\therefore\Phi$ = 250 x 300/0.4 x 0.9 = 208,333 lm

Flux emitted/lamp = 300 x 14 = 4200 lm;

No. of lamps reqd.= 208,333/4200 = **50.**

Example 4.3 it is required to provide an illumination of 100 lux in a factory hall 30m x 15m. Assume the depreciation factor is 0.8, coefficient of utilization is 0.4 and efficiency of lamp is 14 lumen/watt. Suggest the number of lamps and their ratings are 100w,250w,400w and 500w.

Solution:

Illumination required E = 100 lux

Area to be illuminated A = 30 x 15= 450 m2

D.F =0.8 , U.F =0.4 , Lumens/watt =14

Total lumen = $\Phi = \frac{E.A}{\eta . p}$

$= \Phi = \frac{450 \times 100}{0.8 \times 0.4}$ =140625

Total wattage required = $\frac{total lumens}{lumen/watt} = \frac{140625}{14}$ = 10044.6W=10,000W

Number of lamps 100W $= \frac{10000}{100} =$ 100

Number of lamps 250W $= \frac{10000}{250}$ =40

Number of lamps 100W $= \frac{10000}{400} =$ 25

Number of lamps 100W $= \frac{10000}{500} =$ 20

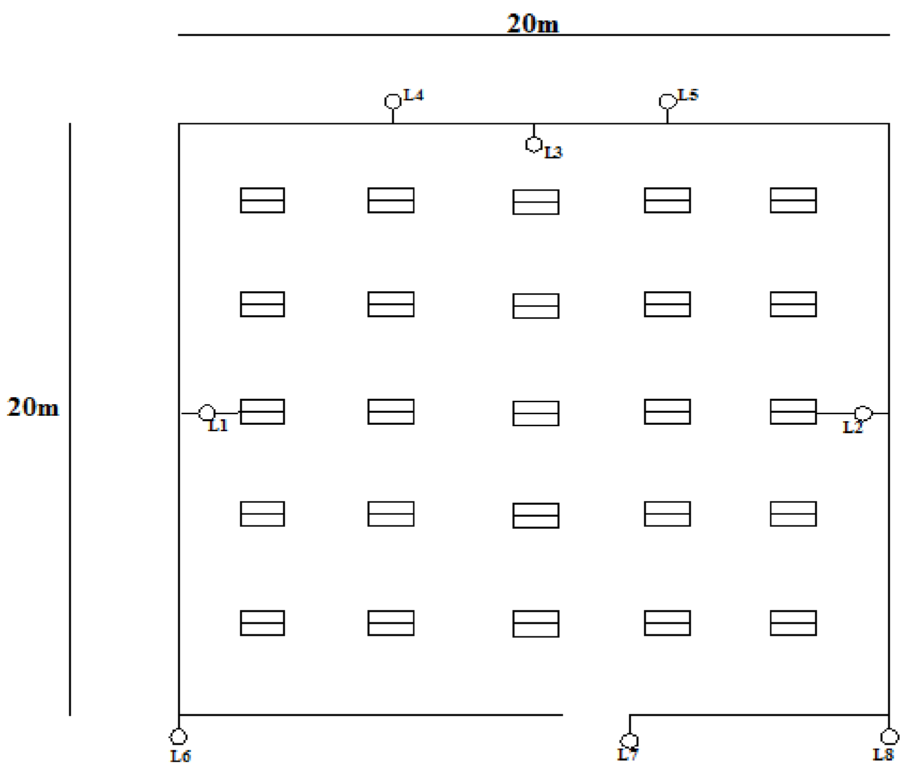
Example 4.4.

A factory of size 20 m*20 m is to be illuminated, so as to get the illumination of 20 lux at working plane .Find the number of lamps to be provided.(use twin tube lights of each 40 w)

Solution:

1. Assumptions:

1. **Area of room 20 mX20 m=400 sq m**
2. **Illumination required =20 lux**
3. **Deprecation factor= 0.7**
4. **Coefficient of utilization= 0.4**
5. **Efficiency of lamps=10.5 lumen/watt**
6. **Three phase 4 wire system is needed.**
7. **Height of ceiling=4m**
8. **Fluorecent twin tube light sets to be hang below ceiling =1m**



Total illumination required $= \frac{\text{Area X level of illumination}}{\text{Coefficient of utilisation X Deprecient factor}}$

$\frac{400\times 20}{0.4\times 0.7}$= **28571 lumens.**

Wattage required $= \frac{\text{lumens}}{\text{effeciency of lamp}}$ $= \frac{28571}{10.5}$**=2721watts**

If we select 80 w lamps =2721/80 =34 lamps

For room size 20 m*20 m we can select the lamps with space between lamps=2X2m.

The load can be distributed as:

In each bay =5 lamps, Totally 5 bays,

1.Therefore total lamps=5X5 =25 twin tube lights of each 80w=25X80 =2000w

2.In all four side walls four numbers of lamps of 100w =4X100w =400w

3.In front side entrance three numbers of 100w lamps =3X100 =300w

4.In back side wall one lamp of 100w =1X100 =100w

4.10.Sources of light

Various sources of lights are

i) Natural sources ex: sun, stars…

ii) Artificial Sources of Light ex: candles, kerosense lamps, petromax…

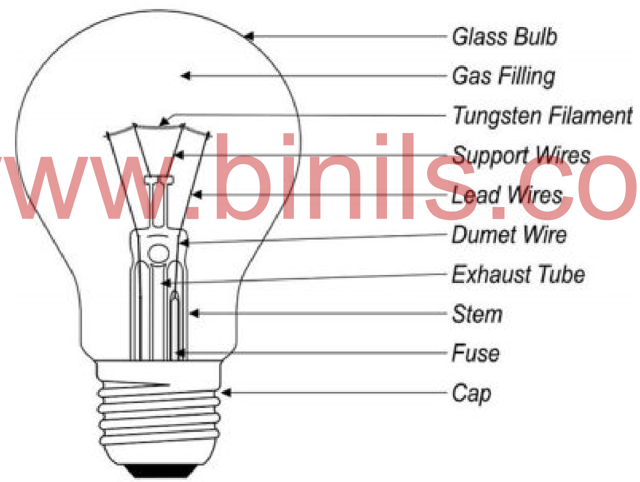
The different methods of producing light by electricity may, in a broad sense, be divided into three groups.

1. **By temperature incandescence**. In this method, an electric current is passed through a filament of thin wire placed in vacuum or an inert gas. The current generates enough heat to raise the temperature of the filament to luminosity.
Incandescent tungsten filament lamps are examples of this type and since their output depends on the temperature of their filaments, they are known as temperature radiators.

2. By establishing an arc between two carbon electrodes. The source of light, in their case, is the incandescent electrode.

3. Discharge Lamps. In these lamps, gas or vapor is made luminous by an electric discharge through them. The cplour and intensity of light i.e. candle-power emitted depends on the nature of the gas or vapor only. It should be particularly noted that these discharge lamps are luminescent-light lamps and do not depend on temperature for higher efficiencies. In this respect, they differ radically from incandescent lamps whose efficiency is dependent on temperature. Mercury vapor lamp, sodium-vapor lamp, neon-gas lamp and fluorescent lamps are examples of light sources based on discharge through gases and vapors.

4.11.Incandescent Lamp



An incandescent lamp essentially consists of a fine wire of a high-resistance metal placed in an evacuated glass bulb and heated to luminosity by the passage of current through it. Such lamps were.

The superiority of tungsten lies mainly in its ability to withstand a high operating temperature without undue vaporization of the filament. The necessity of high working temperature is due to the fact that the amount of visible radiation increases with temperature and so does the radiant efficiency of the luminous source.
In these lamps, the current is passed through a fine wire or filament of suitable material (tungsten), it is heated and temperature of the wire raises and heat as well as light energy will be radiated at low temperature.
At high temperature, the heat as well as light energy will be radiated, higher temperature of the wire, higher the amount of light energy radiated.
It is necessary to use a substance which can be made into a fine filament and raised quickly to a high temperature without being destroyed.

In fact, the ideal material for the filament of incandescent lamps is one which has the following properties:

1. A high melting and hence operating temperature

2. A low vapor pressure

3. A high specific resistance and a low temperature coefficient

4. Ductility and mechanically strong
5. Sufficient mechanical strength to withstand vibrations.

Since tungsten possesses practically all the above mentioned qualities, it is used in almost all modern incandescent lamps.

The object of vacuum was twofold :

(*a*) To prevent oxidation and

(***b***) To minimize loss of heat by convection and the consequent lowering of filament temperature.

However, vacuum favored the evaporation of the filament with the resulting blackening of the lamp so that the operating

4.12. Arc lamp

An **arc lamp** or **arc light** is a lamp that produces light by an electric arc (also called a voltaic arc). It continued in use in more specialized applications where a high intensity point light source was needed, such as searchlights and movie projectors until after World War II. The carbon arc lamp is now obsolete for all of these purposes and is only still made for very specialized purposes where a high intensity UV source is needed.

The term is now used for gas discharge lamps, which produce light by an arc between metal electrodes through an inert gas in a glass bulb. The common fluorescent lamp is a low-pressure mercury arc lamp. The xenon arc lamp, which produces a high intensity white light, is now used in many of the applications which formerly used the carbon arc, such as movie projectors and searchlights.

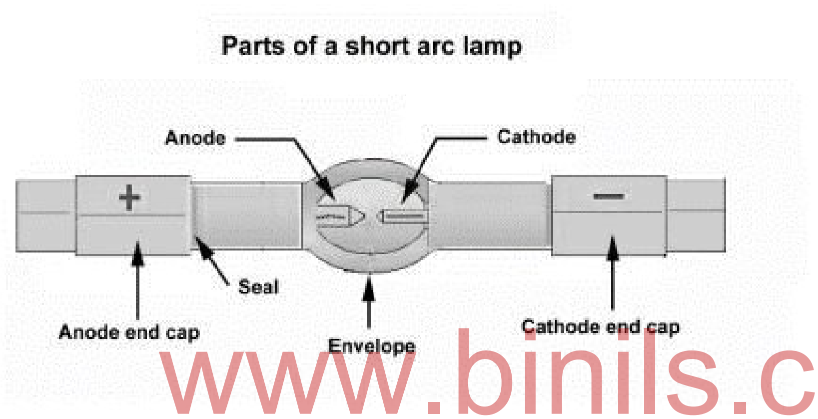
An *arc* is the discharge that occurs when a gas is ionized. A high voltage is pulsed across the lamp to "ignite" or "strike" the arc, after which the discharge can be maintained at a lower voltage. The "strike" requires an electrical circuit with an *igniter* and a ballast. The ballast is wired in series with the lamp and performs two functions.

First, when the power is first switched on, the igniter/starter (which is wired in parallel across the lamp) sets up a small current through the ballast and starter. This creates a small magnetic field within the ballast windings. A moment later the starter interrupts the current flow from the ballast, which has a high inductance and therefore tries to maintain the current flow (the ballast opposes any change in current through it); it cannot, as there is no longer a 'circuit'. As a result, a high voltage appears across the ballast momentarily - to which the lamp is connected, therefore the lamp receives this high voltage across it which 'strikes' the arc within the tube/lamp. The circuit will repeat this action until the lamp is ionized enough to sustain the arc.

When the lamp sustains the arc, the ballast performs its second function, to limit the current to that needed to operate the lamp. The lamp, ballast and igniter are rated matched to each other; these parts must be replaced with the same rating as the failed component or the lamp will not work.

A krypton arc lamp during operation:

The temperature of the arc in an arc lamp can reach several thousand degrees Celsius. The outer glass envelope can reach 500 degrees Celsius, therefore before servicing one must ensure the bulb has cooled sufficiently to handle. Often, if these types of lamps are turned off or lose their power supply, one cannot restrike the lamp again for several minutes (called cold restrike lamps). However, some lamps (mainly fluorescent tubes/energy saving lamps) can be restruck as soon as they are turned off (called hot restrike lamps).

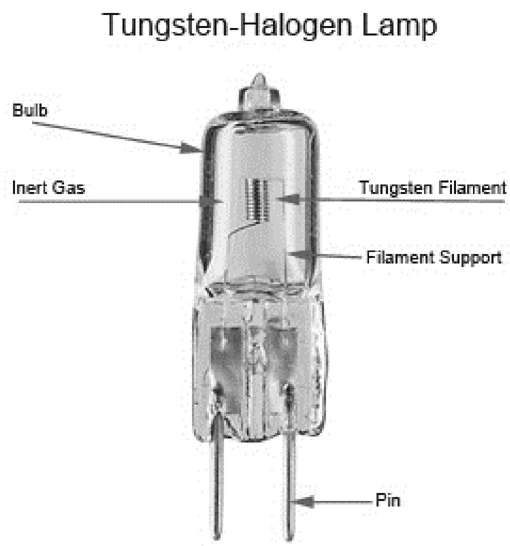


. In a **carbon arc lamp**, the electrodes are carbon rods in free air. To ignite the lamp, the rods are touched together, thus allowing a relatively low voltage to strike the arc.The rods are then slowly drawn apart, and electric current heats and maintains an arc across the gap. The tips of the carbon rods are heated and the carbon vaporizes. The carbon vapor in the arc is highly luminous, which is what produces the bright light. The rods are slowly burnt away in use, and the distance between them needs to be regularly adjusted in order to maintain the arc.

The Yablochkov candle is a simple arc lamp without a regulator, but it has the drawbacks that the arc cannot be restarted (single use) and a limited lifetime of only a few hour

Arc lamps were used in some early motion-picture studios to illuminate interior shots.
These were used aboard warships of all navies during the 20th century for signaling and illuminating enemies. In the 1920s, carbon arc lamps were sold as family health products, a substitute for natural sunlight, cinema projection, follow spots, and searchlights.

4.13. Halogen lamp



In incandescent lamps, the life and efficiency is reduced due to slow evaporation of filament and also due to black deposits formed on inner side of the bulb. The addition of a small amount of halogen vapor to the iodine gas restores part of the evaporated tungsten back to the filament by means of chemical reaction. This eliminated blackening which is normally caused by a deposit of evaporated tungsten on the walls of the envelope and a high luminous efficiency is maintained throughout the life of the lamp. The life of the halogen lamp is nearly double the tungsten filament lamp as the small envelope is used with resultant high gas filling pressure.

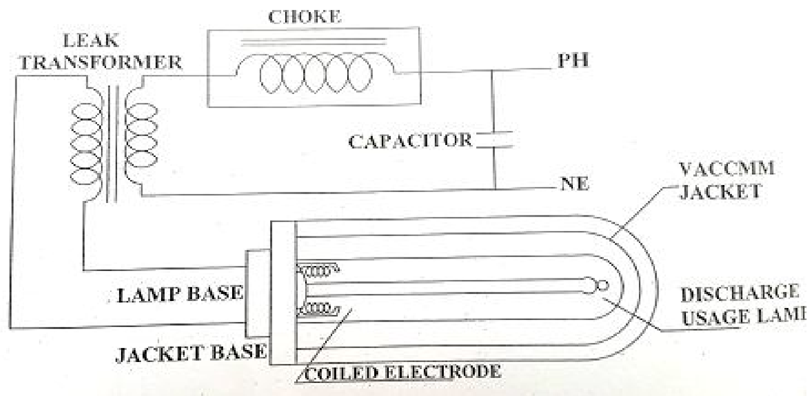
Advantages

i) Long life
ii) Better colour emitting
iii) No blackening of lamp, so no depreciation of lumen output through out the life of the lamp.
iv) Better luminous efficiency
v) Reduced dimensions of lamp is offered.
vi) Manufacturedupto 5kW.

Applications

Suitable for outdoor illumination of buildings, play ground, car parks, air port run ways, large garden

4.14.SodiumVapour Lamp



The glass of the inner tube is a special chemical resistant glass and is capable to withstand chemical action of hot sodium. One type of low-pressure sodium-vapour lamp along with its circuit connection is shown in Fig. It consists of an inner U-tube, containing small amount of sodium. Neon gas and electrodes. The tube is made of a special sodium-vapour-resisting glass. It houses the two electrodes and contains sodium together with the small amount of neon-gas at a pressure of about 10 mm of mercury and one per cent of argon whose main function is to reduce the initial ionizing potential. The discharge is first started in the neon gas (which gives out redish colour). After a few minutes, the heat of discharge through the neon gas becomes sufficient to vaporise sodium and then discharge passes through the sodium vapour. In this way, the lamp starts its normal operation emitting its characteristic yellow light

They have a starting time of 5 to 6 minutes. They go off and cannot be restarted after the recovery of the voltage till its value falls to the normal value. The colour of their light is yellowish and produces cplour distortion.

The tungsten-coated electrodes are connected across auto-transformer *T* having a relatively high leakage reactance. The open-circuit voltage of this transformer is about 450 V which is sufficient to initiate a discharge through the neon gas. The leakage reactance is used not only for starting the current but also for limiting its value to safe limit. The electric discharge or arc strikes immediately after the supply is switched on whether the lamp is hot or cold. The normal burning position of the lamp is horizontal although two smaller sizes of lamp may be burnt vertically. The lamp is surrounded by an outer glass envelope *B* which serves to reduce the loss of heat from the inner discharge tube *A* . In this way, *B* helps to maintain the necessary high temperature needed for the operation of a sodium vapour lamp irrespective of draughts. The capacitor *C* is meant for improving the power factor of the circuit.

The light emitted by such lamps consists entirely of yellow colour. Like sodium-vapour lamp, this lamp is also classified as electric discharge lamp in which light is produced by gaseous conduction. Such a lamp usually consists of two bulbs — an arc-tube containing the electric discharge and an outer bulb which protects the arc-tube from changes in temperature.

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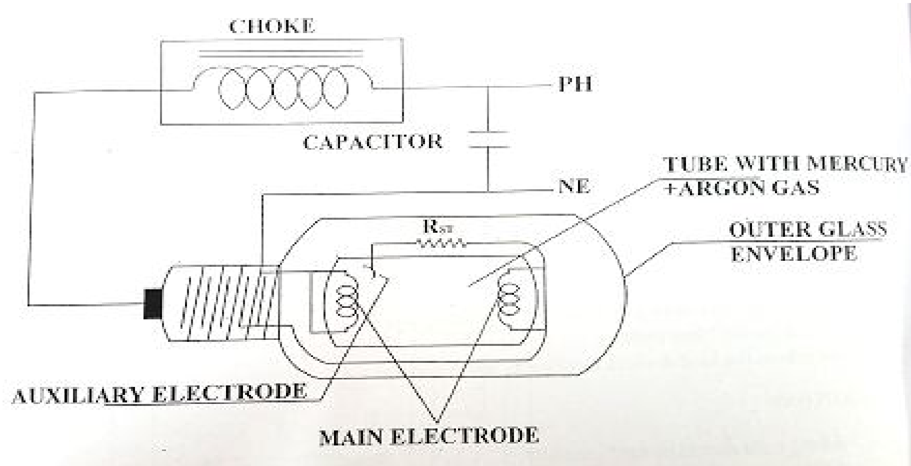
As compared to an incandescent lamp, a mercury-vapour lamp is (*a*) smaller in size (*b*) has 5 to 10 times longer operating life and (*c*) has 3 times higher efficiency *i.e.* 3 times more light output for given electrical wattage input.

4.15. High-pressure Mercury Vapour Lamp



They take 5 to 6 minutes for starting. They go off and cannot be restarted after the recovery of the voltage till the pressure falls to normal. They suffer from high colour distortion. They are suitable for open space like yards, parks and highway lighting etc. Change in voltage effects their starting time and colour of radiations emitted by them. Switching does not affect their life period. They have very limited utility that too on mains voltage. They are suitable for vertical position of working. They have an average working life of 3000 hours and an efficiency of 40 lm/W.

Like sodium-vapour lamp, this lamp is also classified as electric discharge lamp in which light is produced by gaseous conduction. Such a lamp usually consists of two bulbs — an arc-tube containing the electric discharge and an outer bulb which protects the arc-tube from changes in temperature. The inner tube or arc tube *A* is made of quartz (or hard glass) the outer bulb *B* of hard glass. As shown in Fig., the arc tube contains a small amount of mercury and argon gas and houses three electrodes *D*, *E* and *S*. The main electrodes are *D* and *E* whereas *S* is the auxiliary starting electrode. *S* is connected through a high resistance *R* (about 50 kΩ) to the main electrode situated at the outer end of the tube. The main electrodes consist of tungsten coils with electron-emitting coating or elements of thorium metal.

When the supply is switched on, initial discharge for the few seconds is established in the argon gas between *D* and *S* and then in the argon between *D* and *E*. The heat produced due to this discharge through the gas is sufficient to vaporize mercury. Consequently, pressure inside *A* increases to about one or two atmospheres and the p.d. across *D* and *E* grows from about 20 to 150 V, the operation taking about 5-7 minutes. During this time, discharge is established through the mercury vapours which emit greenish-blue light.

The choke serves to limit the current drawn by the discharge tube *A* to a safe limit and capacitor *C* helps to improve the power factor of the circuit.

True colour rendition is not possible with mercury vapour lamps since there is complete absence of red-light from their radiations. Consequently, red objects appear black, all blues appear mercury-spectrum blue and all greens the mercury-spectrum green with the result that colour values are distorted.

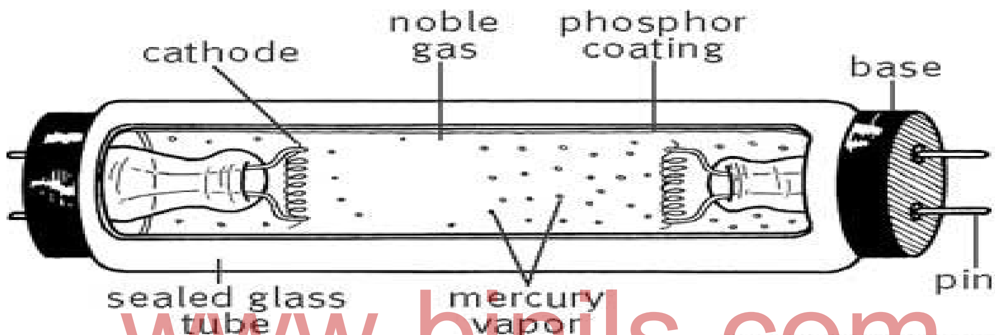
There has been tremendous improvement in the construction and operation of mercury-vapour lamps, which has increased their usefulness and boosted their application for all types of industrial lighting, floodlighting and street lighting etc. As compared to an incandescent lamp, a mercury-vapour lamp is (*a*) smaller in size (*b*) has 5 to 10 times longer operating life and (*c*) has 3 times higher efficiency *i.e.* 3 times more light output for given electrical wattage input.

Typical mercury-vapour lamp applications are :

Typical mercury-vapour lamp applications are :

1. High-bay industrial lighting — where high level illumination is required and colour rendition is not important.
2. Flood-lighting and street-lighting
3. Photochemical applications — where ultra-violet output is useful as in chlorination, water sterilization and photocopying etc.
4. For a wide range of inspection techniques by ultra-violet activation of fluorescent and phosphorescent dyes and pigments.
5. Sun-tan lamps — for utilizing the spectrum lines in the region of ultra-violet energy for producing sun-tan.

4.16.Fluorescent Lamps.



The Fluorescent tube consists of a glass tube 25mm in diameter and 0.6mt, 1.2mt and 1.5 mt in length. The tube contains argon gas at low pressure of 2.5 mt and one or two drops of mercury and inside surface of the tube is coated with a thin layer of Fluorescent material in the form of a powder. The coating material used depends upon the colour effect desired and may consists of zinc silicate, cadmium silicate or calcium tungsten. These organic chemicals are known as phosphorous which transformers short waves invisible radiation into visible light.

At start, current is passed through filaments which get heated up and emit electrons. This is achieved by use of choke with starter.

The choke is connected in series with the tube which acts as ballasts in running conditions and provides a high voltage impulse or surge for starting. At the time when switch is operated the starter is provided and the electrodes get heated and

Start emitting sufficient electrons. The switches or starters are of two types:

a) Thermal type starter   b) Glow type starter

Circuit diagram of fluorescent lamp with glow type starter is shown.

The bimetallic strips of the starter are normally open. When the supply is switched ON, full voltage is available across the bimetallic strips of the starter. This discharge heats the bimetallic strips of the starter causing them to bend and make contact. Now the tube filaments get heated and emit electrons inside the tube due to flow of current.

Now the voltage across the strips of the starter is reduced to zero. Hence the bimetallic strips cool down and the contacts open. Due to the change of current, high voltage is induced in the choke $e= L\, di/dt$. The high voltage produces an arc between the filaments of the tube. Hence the mercury in the tube discharges and the tube emit light. After the establishment of light in the tube , the voltage maintain light is reduced to 110V.As the tube current flows through the choke , sufficient voltage drop occurs in the choke. There by allowing only the required voltage to be applied across the tube. Also the choke limits the current in the lamp circuit. Due to the choke, the power factor of the circuit is low. Hence to improve the power factor a capacitor is connected across the supply.

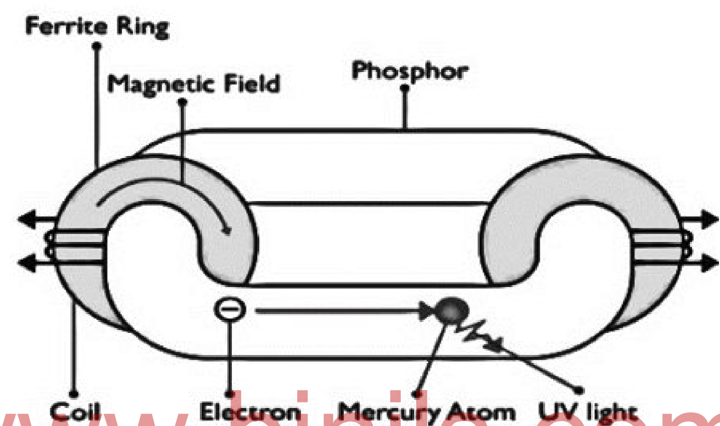
Advantages

i) Efficiency and life under normal conditions are three times of those for filament lamp

ii) The quality of light obtained is much superior.

Since stroboscopic effect is present, they are suitable for semi-direct lighting, domestic, industrial, commercial, roads and halls etc.

4.17.Induction lamp



The internal electrodes lamp or induction light is a gas discharge lamp in which the power required to generate light is transferred from outside the lamp envelope to the gas inside via an electric or magnetic field, in contrast with a typical gas discharge lamp that uses internal electrodes connected to the power supply by conductors that passes through the lamp envelop. There are two advantages to elimination of the internal electrodes.

1. Extended lamp life

2. The ability to use light generating substances of higher efficiency that would react with internal metal electrodes in normal lamps

Two types of lamps

1. Plasma lamps

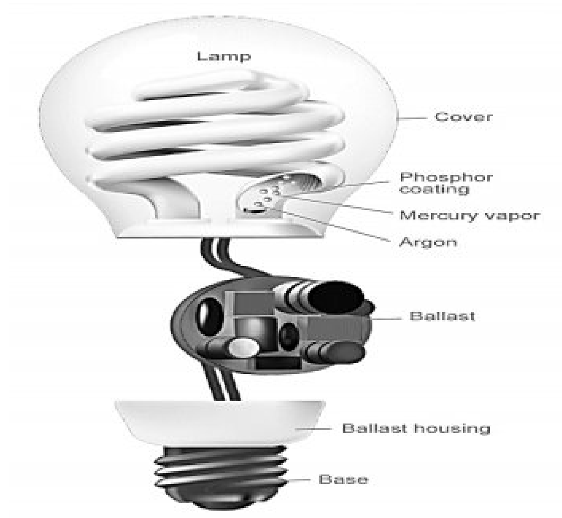
2. Fluorescent induction lamp

1. Plasma lamps which uses electrostatic induction to energies a bulb filled with sulfur vapor or metal halides.

2. Fluorescent induction lamps, based upon a conventional fluorescent lamp bulb in which current is induced by an external coil of wire via electrodynamics induction.

4.18. Energy saving lamps (CFL & LED)

a).Compact fluorescent lamp



A compact fluorescent lamp (CFL), also called compact fluorescent light, energy-saving light, and compact fluorescent tube, is a fluorescent lamp designed to replace an incandescent light bulb. Some types fit into light fixtures designed for incandescent bulbs. The lamps use a tube which is curved or folded to fit into the space of an incandescent bulb, and a compact electronic ballast in the base of the lamp.

The principle of operation remains the same as in other fluorescent lighting: electrons that are bound to mercury atoms are excited to states where they will radiate ultraviolet light as they return to a lower energy level; this emitted ultraviolet light is converted into visible light as it strikes the fluorescent coating (as well as into heat when absorbed by other materials such as glass).

Conventional light fixture using an adapter containing a built-in magnetic CFLs have two main components: a magnetic or electronic ballast and a gas-filled tube where ballasts contain a small circuit board with a bridge rectifier, a filter capacitor and usually two switching transistors, which are often insulated-gate bipolar transistors. The incoming AC current is first rectified to DC, and then converted to high frequency AC by the transistors, connected as a resonant series DC to AC inverter. The resulting high frequency is applied to the lamp tube. Since the resonant converter tends to stabilize lamp current (and light produced) over a range of input voltages. CFLs emit light from a mix of phosphors, each emitting one band of colour with some bands still in the ultraviolet range as can be seen on the light spectrum. This is the reason why additional UV filtering, for example double-envelope, is required to reduce damage to the retina.

CFL light output is roughly proportional to phosphor surface area. Standard shapes of CFL tube are a helix with one or more turns, multiple parallel tubes, circular arc, or a butterfly.

CFLs use three or four phosphors to achieve a "white" light with a colour rendering index (CRI) of about 80, where the maximum 100 represents the appearance of colours under daylight or other sources of black-body radiation such as an incandescent light bulb

b) There are two types of CFLs:

1. Integrated 2. Non-integrated lamps

Integrated lamps combine the tube and ballast in a single unit. These lamps allow consumers to replace incandescent lamps easily with CFLs. Integrated CFLs work well in many standard incandescent light fixtures, reducing the cost of converting to fluorescent. 3-way lamps and dimmable models with standard bases are available.

Non-integrated CFLs have the ballast permanently installed in the luminaries. Non-integrated CFL housings can be both more expensive and sophisticated. They have two types of tubes: a bi-pin tube designed for conventional ballast, and a quad-pin tube designed for electronic ballast or conventional ballast with an external starter.

c) Comparison of CFL with incandescent lamp:

- If a building's indoor incandescent lamps are replaced by CFLs, the heat produced due to lighting is significantly reduced. In warm climates or in office or industrial buildings where air conditioning is often required, CFLs reduce the load on the cooling system when compared to the use of incandescent lamps, resulting in savings in electricity in addition to the energy efficiency savings of the lamps themselves
- CFLs typically have a rated service life of 6,000–15,000 hours, whereas standard incandescent lamps have a service life of 750 or 1,000 hours
- Compared to general-service incandescent lamps giving the same amount of visible light, CFLs use one-fifth to one-third the electric power, and last eight to fifteen times longer.
- A CFL has a higher purchase price than an incandescent lamp, but can save over five times its purchase price in electricity costs over the lamp's lifetime
- CFLs radiate a spectral power distribution that is different from that of incandescent lamps. Improved phosphor formulations have improved the perceived colour of the light emitted by CFLs, such that some sources rate the best "soft white" CFLs as subjectively similar in colour to standard incandescent lamps

d) Limitations of CFL

- CFLs, like all fluorescent lamps, contain mercury as vapor inside the glass tubing.
- Like all fluorescent lamps, CFLs contain toxic mercury which complicates their disposal. In many countries, governments have banned the disposal of CFLs together with regular garbage.
- Most CFLs contain 3–5 mg per bulb, with the bulbs labeled "eco-friendly" containing as little as 1 mg.
- Because mercury is poisonous, even these small amounts are a concern for landfills and waste incinerators where the mercury from lamps may be released and contribute to air and water pollution.
- Health and environmental concerns about mercury have prompted many jurisdictions to require spent lamps to be properly disposed of or recycled, rather than being

included in the general waste stream sent to landfills. Safe disposal requires storing the bulbs unbroken until they can be processed.

4.19. LED lamp

An **LED lamp** is a light-emitting diode (LED) product that is assembled into a lamp (or light bulb) for use in lighting fixtures. LED lamps have a lifespan and electrical efficiency which are several times greater than incandescent lamps, and are significantly more efficient than most fluorescent lamps

General-purpose lighting needs white light. LEDs emit light in a very narrow band of wavelengths, emitting light of a colour characteristic of the energy band gap of the semiconductor material used to make the LED. To emit white light from LEDs requires either mixing light from LEDs of various colours, or using a phosphor to convert some of the light to other colours.

The two simplest methods of producing white light LEDs are RGB or phosphor. RGB or tri chromatic white LEDs uses multiple LED chips emitting red, green, and blue wavelengths. These outputs combine to produce white light. The colour rendering index (CRI) is poor, typically 25 - 65, and due to the narrow range of wavelengths emitted.

The second basic method uses LEDs in conjunction with a phosphor to produce complementary colours from a single LED. The most common method is to combine a blue LED with a yellow phosphor, producing a narrow range of blue wavelengths and a broad band of "yellow" wavelengths actually covering the spectrum from green to red. The CRI value can range from less than 70 to over 90, although a wide range of commercial LEDs of this type have a colour rendering index around 82.

LED lamps are used for both general and special-purpose lighting. Where coloured light is needed, LEDs that inherently emit light of a single colour require no energy-absorbing filters.

White-light LED lamps have longer life expectancy and higher efficiency (more light for the same electricity) than most other lighting when used at the proper temperature. LED sources are compact, which gives flexibility in designing lighting fixtures and good control over the distribution of light with small reflectors or lenses. Because of the small size of LEDs, control of the spatial distribution of illumination is extremely flexible, and the light output and spatial distribution of an LED array can be controlled with no efficiency loss.

LEDs using the colour-mixing principle can emit a wide range of colours by changing the proportions of light generated in each primary colour. This allows full colour mixing in lamps with LEDs of different colours.

a)Advantages of LED lamps

- In keeping with the long life claimed for LED lamps, long warranties are offered
- Reduces energy costs — uses at least 75% less energy than incandescent lighting, saving on operating expenses.
- Reduces maintenance costs — lasts 35 to 50 times longer than incandescent lighting and about 2 to 5 times longer than fluorescent lighting. No lamp-replacements, no ladders, no ongoing disposal program.
- Reduces cooling costs — LEDs produce very little heat.
- Is guaranteed — comes with a minimum three-year warranty — far beyond the industry standard.
- Offers convenient features — available with dimming on some indoor models and automatic daylight shut-off and motion sensors on some outdoor models.
- Is durable — won't break like a bulb.

Limitations

- Many will not work with existing dimmer switches designed for [higher power] incandescent lamps.
- Colour rendering is not identical to incandescent lamps which emit close to perfect Black-body radiation as that from the sun and for what eyes have evolved.
- LED efficiency and life span drop at higher temperatures,.
- LED lamps are sensitive to excessive heat, like most solid state electronic components.
- The long life of LEDs, expected to be about 50 times that of the most common incandescent lamps and significantly longer than fluorescent types.

4.20.Comparison of Incandescent, CFL,LED lamps

Sl.no	Property	Incandescent	CFL	LED
1	Watts	60	14	6.5
2	lumens (mean)	860	775	800
3	lumens/watt	14.3	55.4	123.1
4	Cplour Temperature kelvin	2700	2700	2700
5	CRI	100	82	80
6	Lifespan (hours)	1,000	10,000	15,000

Review questions

Part A & B

1. What is the normal Space –height ratio of industrial Lighting?
2. What is Flood Lighting?
3. Mention the power ratings of CFL?
4. What is meant by Illumination?
5. What are the factors to be consider while designing good lighting system
6. State the requirements of good lighting system?
7. State the disadvantages of Incandescent lamp?
8. Define Utilization factor.
9. What is the energy saving procedures for fluorescent lamp?
10. Explain the two types of induction lamp.
11. Define Luminous Intensity
12. Explain the two types of CFL.
13. What are the advantages of CFL over Fluorescent tube?
14. Justify that the gaseous lamp
15. How stroboscopic effect can be avoided?
16. How is discharge lamps are superiors than Incandescent lamp?
17. Explain Lamberts Cosine Law.
18. What the factors to be considered while designing Indoor Lighting Scheme?
19. What are the Advantages of LED lamps
20. What are the Limitations of CFL
21. What are the applications of mercury-vapour lamp
22. What are the advantages and applications of halogen lamp?

Part C

14. State and explain the 2 laws of Illumination.
15. Explain with a sketch the working of High pressure mercury Vapour lamp.
16. Explain with a sketch the working of sodium vapour lamp.
17. List the five types of Lighting Schemes with a brief note on each type.
18. Give a Detailed account of Fluorescent lamp of various types? What are their advantages and Disadvantages as compared to other light sources?
19. Explain with a sketch the working of incandescent lamp.
20. Explain with a sketch the working of halogen lamp.
21. Explain with a sketch the working of induction lamp
22. Explain with a sketch the working of carbon arc lamp
23. Explain with a sketch the working of CFL & LED lamp
24. Explain the various factors to be taken into account for designing scheme for (i)street lighting (ii)flood lighting

UNIT V

ELECTRIC HEATING and WELDING

5.1.1. INTRODUCTION – HEATING

Electric heating is preferred than other heating methods because of its simplicity. Electric heating is based on the principle that when electric current passed through a medium, heat will be produced. Electric heating characteristics of current is used in industrial & domestic heating appliances

ADVANTAGES OF ELECTRIC HEATING

- Economical
- High η (75 to 100%)
- Cleanliness
- Absence of flue gases
- Ease of control
- Automatic protection
- Localized application
- Uniform heating
- Low attention & low maintenance cost
- Better working conditions

5.1.2. CLASSIFICATION OF HEATING METHODS BASED ON TEMPERATURE RANGE

- Low temperature heating (upto 400^0 C)
- Medium temperature heating (400^0- 1150^0C)
- High temperature heating (above 1150^0 C)

5.1.3. MODES OF HEAT TRANSFER

1. Conduction

Heat transfer depends on temperature difference between parts of body

Heated molecules transform heat to adjacent molecules

Applicable for Solids

2. Convection

By actual motion of particles

Applicable for Liquids

Amount of heat dissipation = $3.876X10^{-4}(T_1 - T_2)^{1.25}$ Watts / cm^2

T_1 = Temperature of heating surface

T_2 = Temperature of air

3. Radiation

By heat Waves

Do not heat the medium between bodies

Heat the body which intercepts waves

Heat transmitted = $5.72X10^4 ke \{ (T_1/1000)^4 – (T_2/1000)^4 \}$ Watts / cm^2

k = radiating efficiency

e = emissivity constant

T_1 = Temperature of heating surface

T_2 = Temperature of substance to be heated

5.1.4. TYPES OF ELECTRIC HEATING:

I. Power frequency heating
   a) Direct resistance heating
   b) Indirect resistance heating
   c) Radiant / Infra red heating
   d) Salt bath heating

II. High frequency heating
   a) Direct induction heating
   b) Indirect induction heating
   c) Dielectric heating
   d) Electric arc heating

5.1.5. DIRECT RESISTANCE HEATING

Working principle:

In this method the material (or charge) to be heated is treated as a resistance and current is passed through it. The charge may be in the form of powder, small solid pieces or liquid. The two electrodes are inserted in the charge and connected to either a.c. or d.c. supply . Obviously, two electrodes will be required in the case of d.c. or single-phase a.c. supply but there would be three electrodes in the case of 3-phase supply. When metal pieces are to be heated, a powder of high resistivity material is sprinkled over the surface of the charge to avoid direct short circuit.. Heat is produced when current passes through it. This method of heating has high efficiency because the heat is produced in the charge itself.

- Material to be heated is called as Charge
- Non- metal Charges are in the forms of Powder, Pieces or liquid
- They form a resistance for the current flow
- For heating Metal Charges, High resistance powder is sprinkled, to avoid short circuit
- DC & 1 Ø AC supplies – 2 Electrodes

- 3 Ø AC supply – 3 Electrodes

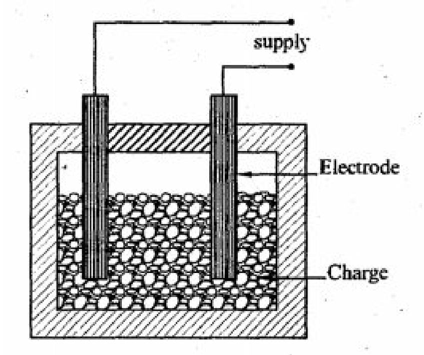


Fig. 5.1 Direct Resistance Heating

ADVANTAGES

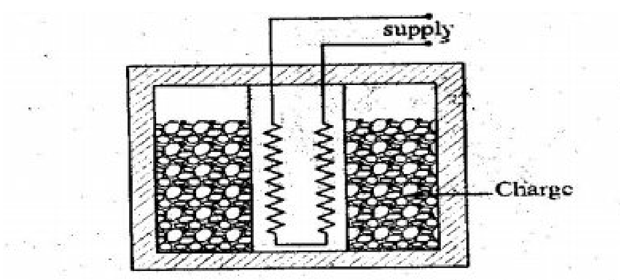
- High Ƞ
- Gives uniform heat
- Gives high temperature

DISADVANTAGES

- Current is not easily variable
- Automatic temperature control is not possible

5.1.6. INDIRECT RESISTANCE HEATING

Working principle: In this method of heating, electric current is passed through a resistance element which is placed in an electric oven. Heat produced is proportional to I 2 R losses in the heating element. The heat so produced is delivered to the charge either by radiation or convection or by a combination of the two. Sometimes, resistance is placed in a cylinder which is surrounded by the charge placed in the jacket as shown. This arrangement provides uniform temperature. Moreover, automatic temperature control can also be provided.



ADVANTAGES

1. Gives uniform heat

2. Automatic temperature control is possible

DISADVANTAGES

- Lower efficiency.

5.1.7. INFRA RED / RADIANT HEATING

Working principle:

This type if heating is used for low and medium temperatures. In this method a special tungsten filament lamp is operated at the temperature of 2300°C. The lamp at this temperature emits a large amount of infra red radiation. Operating the lamp at this temperature also increases the life of the filament. In comparison to other resistance heater, this lamp emits a large amount of heat, which is being reflected to the charge. In this method, heat emission about 7500 watts/m² can be obtained. The temperature of charge obtained will be 200 to 300°C.

This type of heating is employed in drying paint and foundry moulds and plastic heating at low temperatures.

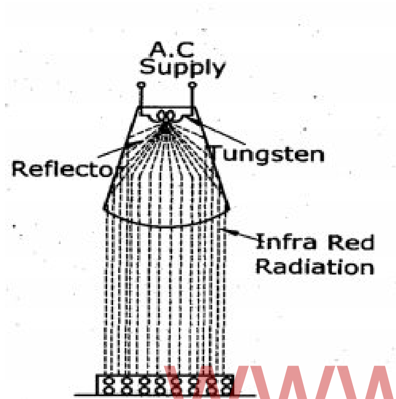


Fig. 5.3Infra Red Heating

ADVANTAGES

1. High heat transfer rate
2. Reduce the heating time
3. Heat absorption is more

APPLICATIONS

1. Paint drying
2. Plastic heating at low temperatures
3. Foundry molding

5.1.8. ARC HEATING

When high voltage is applied across two electrodes separated by air gap, air is ionized due to electrostatic stress. The Ionized air is a conducting material, therefore Current starts flowing through air gap, by continuous sparks i.e. arc with Graphite / Carbon electrodes, temperature obtained will be 3000^0 C to 3500^0 C

a)Direct Arc Heating

Direct& Indirect Arc Heating methods are discused in detail under arc furnaces topic later as the principle is the same for both.

Fig. 5.4Direct Arc Heating

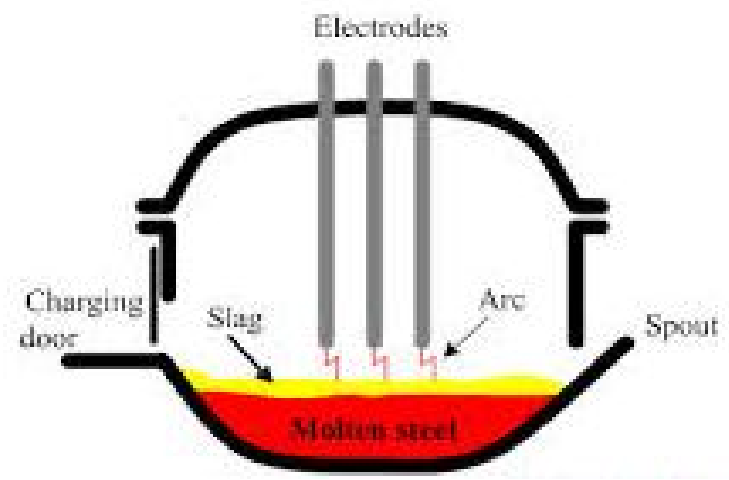
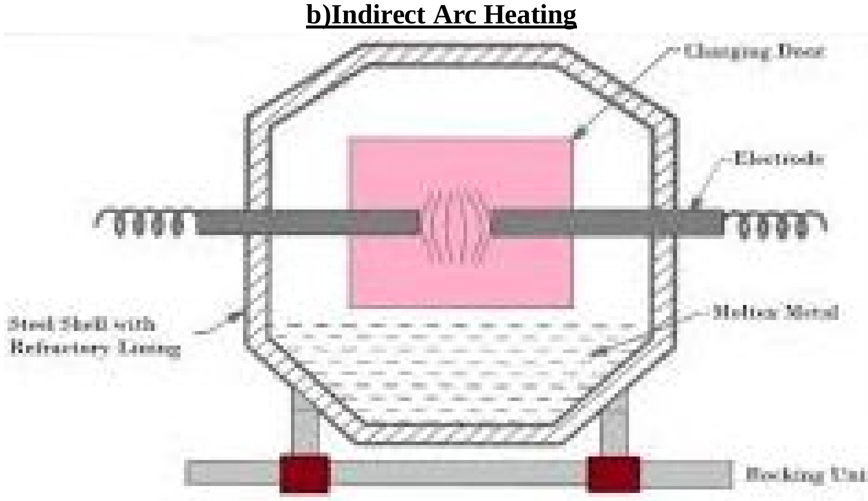


Fig. 5.5 Indirect Arc Heating

b)Indirect Arc Heating



5.1.9.HIGH FREQUENCY ELECTRIC HEATING- INDUCTION HEATING

Working principle:

Introduction heating is based on the transformer principle. There is a primary winding through which an a.c current is passed. The coil is magnetically coupled with the metal to be heated, which acts as the secondary. When an a.c current is passed through the primary winding, an electric current will be induced in the metal. This induced current produce heat in the metal. Alternating current induced in charge depends upon magnitude of primary current

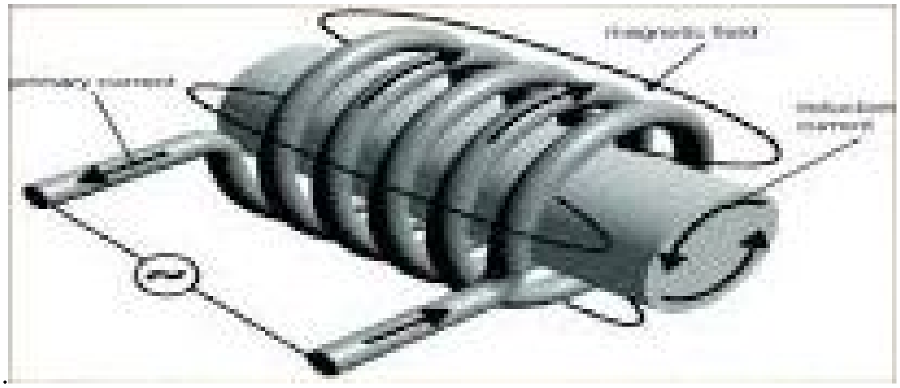


Fig.5.6 Induction Heating

USES OF INDUCTION HEATING

- Surface hardening
- Deep hardening
- Tempering
- Soldering
- Melting
- Smelting (Extraction of metals from their ores)

Example: INDUCTION STOVE

Induction stoves cook by magnetic induction, instead of thermal conduction, by flame or electrical heater

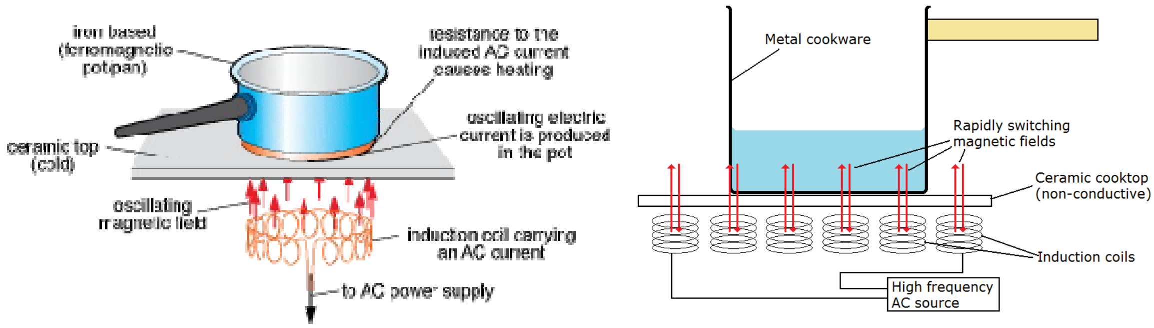
Usually have glass tops and Heats the pot/vessel directly. Rapid increase in temperature is achieved by a copper coil in induction stove is given with high frequency ac supply (Eg.24 KHz).The oscillating magnetic field induces a magnetic flux, which magnetizes the pot placed over the stove and the pot acts as the core of a transformer so, large eddy currents are produced in the pot, based on its resistance for heating.

Cooking vessel/pot must be made of, or contain, a ferromagnetic metal (Cast iron, Stainless steel, etc.)

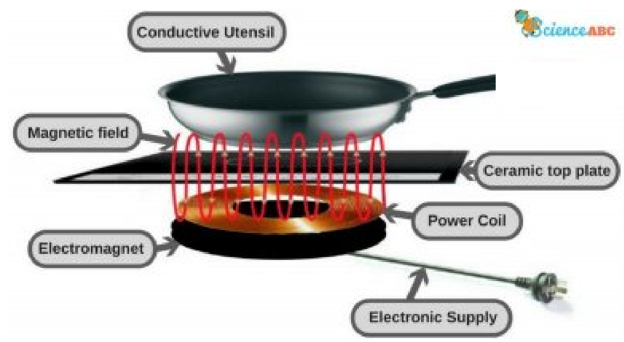
Advantages

1. Highly efficient (Fast heating)
2. Less wastage of heat
3. Can be quickly turned off
4. Safe (No hazardous temperature)
5. Easy to clean
6. Consistent

Fig.5.6 a. Induction stove - Principle



<u>Fig.5.6 b. Induction stove</u> (Only for understanding purpose)



Disadvantages

1. Cooking vessel should be ferromagnetic
2. Noise production due to running fan inside stove
3. Some cooking techniques are not applicable
4. Persons with implanted cardiac pacemakers should avoid magnetic fields from induction stove
5. Radio receivers near stove may pick up electromagnetic interference
6. Costlier
7. Needs electricity

5.1.10.a) EDDY CURRENT HEATING

Working principle:

- High frequency eddy current heating is nothing but a form of induction heating. Usually if is used for hardening, annealing and tempering of machine parts. The machine part to be heated is surrounded by a coil through which an alternating current at high frequency is passed. Electromagnetic field in coil produces heating effect, due to eddy currents set up.

Area of the machine parts or metal. The heating effect is due to eddy currents set up in the machine parts. Due to skin effect the induced heating current concentrate near the surface of the conductor through which flux is set up. At high frequencies the eddy currents developed are concentrated at the surface. Therefore high frequency is used for heating light machine parts and low frequency is used for heavy machine parts.

<u>Fig.5.7 a. Eddy Current Heating</u>

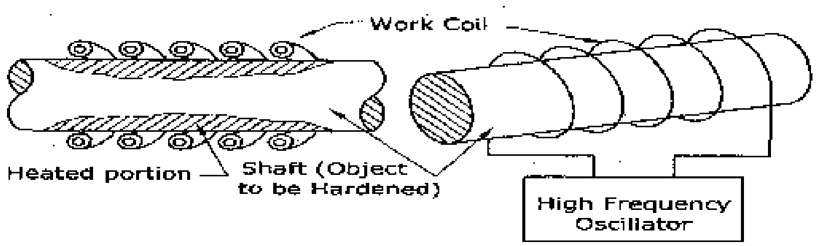
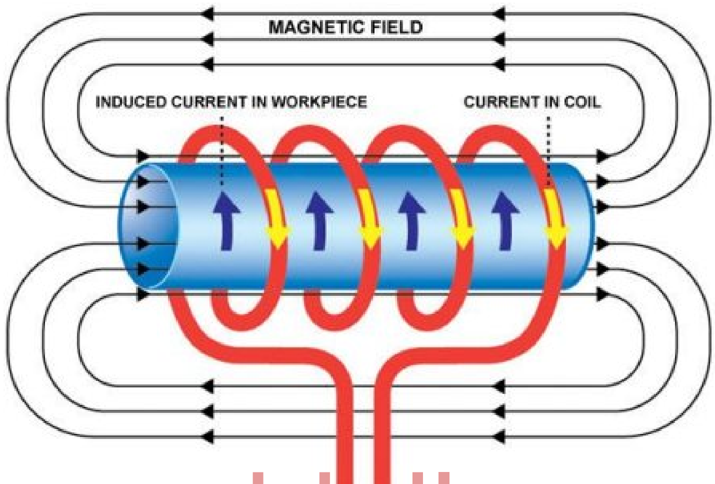


Fig.5.7 b. Eddy Current Heating(Only for understanding purpose)



Applications

1. Hardening, Annealing & Tempering of machine parts
2. Zonal Heating
3. Hardening of drilled holes
4. Hardening of shafts, tools, endless saw blades & Gears
5. Soldering
6. Vacuum tube heating

b) DIELECTRIC HEATING

Working principle:

Dielectric heating is also sometimes called as high frequency capacitance heating. If non metallic materials ie, insulators such as wood, plastics, china clay, glass ceramics etc are subjected to high voltage A.C current , their temperature will increases after some time. The increase in temperature is due to the conversion of dielectric loss into heat. The dielectric loss is dependent upon the frequency and high voltage. Therefore for obtaining high heating effect high voltage at high frequency is usually employed.

The metal to be heated is placed between two sheet type electrodes which form a capacitor.

When A.C supply is connected across the two electrodes, the current drawn by it is leading the voltage exactly 90°. The angle between voltage and current is slightly less than 90°, with the result that there is a in phase component of the current. This current produces power loss in the dielectric of the capacitor.

At normal supply frequency the power loss may be small. But at high frequencies, the loss becomes large which is sufficient to heat the dielectric. Rate of heat production can also be increased by applying high potential but it is also limited because of the following considerations:

(a) Possibility of formation of standing waves between the surface of two electrodes having wavelength nearly equal to or more than one quarter of the wavelength of the particular frequency used.

(b) Necessity of employing special matching circuit at higher frequencies due to the fact that maximum power transfer takes place when the oscillator impedance equals the load impedance.

(c) At higher frequencies it is difficult for tuning inductance to resonate with the charge capacitance.

(d) At higher frequencies, it is almost impossible to get uniform voltage distribution.

Fig.5.8.a. Dielectric Heating

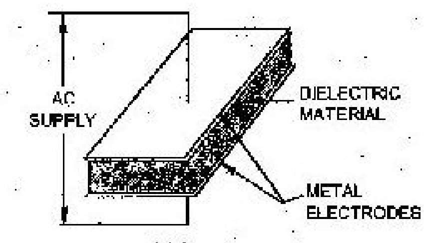
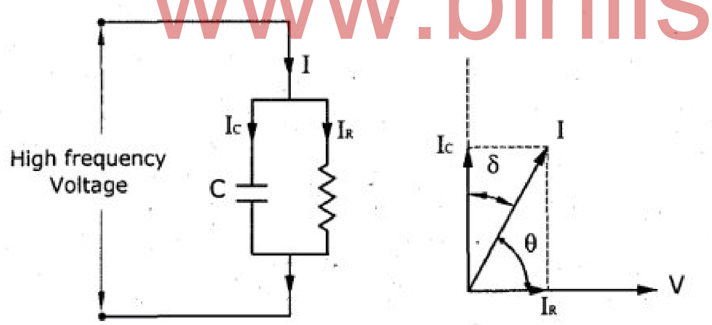


Fig.5.8.b. Equivalent circuit & Vector diagram



Advantages

1. Uniform heat
2. Simple
3. Low running cost
4. Heat generated can be controlled accurately
5. Better Working conditions
6. Less Time of Operation
7. Also called as Capacitance Heating
8. For heating non metallic materials Eg. Wood, Plastic, China Clay, Glass, Ceramics

Applications

1. Manufacturing of synthetics
2. Wood processing

3. Foundry course baking
4. Food processing

5.2. ELECTRIC FURNACES

RESISTANCEFURNACES:

5.2.1.REQUIREMENTS OF HEATING ELEMENT MATERIALS

- High resistivity
- High Melting point
- High Mechanical Strength
- High Corrosion resistance
- Low RTC (Resistance Temperature Coefficient)
- Free from oxidation
- Withstand vibrations

5.2.2. COMMONLY USED HEATING ELEMENT MATERIALS

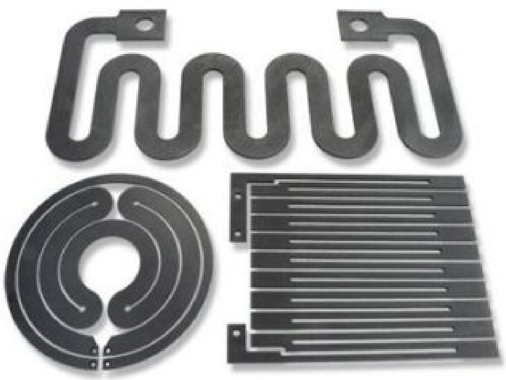
- Nickel Chromium Alloy (Nichrome)
- Nickel Chromium Copper Iron Alloy (Eureka / Constantan)
- Aluminum Chromium Iron Alloy (Kanthal)

5.2.3. RESISTANCE FURNANCE FOR SPECIAL PURPOSES;

The two important resistance ovens are:

1. Air circulation oven

2. Bright annealing furnace



1.Air circulation oven:

In this type, the heat is transferred to the charge by convection currents. These are usually employed for drawing and hardening steel wire and providing heat treatment to soft metals like aluminum etc. Gas or Screened air is passed by Blowers or Fans, to avoid radiation and used to circulate the gases or air. Air circulation from Top to bottom or from bottom to top. The hot gas or air is passed through the furnace containing charge. The hot gasses circulating in the furnace, heat up the charge uniformly.

The direction of flow of air circulation is reversed periodically in order to make the distribution of heat more uniform.

Application

NITRIDING (Steel after heated by hot air, exposed to Ammonia)

2. Bright annealing furnace

Annealing is the process in which the charge is heated and cooled slowly for elimination of brittleness. If the cooling is done in air, due to oxygen and water vapours the charge surface is covered with scale formation, resulting into a dull finish. In this type of furnaces, the charge is heated in a sealed furnace and the air is discharged during heating through a non return valve. Thus the cooling is carried out in an air free atmosphere and it keeps the surface of the charge bright and then air is expelled through a non- return valve.

5.2.4. TEMPERATURE CONTROL OF RESISTANCE FURNACES

1. By varying the number of elements ($T \propto R$)
2. Change in connections (Series, Parallel)
3. Adding a variable external resistance, in series with the element
4. Changing transformer tappings ($V \propto I$)

Fig.5.9. Resistance furnace(Only for understanding purpose)

5.2.5. ELECTRIC ARC FURNACES

PRINCIPLE

When a high voltage is applied across 2 electrodes, separated by air gap, the air ion between gets ionized by electrostatic forces. Electrodes are made of Carbon/Graphite. By this ionized air current flows through the air gap as in form of sparks. This arc provides a large quantity of power in a small volume. Concentration of heat develops at high temperatures of 3000 to 3500˚C. Heating chamber is constructed with refractory lining.

ADVANTAGES

- Arc furnaces operate with 100% steel scrap, cheaper than pig iron
- Capital cost is lesser than open hearth furnace for same output power (2/3rd)

TYPES OF ARC FURNACES

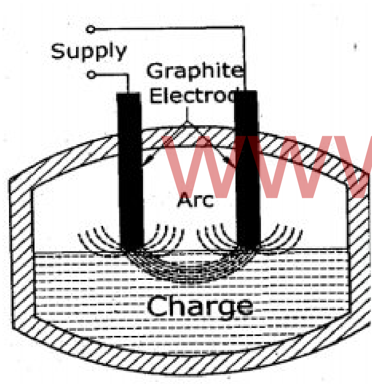
1. Direct arc furnace
2. Indirect arc furnace

1. Direct arc furnace

Working principle:

In this type the charge acts as another electrode. There are two carbon or graphite electrodes and the arc is developed at two places. The arc is directly in contact with the charge and the arc is due to the current in the charge, therefore the charge is heated to very high temperature. Single arc or 2/3 arcs are established between electrodes. Current flows through the body of charge, develops heat due to electric resistance.

Fig.5.10 Direct arc furnace



Advantages

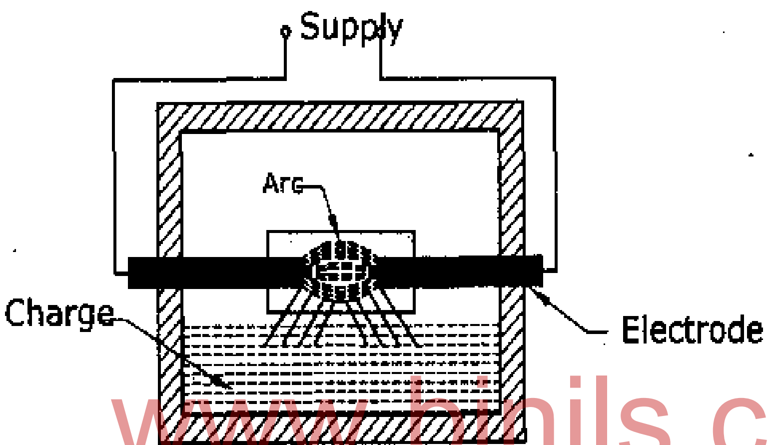
1. Very high temperature is obtained
2. More uniform in composition
3. Stirring action takes place.
4. Used for steel production
5. Power factor is 0.8
6. Size of the furnace is from 5 to 10 tones (small), from 50 to 100 tones (large)

2. Indirect arc furnace

Working principle:

The arc is produced between two electrodes and the heat is transmitted to the charge by radiation. Current flows through electrodes & Arc Exists between two electrodes. Heat is radiated from arc to the charge. It is only of single phase type, because of limitation of number of electrode. The current does not flow through the charge; hence there is no automatic stirring. So the furnace is required to be rocked mechanically. Indirect arc furnaces are used for melting non ferrous metals. Maximum temperature attained by charge is low. Used in iron industries, where intermittent supply of molten metal is required

Fig.5.11 Indirect arc furnace



Advantages

- Flexibility
- High melting speed
- Economy
- Low metal losses
- Sound castings

Applications

- To make castings of alloy iron for heat resisting, abrasion resisting & similar special purposes
- Suited for non- ferrous castings of copper, bronze, nickel alloy etc,
- Hydraulic & other pressure fittings

3. SUBMERGED ARC FURNACE

These are cylindrical furnaces in which arc is formed between the carbon electrodes and hearth electrodes. The hearth lining is of magnetite which becomes comparatively good electrical when hot. The number of electrodes taken from the roof depends on the type of supply. One for single phase, two or four for two phases and three for three phase supply, bottom conductor being connected to the neutral. Usually 3 phase supply is used for large power requirement. The current from the top electrode passes through the arc to the charge and returns through the electrode at the bottom of the charge. In this furnace, uniform heating and mixing of charge takes place. Power is controlled by varying the distance between the electrodes or by varying the voltage applied to the electrodes. These furnaces are used for the manufacture of ferroalloy like Ferro - chromo and Ferro -manganese.

5.2.6.a.POWER SUPPLY TO ARC FURNACE

- Small Arc furnaces of ½ tone capacity require power of about 500KW/Tone
- Large furnaces of 50 to 100 tonnecapacity require power of about 200KW/Tone
- Heating effect is directly proportional to square of the current
- High voltage between electrode & charge produces High voltage gradient
- High currents & low voltage keep the electrodes very near to charge

Temperature control of arc furnaces

- By varying resistance of arc.
- By increasing/decreasing distance between gaps (Electrode & Charge)
- Changing transformer tappings.

b. REASONS FOR EMPLOYING HIGH CURRENT & LOW VOLTAGE SUPPLY FOR ARC FURNACES

- Heating Effect is directly proportional Square of Current. High current gives more heat.
- Electrodes can be kept near to the charge.
- Life of roof refractory is increased.
- Less insulation & more safety

5.2.7. TYPES OF INDUCTION FURNACES

a) Core type induction furnace
1. Direct core type induction furnace
2. Vertical Core (AJAX WYATT) induction furnace
3. Indirect core type induction furnace

b) Coreless induction furnace

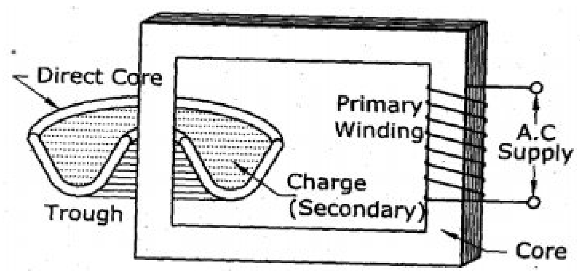
1. DIRECT CORE TYPE INDUCTION FURNACE

Working principle:

It consists of an iron core, crucible and primary winding connected to an A.C supply. The charge is kept in the crucible, which forms a single turn short circuited secondary of transformer.. The current in the charge is very high in the order of several thousand amperes. The charge is magnetically coupled to the primary winding. When high current induced in it the charge is melted. Current of

Several thousand Amperes melts charge. When there is no molten metal, no current will flow in the secondary. To start the working of the furnace, molten metal is to be poured or some quantity must be left in oven

Fig.5.12. Direct core type induction furnace



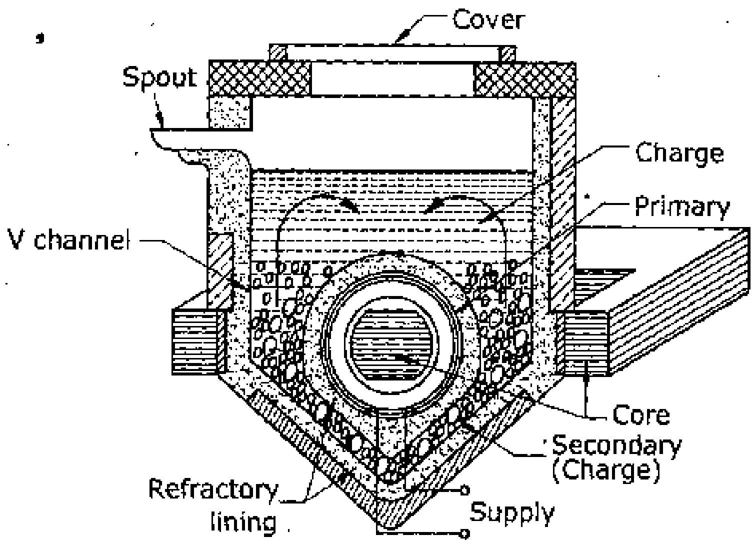
DRAWBACKS

1. Magnetic coupling between primary & secondary is poor (Power factor will be low)
2. Low frequency supply is essential (Normal frequency causes turbulence in charge)
3. Crucible is of odd shape (Inconvenient from metallurgical point)
4. Inconvenient for intermittent services (Cannot operate when secondary is open)
5. PINCH EFFECT: If current density exceeds $5A/mm^2$, electromagnetic field interrupts secondary current(Heating is interrupted)

2. Vertical core (AJAX WYATT) induction furnace

- Improved type of core type induction furnace. It has a vertical channel for the charge, so the crucible used is also vertical. The principle of operation is that of a transformer in which the secondary turns are replaced by a closed loop of molten metal. The primary winding is placed on the central limb of the core. Hence leakage reactance is comparatively low and power factor is high. An inner wall of furnace is coated with refractory lining of suitable material. The top of the furnace is covered with an insulated cover which can be removed for charging. Arrangements are made for tilting the furnace. The molten metal in the 'V' portion acts as a short circuited secondary. When primary is connected to the A.C supply, high current will be induced in the short circuited secondary. This current melts the charge. As the furnace is having a narrow V-shape at the bottom, the molten will be accumulated at the bottom and even a small amount of charge will keep the secondary completed. Hence chances of discontinuity of the circuit are less.

Fig.5.13.Vertical core (AJAX WYATT) type induction furnace



ADVANTAGES

- Magnetic coupling between primary and secondary is better
- Low leakage reactance. So power factor is better
- Discontinuity of circuit is less. (Can used for intermittent services)
- Energy consumption for melting non- ferrous metal is about 300-500 units per tone
- Can be operated with normal frequency

APPLICATIONS

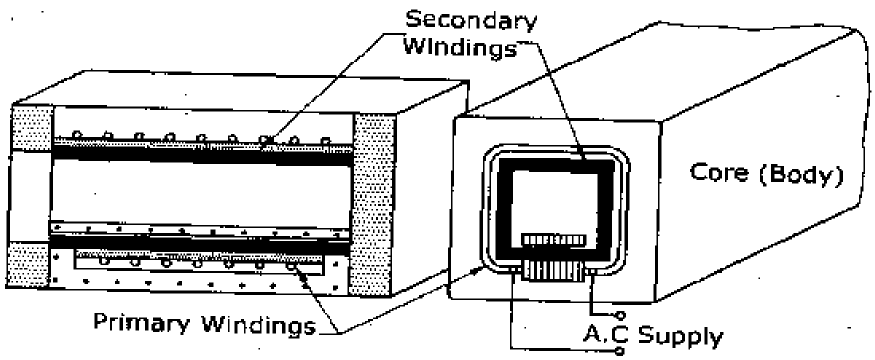
- To melt
- Brass
- Bronze
- Copper
- Zinc
- Tin

3. Indirect core type induction furnace

- **Working principle:** In this type of furnace by induction principle, Inductively heated element transfers heat to charge by radiation..It has Iron Core linking with primary & secondary. Secondary consists of metal container, forming walls of furnace. When the primary winding is connected to the supply, current is induced in the secondary of the metal container. So heat is produced due to induced current. This heat is transmitted to the charge by radiation. AB – Bar of special alloy is kept inside furnace chamber. When furnace attains critical temperature, reluctance of bar increases and cut down heat. The special alloy will loose its magnetic properties at a particular temperature and the magnetic properties are regained when the alloy will be cooled.. Thus the temperature of the furnace can be controlled very effectively.

AB is removable & can be replaced with different critical temperature. Thus temperature control is effective.

Fig.5.14.Indirect core type induction furnace



5.2.8. CORELESS INDUCTION FURNACE

Working principle: Coreless induction furnace also operates on the principle of transformer. In this furnace there is no core and thus the flux density will be low. Hence for compensating the low flux density, the current supplied to the primary should have sufficiently high frequency. The flux set up by the primary winding produces eddy currents in the charge. The heating effect of the eddy currents melts the charge. Stirring of the metals takes place by the action of the electromagnetic forces. Coreless furnace may have conducting or non conducting containers.

A coreless induction furnace in which container is made up of conducting material. Charge container may be conducting (Fig 5.15a) material. The container act as secondary winding and the charge can have either conducting or non conducting properties. Thus the container forms a short circuited single turn secondary. Hence heavy current induced in it and produce heat. This heat produced is transferred to the charge by convection. To prevent the primary winding from high temperature, refractory linings are provided between primary and secondary windings.

A coreless induction furnace in which the container may be made up of ceramic material (Fig 5.15b) type and the charge must necessarily have conducting properties. The flux produced by the primary winding produces eddy currents in the charge.

Eddy current $\propto B^2 f^2$

The heating effect of the eddy currents melts the charge. Stirring action in the metals takes place by the action of the electromagnetic forces.

Advantages

- Melting time is less
- Power control is possible
- Any Shape of Crucible can be used
- Charging & Pouring is simple
- Automatic Stirring
- Low Erection cost
- Low Running cost
- Absence of dirt, smoke, noise

Fig.5.15.Coreless induction furnace

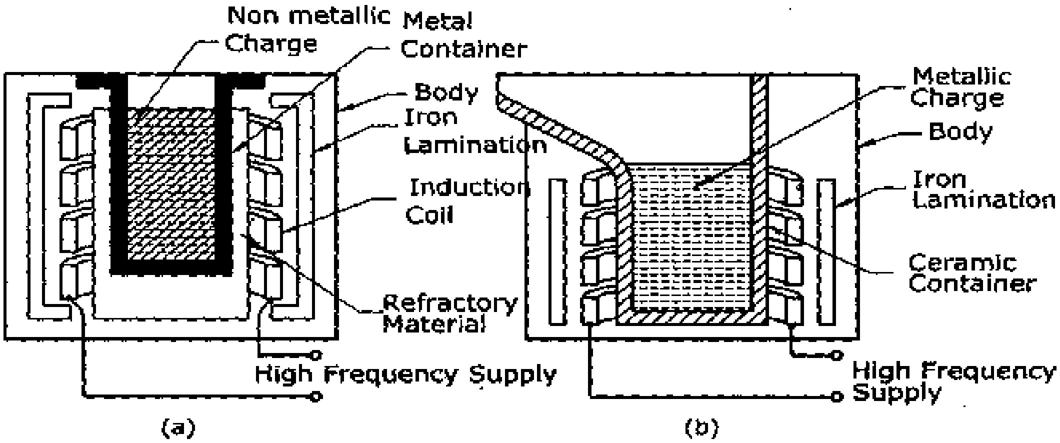
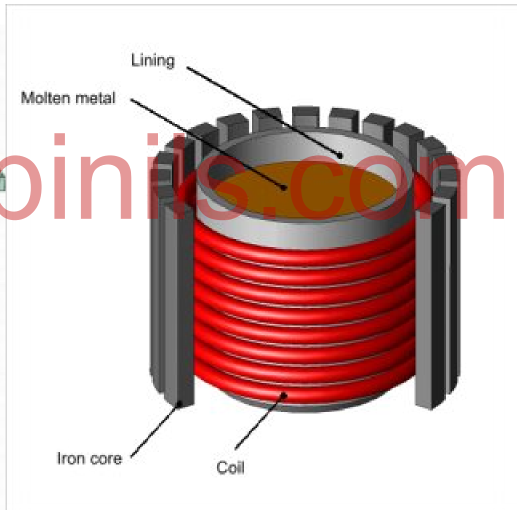


Fig.5.15 c.Coreless induction furnace **(Only for understanding purpose)**



METHODS OF OBTAINING HIGH FREQUENCY POWER SUPPLY FOR CORELESS INDUCTION FURNACE

1. Motor Generator set with Salient pole alternator (Suitable for frequencies upto 1000 Hz & for any output)
2. Motor Generator set with Induction Generator (Suitable for frequencies upto 10,000 Hz & for output of 1 tone)
3. Vacuum Tube Oscillator (Suitable for frequencies upto 1 million Hz & for small output)

5.3 WELDING

Welding is defined as the process of joining similar metals by the application of heat, to form a permanent joint. Edges of metal pieces are either melted or brought into plastic condition. It can be done with or without pressure

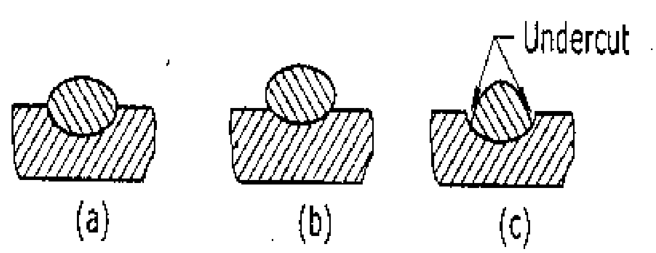
a. Types of welding

1. Resistance welding
   a. Butt welding
      i. Upset butt welding
      ii. Flash butt welding
   b. Spot welding
   c. Seam welding
   d. Projection welding
2. Arc welding
   a. Carbon Arc welding
   b. Metal Arc welding
   c. Atomic hydrogen Arc welding
   d. Inert gas metal arc welding
3. Radiation welding
   a. Ultrasonic welding
   b. Electron beam welding
   c. LASER beam welding

b. REQUIREMENTS OF GOOD WELDING

- Uniformly rippled surface of the weld
- Even contour of the weld
- Even width of the weld
- Absence of surface defects like overlap, undercut, crack & surface porosity
- Absence of internal defects like blow holes, hidden porosity in deposited metal & hidden crack in weld & work piece

Fig.5.16. Understanding good welding



In fig 5.16 (a), Weld metal has been deposited with correct welding current

1. Toes of bead smoothly change into parent metal and there is thorough penetration

2. In fig 5.16 (b), the welding has been done with insufficient current
3. It lacks proper penetration
4. In fig 5.16 (c), the welding has been formed with excess current giving under cutting at the toe of bead

c. Preparation work for welding

1. Preparing the job
    a. Gather the materials, such as welding machine, electrode holder & ground clamp with lead, electrodes, chipping hammer, wire brush and metal to be welded
    b. Put safety gear, such as welding helmet, jacket, work boots, gloves and safety glasses
    c. Prepare area to be welded. Remove all flammable materials, put the ground connection on the piece to be welded
    d. Set up the machine
    e. Use correct electrode, appropriate for DC or AC welding
    f. Clean the metal before welding
    g. Set the joint. Use clamps and vises to hold the welding

1. Start the weld
a. Strike a welding arc
b. Build up a weld pool
c. Start moving the weld pool across the metal
2. Finish the job
a. Pull the electrode back from metal and allow it to cool
b. Clean the slag
c. Examine the weld
d. Allow the metal to cool.

5.3.1.Resistance welding

Working principle: In resistance welding heavy current is passed through the metal pieces to be welded. Heat will be developed by the resistance of the work piece. The heat produced for welding is given by

$$H = I^2Rt$$

Where H = Heat developed at the contact area.

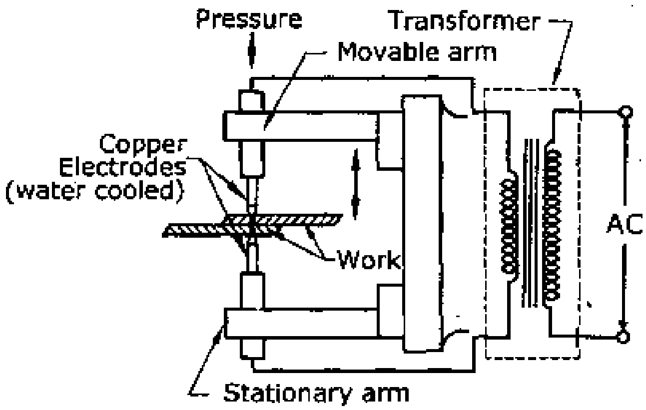
I = Current in amperes

R = Resistance in ohms

T = time of flow of current

The A.C supply is given to the primary winding of the transformer through a controlled contactor. Welding transformer used in this is of step down type. The Secondary voltage of the transformer is 1 to 10 V and current is 50 to 1000 A.

. **Fig.5.17 . Resistance welding**



APPLICATIONS OF RESISTANCE WELDING

- For mass production of
- Sheet metal
- Wire
- Tubes
- Bars
- Boxes
- Cans
- Rods and
- Frames

Types of resistance welding

Butt Welding

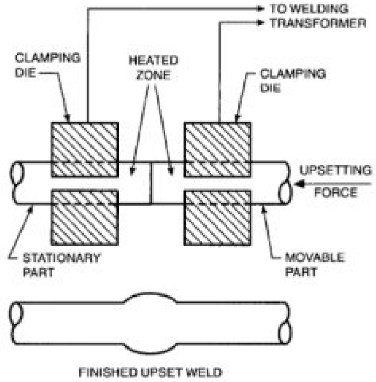
Types:

1. Upset butt welding
2. Flash butt welding

A) Upset butt welding

This method is applicable for end to end joints. Pressure is applied in axial direction. Used for Welding Chains, Pipes, Wires & Rods, Rail ends, Rolled sections of shaft axles. In this process heat is generated by the contact resistance between two components. In this type of welding the metal parts to be welded are joined end to end . Sufficient pressure is applied along the axial direction. A heavy current is passed from the welding transformers which creates the necessary heat at the joint due to high resistance of the contact area. Due to the pressure applied, the molten metal forced to produce a bulged joint. This method is suitable for welding pipes, wires and rods.

Fig.5.18 a.Upset Butt Welding



B) Flash butt welding

Similar to Butt Welding, but current is applied to metal parts, before they brought together. When the pieces come together, a flash takes place. Pieces to be welded are clamped with light pressure. After the welding temperature is reached, power is cut off. Pressure is applied till the weld gets cooled. Pure & clean weld is applied (As Flash burn contact surfaces).Less power requirement. All the foreign metals appearing on the contact surface is burnt due to the flashes. Thus pure and clean weld is obtained

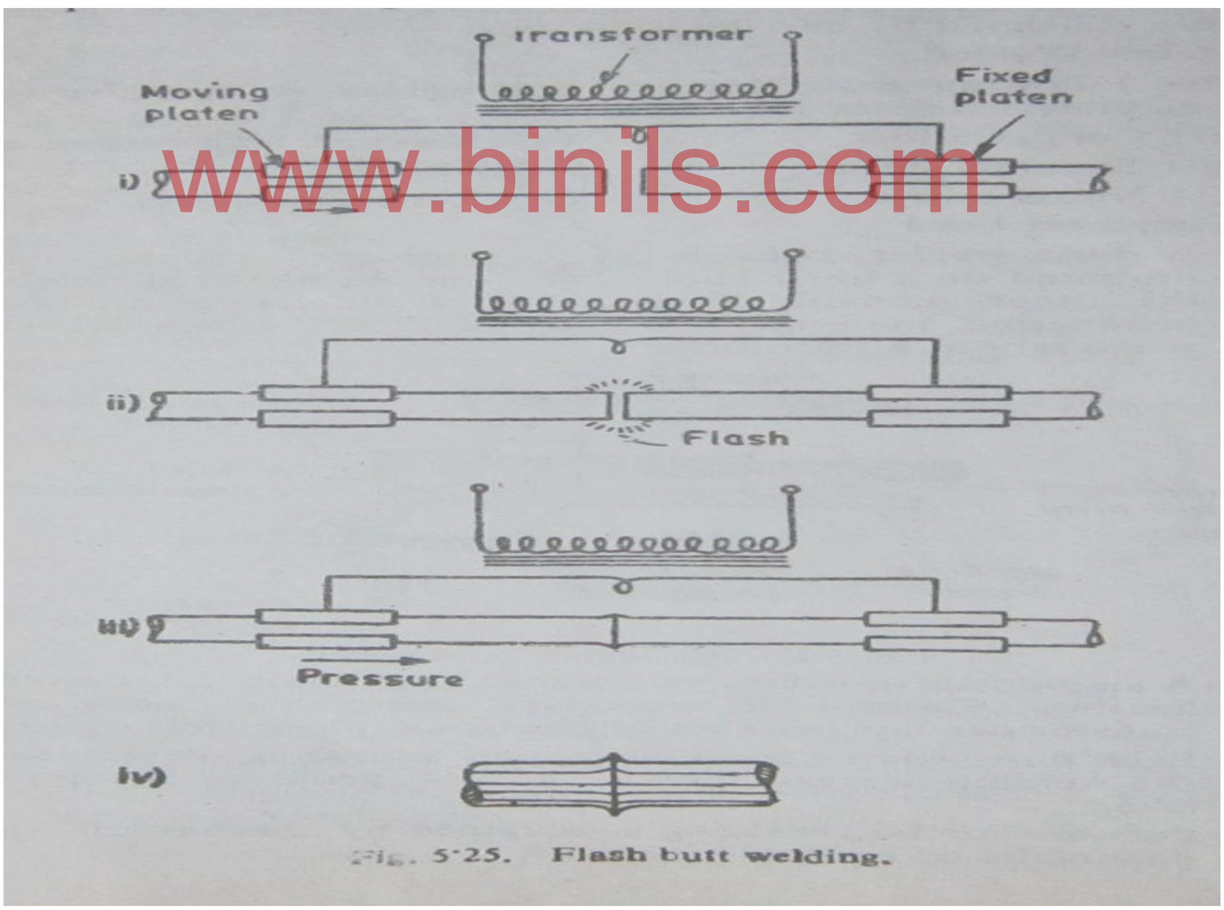
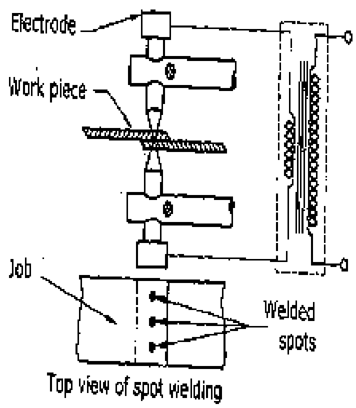


Fig.5.18 b. Flash Butt Welding

C) Spot Welding

This method is used to join over lapping sheets or plates of metal at small areas. It provides mechanical strength only (Welded surfaces are not air/water tight).It can be done on metal strips of up to 12 mm size. . The welding current flows through electrode tips producing a spot weld. The welding current and period of current flow depends on the thickness of the plates. It is used in welding of boxes, cams and frames of automobiles.

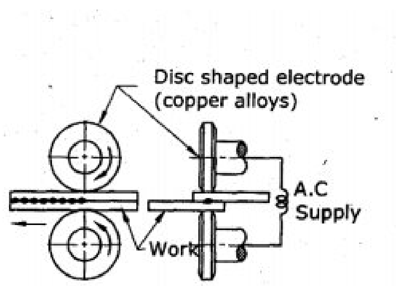
Fig.5.19.Spot Welding



D) Seam welding

Used to make a continuous joint on leak proof tanks, drums and radiators. Wheels or roller type electrodes are used. Seam welding can be defined as series of continuous spot welds. This process is employed for making continuous joint between two overlapping pieces of sheet metal. In this type of welding, two wheels or roller type electrodes are used. The electrodes provide sufficient mechanical pressure and also carry sufficient current for producing continuous welds. In this type, either the wheels are moved or the metal plates are moved between the wheels. Normally rotating wheeled electrodes are used

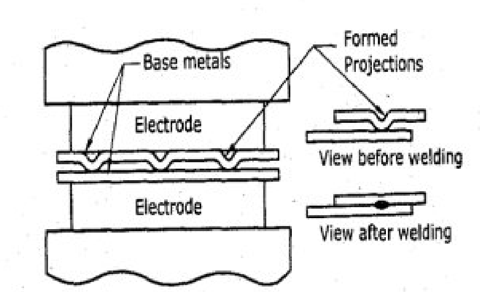
Fig.5.20. Seam Welding



E) Projection welding

It is a modified form of spot welding. Forms projections on sheet metal. These projections are pressed (by heat/pressure) into contact with another sheet. Projection welding consists of forming slight projections on the sheet of metal. After the projections are formed the raised portions on one piece are pressed into contact with another piece. The work is held between two copper plate electrodes and pressure is applied by the movable arm. Current is then passed and good welds at all points of contacts are made due to flattening flattering out of the projections under heat and pressure. The surface at the projection must be clean. Used for joining thin sheet metals

Fig.5.21 Projection welding



5.3.2. ELECTRIC ARC WELDING

An electric arc is the flow of current through ionized part. Arc is struck by short circuiting two electrodes and withdrawing them with small distance. An electric arc is struck by short circuiting two electrodes and then with drawing them apart by small distance. Current through gap gives heat for welding. This heat melts part of work piece and filler material and forms joint. Used for repairing fractured castings, deposition of new metals on worn out parts. Heat developed in this is also used for cutting the metal

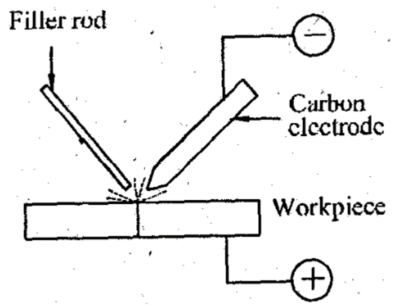
Types of arc welding

1. Carbon arc welding
2. Metal arc welding
3. Atomic Hydrogen arc welding
4. Inert gas metal arc welding
5. Submerged arc welding

1. Carbon Arc welding

DC supply is used is used in this method. Filler material used is the same metal to be welded. Electrode material is carbon. It is used as negative electrode only, to avoid brittleness. Work piece acts as positive electrode. Heat from arc forms molten pool. Extra metal is supplied by filler. The work piece is connected to positive wire. Flux and filter are also used. Filter is made of similar metal as that of metal to be welded. If the electrode is made `positive then the carbon contents may flow into the weld and cause brittleness. The heat from the arc forms a molten pool and the extra metal required to make the weld is supplied by the filter rod. This type of welding is used for welding copper and its alloy.

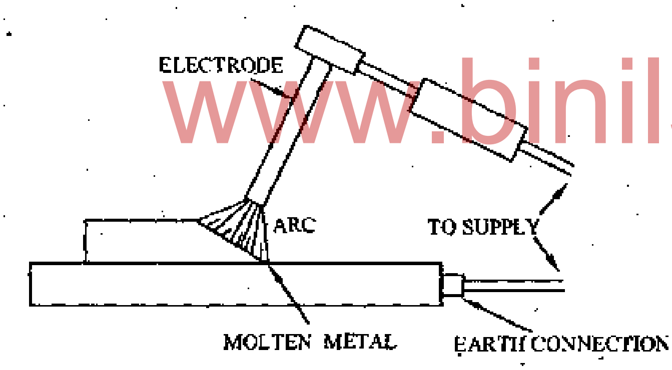
Fig.5.22 Carbon Arc welding



2. Metal arc welding

AC or DC supply can be used. No need of filler material. In metal arc welding a metal rod of same material as being welded is used as an electrode. The electrode also serves the purpose of a filter. Electric supply is connected between electrode and work piece. The work piece is then suddenly touched by the electrode and then separated from it a little. This results in an arc between the job and the electrode. A little portion of the work and the tip of the electrode melt due to the heat generated by the arc. When the electrode is removed the metal cools and solidifies giving a strong welded joint

Fig.5.2. Metal arc welding

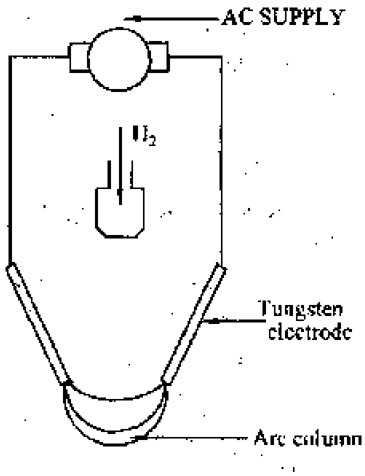


3. Atomic Hydrogen arc welding

In this method of welding two Tungsten electrodes are used in Hydrogen atmosphere with ac supply.

- The arc is developed between the two electrodes. While heating, molecules of hydrogen are converted into atomic form. When in contact with cold metal, they recombine and develop high heat. This temperature facilities high speed welding. This method is usually employed for welding alloy steel, carbon steel, stainless steel and aluminum.

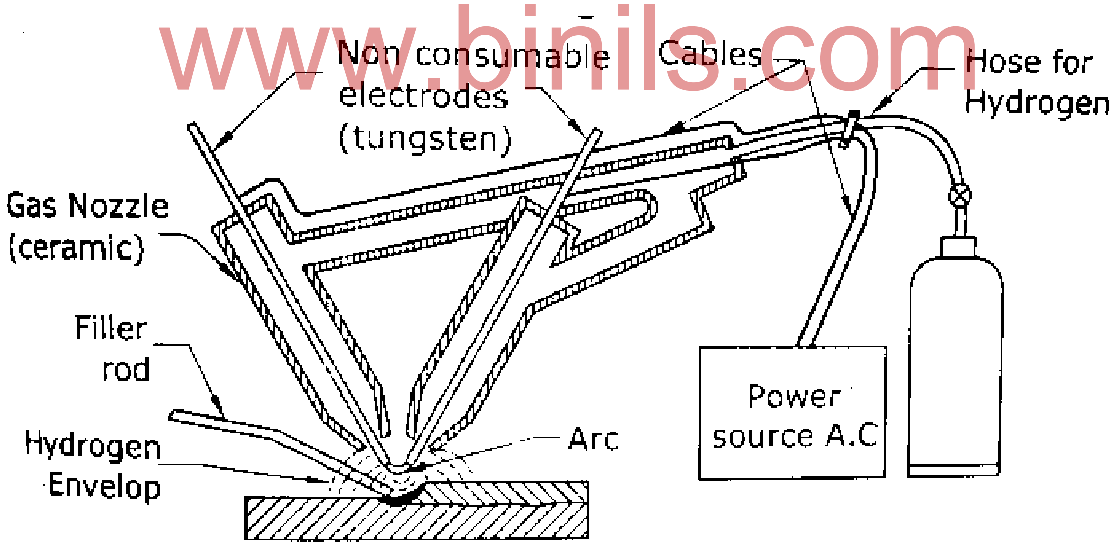
Fig.5.24 Atomic Hydrogen arc welding



4. Inert Gas Metal Arc Welding (Helium Or Argon Arc Welding)

Two Tungsten electrodes are shielded by argon or helium gas. For filling, separate filling rods are used.AC or DC supply can be used. Arc is formed between tungsten and work piece. No Oxidation takes place in inert atmosphere. It is used for welding light alloys of copper, steel and aluminum

Fig.5.25 Inert Gas Metal Arc Welding



5.3.3Comparison between Resistance welding and Arc welding

Sl.No	Description	Resistance Welding	Arc welding
1	Supply	AC	AC or DC
2	Voltage required	Low	High

3	Heat development due to	Flow of current through Resistance	Arc bw electrode & work piece
4	Temperature developed	Low	High
5	Need of external pressure	Needed	Not needed
6	Power Factor	Low	Poor
7	Necessity of filler material	Not needed	Needed
8	Suitability for repair work	Not suitable	Suitable
9	Application	Mass production	Used for repair work

5.3.4. RADIATION WELDING

TYPES:

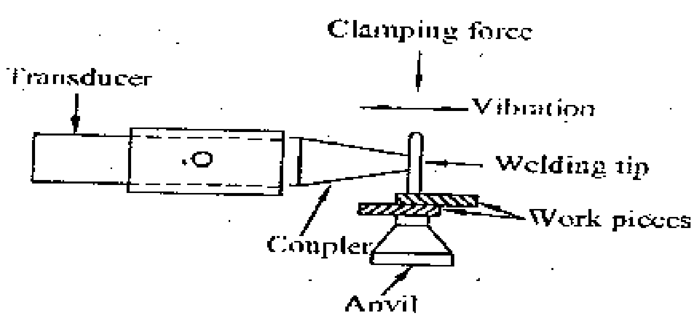
- Ultrasonic welding
- Electron Beam welding
- LASER Beam welding

Ultrasonic Welding

Working principle:

This method is used to joint between similar or dissimilar metals or non-metals by ultrasonic vibrations using Piezo electric effect. It is produced by using Crystal Oscillator. Crystal material used in this is Quartz or Barium titanate. Frequency of welding is from 20 to 60 KHz. Work piece is placed between anvil & welding tip. A transducer is used with welding tip. Vibration produces shear stress in welding tip. This stress melts and welds the metal

Fig.5.26 Ultrasonic welding



Advantages:

- Low power requirement
- No smoke produced
- No flux or filler materials

Applications:

- For welding Electronic PCBs,
- For bonding of plastics, bimetals, foils

5.3.5. Electron Beam welding

When an electron travels in a vacuum at high velocity, it produces kinetic energy. This kinetic energy is converted in to heat energy which joins the metal.

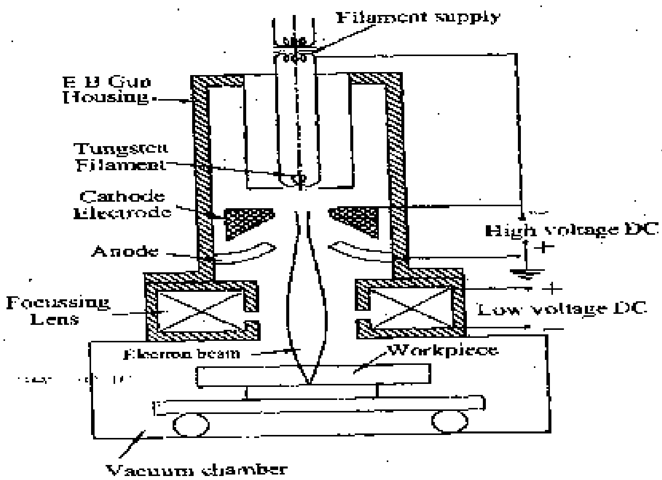
Working principle:

The construction of electron beam welding is shown in fig. when 12 V supply is given to the tungsten filament, Filament gets heated and emits electrons. Electrons emitted by filament are accelerated from cathode to anode. Anode is of a metal ring with HVDC of 10 to 150 KV. Temperature produced is 2500^0 C. The high velocity electrons are focused on the work piece through focusing lenses and so heat energy is produced. Thus fills the narrow weld gap without filler rod.

Advantages:

- Welds are clean
- No porosity, since no air
- Distortion is eliminated
- Fast welding
- Used to weld or cut metal/ceramic/diamond

Fig.5.27. Electron Beam welding



Disadvantages:

- High initial cost
- Requires skilled workers

Applications

To weld Titanium, Tungsten, Molybdenum, Stainless steel and Aluminum

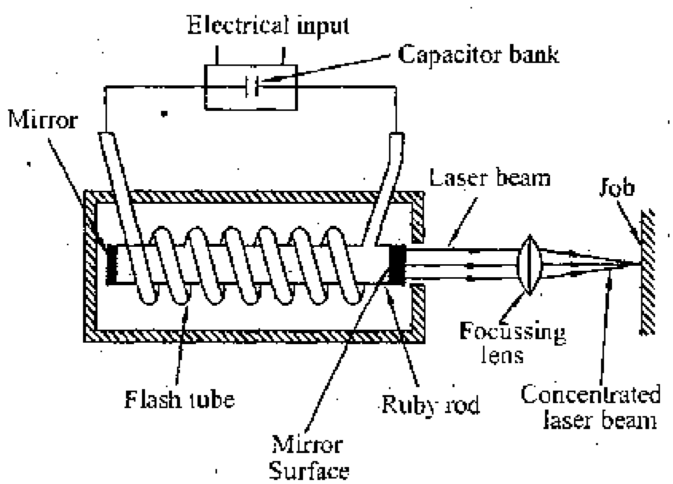
5.3.6. LASER Beam welding

LASRES are generating a very intense beam of optical radiation. LASER in abbreviation is Light Amplification by Stimulated Emission of Radiation

Working principle:

. It generates intense beam of optical radiation. Ruby crystal (Aluminum Oxide coated with Chromium) is used to generate LASER beam. Ends of Ruby rod are coated with silver, to form a mirror surface. A hole is provided at one end of the rod, to let out the beam. Capacitor bank is used for storing electrical energy. A flash tube is wrapped around Ruby rod and energized by capacitor bank. Flash tube converts electrical energy into Light energy. Light energy is converted into LASER, by Ruby crystal. It is used to weld small wires with electronic devices. The laser beam is focused on the metal to be welded through focusing lens. When this laser beam is concentrated heavy amount of heat is produced on the work piece. By this high temperature the metal melts and welding is obtained.

Fig.5.28. LASER Beam welding



Advantages:

- Low energy consumption
- Micro miniature welding is possible
- No vacuum is necessary

Disadvantages:

- Slow speed of operation
- Not possible to weld above 1.5mm depth

Applications

For Welding Tungsten, Chromium, Nickel, Aluminum and Titanium

5.3.7.ELECTRIC WELDING EQUIPMENTS

1. AC welding equipments
2. DC welding equipments
3. Other equipments
   a) Welding Holder
   b) Welding Leads
   c) Ground Connection
   d) Hand Shields

1. AC welding equipments

1. Number of phases used with AC supply
   a) Single phase is suitable for obtaining lower current, thinner sections & small diameter electrodes
   b) Two phase is suitable for higher current and thicker jobs
   c) Three phase is used, where more than one operator has to work simultaneously
2. Current range is up to 600 amperes
3. One circuit voltage is from 70 to 100 volts
4. Single or multi operator sets are used
5. It has drooping characteristics
6. Small Transformers are of air cooled type
7. Large Transformers are of oil cooled type

ADVANTAGES

1. Not having rotating parts
2. Do not produce noise
3. Occupies less space
4. Less initial cost

5. Less maintenance cost
6. Possess High efficiency
7. Consume less energy per unit weight of deposited metal
8. High no load voltage

DISADVANTAGE

- Melting rate of electrode cannot be controlled

2. DC welding equipments

1. AC Transformer with Silicon or Selenium Rectifier (or) DC Generator driven by AC Motor as a prime mover (or) DC Generator driven by Petrol/Diesel engine as a prime mover can be used.

2. Current range is up to 600 amps

3. One circuit voltage is from 45 to 75 volts

4. Drooping, Slightly drooping or flat characteristics

Fig.5.29.DC welding equipment

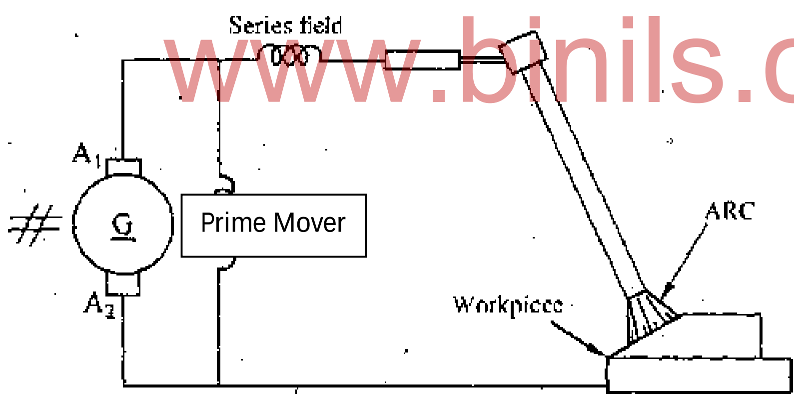
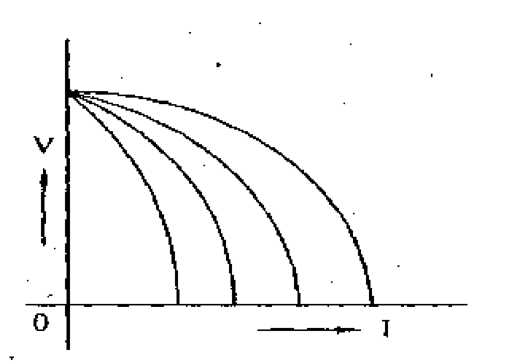


Fig.5.30.Characteristics of DC welding equipments



ADVANTAGES

- At higher arc currents, it gives smoother arc
- No arc blow problem
- Once established, the arc can be easily maintained and controlled
- It is suitable for welding thicker sections

3. Welding Holder

1. Jaws of holder remain under spring pressure
2. Jaws may or may not be insulated
3. Available range from 100 to 500 A
4. They are provided with a heat shield
5. It should be Light & Sturdy
6. It should hold electrode easily
7. It's handle should possess high resistance to heat and Electricity

5.3.8. COMPARISON BETWEEN AC AND DC WELDING

Sl. No	Description	AC Welding Machine	DC Welding Machine
1	Cost	Low	High
2	Maintenance	Less, because of no rotating parts	More
3	Arc blow	No, because of automatic polarity change	Magnetic fields cause arc blow
4	Efficiency	High	Low
5	Possibility of shock	High, because of high voltage	Low
6	Application	For welding heavy metals	For welding cast iron, Aluminium & Bronze
7	Heat Produced	Uniform in Electrode & material	2/3 rd of heat near +ve & 1/3rd of heat near –ve
8	Suitability	Only where ac supply is available	Can be used anywhere, by generating DC

REVIEW QUESTIONS -Part A

1. Classify heating methods based on temperature range
2. State the types of electric heating
3. What is arc heating? State its types
4. State the types of high frequency electric heating
5. State commonly used heating element materials
6. State the methods used for temperature control of resistance furnaces
7. Write notes on power supply to arc furnaces
8. State the methods used for Temperature control of arc furnaces
9. State the reasons for employing high current & low voltage supply for arc furnaces
10. State the types of induction furnaces
11. Define welding
12. State the types of resistance welding
13. State the types of arc welding
14. State the types of radiation welding

Part B QUESTIONS

1. State the advantages of electric heating
2. Explain modes of heat transfer
3. Explain infra red heating
4. Explain induction heating
5. State the requirements of heating element materials used in resistance furnace
6. Write notes on Air circulation oven
7. Write notes on Bright annealing furnace
8. State the principle and advantages of electric arc furnaces
9. State the requirements of good welding
10. Write notes on preparation work for welding
11. What is resistance welding? State its applications.
12. Compare Resistance welding and Arc welding
13. Compare AC and DC welding

Part C QUESTIONS

1. Draw and explain direct & indirect resistance heating with suitable sketches
2. Explain the working of an induction stove with a sketch. State its merits & demerits
3. Explain eddy current heating with a sketch. State its applications.
4. Explain dielectric heating with a sketch. State its applications.
5. Draw and explain direct & indirect arc furnaces with suitable sketches
6. Draw and explain direct core type induction furnace with a sketch.
7. Draw and explain Vertical Core (AJAX WYATT) induction furnace with a sketch.
8. Draw and explain indirect core type induction furnace with a sketch.
9. Draw and explain Coreless induction furnace with a sketch.
10. State the types of Butt welding. Explain them with sketches.
11. Explain the following with sketches.

a. Spot welding

b. Seam welding

c. Projection welding

12. Explain the following with sketches.

a. Carbon arc welding
b. Metal arc welding
13. Explain the following with sketches.
a. Atomic Hydrogen arc welding
b. Inert gas metal arc welding
14. Explain ultrasonic welding with a sketch.
15. Explain electron beam welding with a sketch.
16. Explain LASER Beam welding with a sketch.
17. State and explain electric welding equipments.