ACADEMIC REGULATIONS, COURSE STRUCTURE AND DETAILED SYLLABUS

Effective from the Academic Year 2020-21 onwards

Department of Electrical & Electronics Engineering (EEE)

For

B. Tech. Four Year Degree Programme

(MR18 Regulations)

MALLA REDDY ENGINEERING COLLEGE (Autonomous)

(An UGC Autonomous Institution, Approved by AICTE and Affiliated to JNTUH Hyderabad, Recognized under section 2(f) &12 (B) of UGC Act 1956, Accredited by NAAC with 'A' Grade (II Cycle) and NBA, Maisammaguda, Dhulapally (Post Via Kompally), Secunderabad-500 100
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2020-21 Onwards (MR-19)	MALLA REDDY ENGINEERING COLLEGE (Autonomous)	B.Tech. IV Semester		
Code: 70206	**POWER GENERATION AND DISTRIBUTION**	**L**	**T**	**P**
Credits: : 3		**3**	**-**	**-**

Prerequisites: Applied Chemistry, Electrical Circuit Analysis and Synthesis

Course Objectives:

This course deals about the layout of different types of power stations and various power distribution systems. It also emphasis on the importance of economic aspects & tariff.

MODULE I: Power Stations 9 Periods

Thermal Power Stations: Line diagram of Thermal Power Station (TPS) showing paths of coal, steam, water, air, ash and flue gasses. Brief description of TPS components: Economizers, Boilers, Super heaters, Turbines, Condensers, Chimney and Cooling towers.

Nuclear Power Stations: Nuclear Fission and Chain reaction - Nuclear fuels - Principle of operation of Nuclear reactor. Reactor Components: Moderators, Control rods, Reflectors and Coolants. Radiation hazards: Shielding and Safety precautions. Types of Nuclear reactors and brief description of PWR, BWR and FBR.

Gas Power Stations: Principle of Operation and Components (Block Diagram Approach Only).

MODULE II: Hydroelectric Power Stations and Turbines 10 Periods

Hydroelectric Power Stations: Elements of hydro electric power station – Types - Concept of pumped storage plants - Storage requirements, mass curve (explanation only) estimation of power developed from a given catchment area - Heads and efficiencies.

Hydraulic Turbines: Classification of turbines, impulse and reaction turbines, Pelton wheel, Francis turbine and Kaplan turbine - Working proportions, work done, efficiencies, hydraulic design - Draft tube theory - Functions and efficiency.

MODULE III: Air & Gas Insulated Substations 10 Periods

A: Indoor & Outdoor substations: Substations layout showing the location of all the substation equipment. Bus bar arrangements in the Sub-Stations: Simple arrangements like single bus bar, sectionalized single bus bar, main and transfer bus bar system with relevant diagrams.

B: Introduction to Gas insulated substations, Single line diagram of gas insulated substations, bus bar, Construction aspects of GIS, Maintenance and Advantages of GIS, Comparison of Air insulated substations and Gas insulated substations.

MODULE IV: D.C. and A.C Distribution Systems 10 Periods

Classification of Distribution Systems - Comparison of DC vs AC Distribution Systems, Under Ground vs Over Head Distribution Systems - Requirements and Design features of Distribution Systems. Voltage Drop Calculations (Numerical Problems) in D.C Distributors for the following cases: Radial D.C Distributor fed one end and at the both the ends (equal/unequal Voltages) and Ring Main Distributor. Voltage Drop Calculations (Numerical Problems) in A.C. Distributors for the following cases: Power Factors referred to receiving end voltage and with respect to respective load voltages.

MODULE V: Economic Aspects of Power Generation & Tariff Methods 9 Periods

Define - Load curve, Load duration and Integrated load duration curves - Load, Demand, Diversity, Capacity, Utilization and Plant Use Factors - Numerical Problems. Costs of Generation and their division into Fixed, Semi-fixed and Running Costs.

Desirable Characteristics of a Tariff Method. Tariff Methods: Flat Rate, Block-Rate, two-part, three –part and power factor tariff methods and Numerical Problems.

TEXT BOOKS

1. V.K Mehta and Rohit Mehta, **"Principles of Power Systems",** S.Chand & Company Ltd , New Delhi, 2004.
2. PSR. Murty**, "Electrical Power Systems",** Butterworth-Heinemann Publications, 2017.

REFERENCES

1. R. K. Rajput, **"A Text Book of Power System Engineering"**, Laxmi Publications (P) Limited, 2^{nd} Edition, 2016.
2. S.N.Singh , **"Electrical Power Generation, Transmission and Distribution"** , PHI Learning Pvt. Ltd., 2^{nd} Edition, 2008.
3. C.L.Wadhwa, **"Electrical Power Systems"**, New Age international (P) Limited, 6^{th} Edition, 2010.
4. Dr.B.R.Gupta, **"Generation of Electrical Energy"** , S.Chand & Company Ltd , 6^{th} Edition, 2008.
5. G.Ramamurthy, **"Handbook of Electrical power Distribution"**, Universities Press, 2013.

E - RESOURCES

1. https://www.electrical4u.com/power-plants-types-of-power-plant/
2. http://spectrum.ieee.org/energy
3. http://nptel.ac.in/courses/108102047/

Course Outcomes

At the end of the course, students will be able to

1. Understand the layouts of Thermal Power station, Nuclear Power Plant and Gas Power plant.
2. Demonstrate the operation of hydro electric power plants and turbines.
3. Comprehend about various types of substations and its equipment.
4. Analyze the voltage drops in DC and AC distribution systems.
5. Evaluate the cost of generation and tariff.

UNIT-1

GENERATION OF ELECTRICAL POWER

Thermal power stations introductions

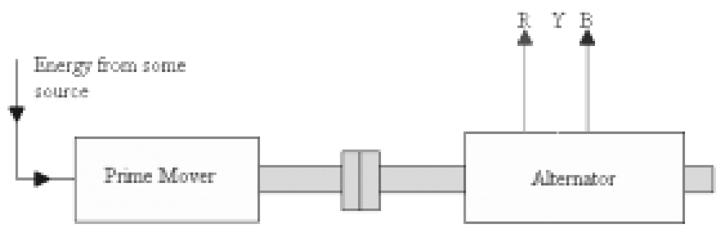
For generating EMF, the following are essential

1. Conductor system

2. Flux lines

3. Relative motion

Generation of electrical energy:



Various sources of energy:

1. Sun

2. Wind

3. Water

4. Fuel

5. Nuclear forces

1. **Sun:**It is the primary source for producing energy. IN this the heat radiated from the sun is concentrated over a small area by using reflectors & that heat is used to raise the temperature of steam & is passed through the prime mover which converts it mechanical energy & that mechanical energy is passed through AC generator which converts it to electrical energy.

Limitations:-

1. Requires large area for generation of small amount of power.
2. Cannot be used during night times & cloudy days
3. Uneconomical

Wind:-Wind flows for a considerable length of time to run the wind mill which drives a small generator. At the time of wind flowing the generator charges the batteries & these batteries will give supply at the time when wind is not flowing.

Water:-It is stored at suitable places to possess potential energy because of head and is very popular because of low production & maintenance cost.

Fuel:-

Solid form-coal

Liquid form-oil

Gaseous form-natural gas

Here, fuel energy is converted into mechanical energy by the prime movers such as steam engines,IC(internal) engines, steam turbine etc.& is converted into electrical energy using alternator.

Nuclear energy:-Large heat is liberated from fissioning of uranium & other nuclear products.

→Heat liberated by 1 kg of nuclear fuel is equal to that of 4500 tons of coal.

Property	Water	Fuel	Nuclear
Initial cost	High	Low	Highest
Running cost	Less	High	Least
Reserves	Permanent	Exhaustible	In-exhaustible
Cleanliness	Cleanest	Dirtiest	Clear
Simplicity	Simplest	Complex	More complex
reliability	most	less	more

I. **Steam power station (or) Thermal power station**

→condensed means steam becomes water

Heat from $\xrightarrow{\text{turbine}}$ mechanical $\xrightarrow{\text{Alternator}}$ electrical energy

Coal combustion energy

→A generating station which converts heat energy of the coal combustion into electrical energy is known

as steam power station.

→It works on the Rankine cycle. Steam is produced in the boiler by receiving the heat from the combustion. The steam is then expanded using prime prime mover i.e. steam turbine & is condensed in a condenser to be fed into the boiler again.

→The steam turbine drives the alternator which converts mechanical energy of the turbine into electrical energy. This type of power station is suitable where coal & water are available in abundance & a large amount of electric power is to be generated.

<u>Advantages</u>:-

1. The fuel (coal) used is quite cheap.

2. Less initial cost as compared to other generating station.

3. It requires less space as compared to the hydroelectric power station.

4. The cost of generation is lesser than that of diesel power station.

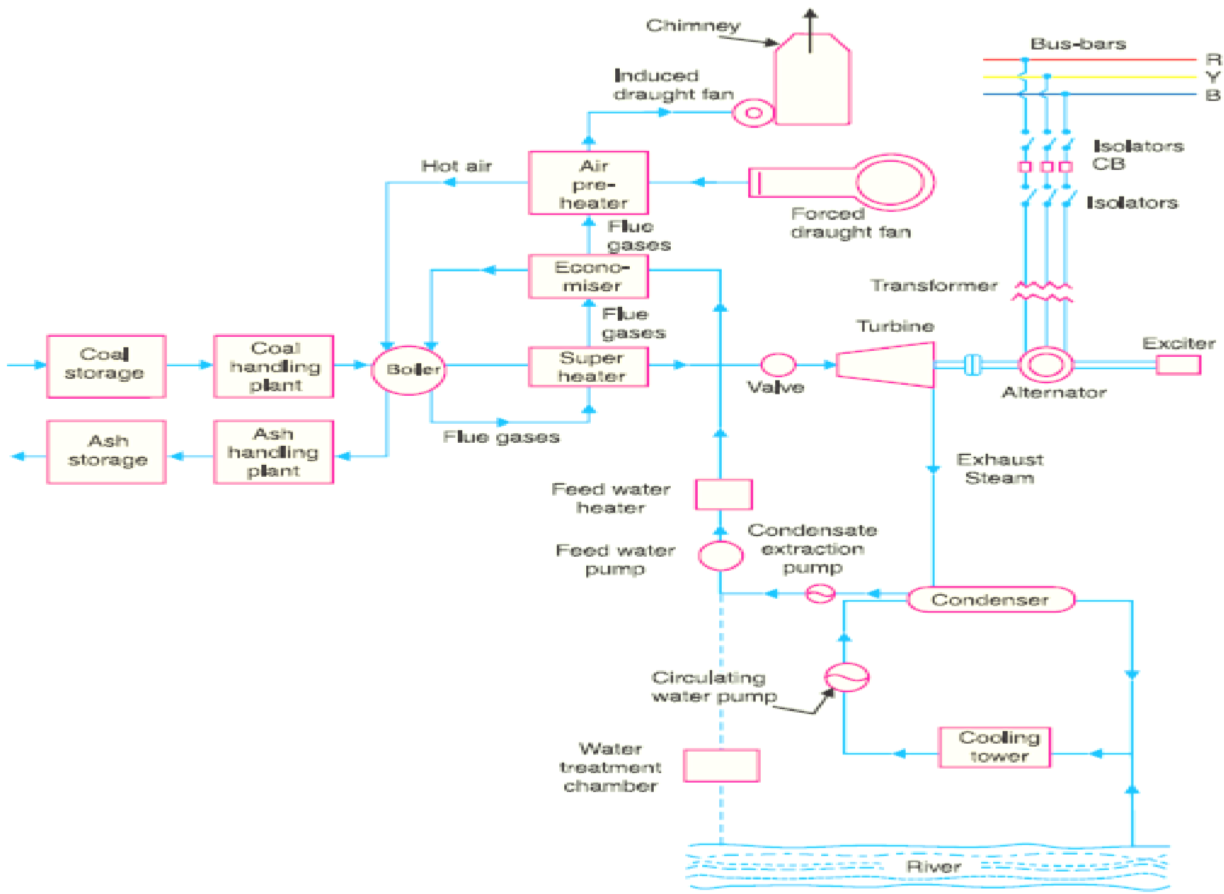
5. It can be installed at any place irrespective of the existence of coal.

6. The coal can be transported to the site of the plant by rail or road.

<u>Disadvantages</u>:-

1. It pollutes the atmosphere due to the production of large amount of smoke & fumes.

2. It is costlier in running cost as compared to hydroelectric plant.



Although steam power station, simply involves the conversion of heat of coal conversion into electrical energy, yet it embraces many arrangements of proper working an efficiency.

→The schematic arrangement of a modern power station is shown in figure & the whole arrangement is divided into the following stages.

1. Coal and ash handling arrangement

2. Steam generating plant

3. Steam turbine
4. Alternator
5. Feed water
6. Cooling arrangement

1. Coal and ash handling plant: The coal is transported to the power station by road or rail and is stored in the coal storage plant. Storage of coal is primarily a matter of protection against coal strikes, failure of transportation system and general coal shortages. From the coal storage plant, coal is delivered to the coal handling plant where it is pulverised (i.e., crushed into small pieces) in order to increase its surface exposure, thus promoting rapid combustion without using large quantity of excess air. The pulverised coal is fed to the boiler by belt conveyors. The coal is burnt in the boiler and the ash produced after the complete combustion of coal is removed to the ash handling plant and then delivered to the ash storage plant for disposal. The removal of the ash from the boiler furnace is necessary for proper burning of coal. It is worthwhile to give a passing reference to the amount of coal burnt and ash produced in a modern thermal power station. A 100 MW station operating at 50% load factor may burn about 20,000 tons of coal per month and ash produced may be to the tune of 10% to 15% of coal fired i.e., 2,000 to 3,000 tons. In fact, in a thermal station, about 50% to 60% of the total operating cost consists of fuel purchasing and its handling.

2. **Steam generating plant**. The steam generating plant consists of a boiler for the production of steam and other auxiliary equipment for the utilization of flue gases.

(i) **Boiler**. The heat of combustion of coal in the boiler is utilized to convert water into steam at high temperature and pressure. The flue gases from the boiler make their journey through super heater, economizer, and air pre-heater and are finally exhausted to atmosphere through the chimney.

(ii) **Super heater**. The steam produced in the boiler is wet and is passed through a super heater where it is dried and superheated (i.e., steam temperature increased above that of boiling point of water) by the flue gases on their way to chimney. Superheating provides two principal benefits. Firstly, the overall efficiency is increased. Secondly, too much condensation in the last stages of turbine (which would cause blade corrosion) is avoided. The superheated steam from the super heateris fed to steam turbine through the main valve.

(iii) **Economizer**. An economizer is essentially a feed water heater and derives heat from the flue gases for this purpose. The feed water is fed to the economizer before supplying to the boiler. The economizer extracts a part of heat of flue gases to increase the feed water temperature.

(iv) **Air preheater**. An air preheater increases the temperature of the air supplied for coal burning by deriving heat from flue gases. Air is drawn from the atmosphere by a forced draught fan and is passed through air preheater before supplying to the boiler furnace. The air preheater extracts heat from flue gases and increases the temperature of air used for coal combustion. The principal benefits of preheating the air are: increased thermal efficiency and increased steam capacity per square meter of boiler surface.

3**. Steam turbine**. The dry and superheated steam from the super heater is fed to the steam turbine through main valve. The heat energy of steam when passing over the blades of turbine is converted into mechanical energy. After giving heat energy to the turbine, the steam is exhausted to the condenser which condenses the exhausted steam by means of cold water circulation.

4. **Alternator**. The steam turbine is coupled to an alternator. The alternator converts mechanical energy of turbine into electrical energy. The electrical output from the alternator is delivered to the bus bars through transformer, circuit breakers and isolators.

5**. Feed water**. The condensate from the condenser is used as feed water to the boiler. Some water may be lost in the cycle which is suitably made up from external source. The feed water on its way to the boiler is heated by water heaters and economizer. This helps in raising the overall efficiency of the plant.

6. **Cooling arrangement**. In order to improve the efficiency of the plant, the steam exhausted from the turbine is condensed* by means of a condenser. Water is drawn from a natural source of supply such as a river, canal or lake and is circulated through the condenser. The circulating water takes up the heat of the

exhausted steam and itself becomes hot. This hot water coming out from the condenser is discharged at a suitable location down the river. In case the availability of water from the source of supply is not assured throughout the year, cooling towers are used. During the scarcity of water in the river, hot water from the condenser is passed on to the cooling towers where it is cooled. The cold water from the cooling tower is reused in the condenser.

Choice of Site for Steam Power Stations:

In order to achieve overall economy, the following points should be considered while selecting a site for a steam power station:

(i) **Supply of fuel**. The steam power station should be located near the coal mines so that transportation cost of fuel is minimum. However, if such a plant is to be installed at a place where coal is not available, then care should be taken that adequate facilities exist for the transportation of coal.

(ii) **Availability of water**. As huge amount of water is required for the condenser, therefore, such a plant should be located at the bank of a river or near a canal to ensure the continuous supply of water.

(iii) **Transportation facilities**. A modern steam power station often requires the transportation of material and machinery. Therefore, adequate transportation facilities must exist i.e., the plant should be well connected to other parts of the country by rail, road. Etc.

(iv) **Cost and type of land**. The steam power station should be located at a place where land is cheap and further extension, if necessary, is possible. Moreover, the bearing capacity of the ground should be adequate so that heavy equipment could be installed.

(v) **Nearness to load centers**. In order to reduce the transmission cost, the plant should be located near the center of the load. This is particularly important if D.C. supply system is adopted. However, if A.C. supply system is adopted, this factor becomes relatively less important. It is because A.C. power can be transmitted at high voltages with consequent reduced transmission cost. Therefore, it is possible to install the plant away from the load centers, provided other conditions are favorable.

(vi) **Distance from populated area**. As huge amount of coal is burnt in a steam power station, therefore, smoke and fumes pollute the surrounding area. This necessitates that the plant should be located at a considerable distance from the populated areas.

Conclusion: It is clear that all the above factors cannot be favourable at one place. However, keeping in view the fact that now-a-days the supply system is a.c. and more importance is being given to generation than transmission, a site away from the towns may be selected. In particular, a site by river side where sufficient water is available, no pollution of atmosphere occurs and fuel can be transported economically, may perhaps be an ideal choice.

Efficiency of Steam Power Station:

The overall efficiency of a steam power station is quite low (about 29%) due mainly to two reasons.

Firstly, a huge amount of heat is lost in the condenser and secondly heat losses occur at various stages of the plant. The heat lost in the condenser cannot be avoided. It is because heat energy cannot be converted into mechanical energy without temperature difference. The greater the temperature difference, the greater is the heat energy converted* into mechanical energy. This necessitates keeping the steam in the condenser at the lowest temperature. But we know that greater the temperature difference, greater is the amount of heat lost. This explains for the low efficiency of such plants.

(i) **Thermal efficiency**. The ratio of heat equivalent of mechanical energy transmitted to the turbine shaft to the heat of combustion of coal is known as thermal efficiency of steam power station.

Heat equivalent of mech. Energy transmitted to turbine shaft Thermal efficiency,

$\eta_{thermal}$= Heat of coal combustion

The thermal efficiency of a modern steam power station is about 30%. It means that if 100 calories of heat is supplied by coal combustion, then mechanical energy equivalent of 30 calories will be available at the turbine shaft and rest is lost. It may be important to note that more than 50% of total heat of combustion is lost in the condenser. The other heat losses occur in flue gases, radiation, ash etc.

(ii) **Overall efficiency**. The ratio of heat equivalent of electrical output to the heat of combustion of coal is known as overall efficiency of steam power station i.e. Heat of combustion of coal

The overall efficiency of a steam power station is about 29%. It may be seen that overall efficiency is less than the thermal efficiency. This is expected since some losses (about 1%) occur in the alternator. The following relation exists among the various efficiencies.

$$\text{Overall efficiency} = \text{Thermal efficiency} \times \text{Electrical efficiency}$$

Equipment of Steam Power Station:

A modern steam power station is highly complex and has numerous equipment and auxiliaries. However, the most important constituents of a steam power station are:

1. Steam generating equipment

2. Condenser

3. Prime mover

4. Water treatment plant

5. Electrical equipment.

1. **Steam generating equipment**. This is an important part of steam power station. It is concerned with the generation of superheated steam and includes such items as boiler, boiler furnace super heater, economizer, air preheater and other heat reclaiming devices.

(i) **Boiler**. A boiler is closed vessel in which water is converted into steam by utilising the heat of coal combustion. Steam boilers are broadly classified into the following two types:

(a) Water tube boilers (b) Fire tube boilers

In a water tube boiler, water flows through the tubes and the hot gases of combustion flow over these tubes. On the other hand, in a fire tube boiler, the hot products of combustion pass through the tubes surrounded by water. Water tube boilers have a number of advantages over fire tube boilers viz., require less space, smaller size of tubes and drum, high working pressure due to small drum, less liable to explosion etc. Therefore, the use of water tube boilers has become universal in large capacity steam power stations.

(ii) **Boiler furnace**. A boiler furnace is a chamber in which fuel is burnt to liberate the heat energy. In addition, it provides support and enclosure for the combustion equipment i.e., burners.

The boiler furnace walls are made of refractory materials such as fire clay, silica, kaolin etc. These materials have the property to resist change of shape, weight or physical properties at high temperatures. There are following three types of construction of furnace walls:

(a) Plain refractory walls

(b) Hollow refractory walls with an arrangement for air cooling

(c) Water walls.

The plain refractory walls are suitable for small plants where the furnace temperature may not be high. However, in large plants, the furnace temperature is quite high* and consequently, the refractory material may get damaged. In such cases, refractory walls are made hollow and air is circulated through hollow space to keep the temperature of the furnace walls low. The recent development is to use water walls. These consist of plain tubes arranged side by side and on the inner face of the refractory walls. The tubes are connected to the upper and lower headers of the boiler. The boiler water is made to circulate through these tubes. The water walls absorb the radiant heat in the furnace which would otherwise heat up the furnace walls.

(iii) **Super heater**: A super heater is a device which superheats the steam i.e., it raises the temperature of steam above boiling point of water. This increases the overall efficiency of the plant. A super heater consists of a group of tubes made of special alloy steels such as chromium-molybdenum. These tubes are heated by the heat of flue gases during their journey from the furnace to the chimney. The steam produced in the boiler is led through the super heater where it is superheated by the heat of flue gases. Super heaters are mainly classified into two types according to the system of heat transfer from flue gases to steam viz.

(a) Radiant super heater (b) Convection super heater

The radiant super heater is placed in the furnace between the water walls and receives heat from the burning fuel through radiation process. It has two main disadvantages. Firstly, due to high furnace temperature, it may get overheated and, therefore, requires a careful design. Secondly, the temperature of super heater falls with increase in steam output. Due to these limitations, radiant super heater is not finding favor these days. On the other hand, a convection super heater is placed in the boiler tube bank and receives heat from flue gases entirely through the convection process. It has the advantage that temperature of super heater increases with the increase in steam output. For this reason, this type of super heater is commonly used these days.

(iv) **Economizer**. It is a device which heats the feed water on its way to boiler by deriving heat from the flue gases. This results in raising boiler efficiency, saving in fuel and reduced stresses in the boiler due to higher temperature of feed water. An economiser consists of a large number of closely spaced parallel steel tubes connected by headers of drums. The feed water flows through these tubes and the flue gases flow outside. A part of the heat of flue gases is transferred to feed water, thus raising the temperature of the latter.

(v) **Air Pre-heater**. Super heaters and economizers generally cannot fully extract the heat from flue gases. Therefore, pre-heaters are employed which recover some of the heat in the escaping gases. The function of an air pre-heater is to extract heat from the flue gases and give it to the air being supplied to furnace for coal combustion. This raises the furnace temperature and increases the thermal efficiency of the plant. Depending upon the method of transfer of heat from flue gases to air, air pre-heaters are divided into the following two classes:

(a) Recuperative type (b) Regenerative type

The recuperative type air-heater consists of a group of steel tubes. The flue gases are passed through the tubes while the air flows externally to the tubes. Thus heat of flue gases is transferred to air. The regenerative type air pre-heater consists of slowly moving drum made of corrugated metal plates. The flue gases flow continuously on one side of the drum and air on the other side. This action permits the transference of heat of flue gases to the air being supplied to the furnace for coal combustion.

2. **Condensers**. A condenser is a device which condenses the steam at the exhaust of turbine. It serves two important functions. Firstly, it creates a very low *pressure at the exhaust of turbine, thus permitting expansion of the steam in the prime mover to a very low pressure. This helps in converting heat energy of steam into mechanical energy in the prime mover. Secondly, the condensed steam can be used as feed water to the boiler. There are two types of condensers, namely:

(i) Jet condenser (ii) Surface condenser

In a jet condenser, cooling water and exhausted steam are mixed together. Therefore, the temperature of cooling water and condensate is the same when leaving the condenser.

Advantages of this type of condenser are: low initial cost, less floor area required, less cooling water required and low maintenance charges.

However, its disadvantages are: condensate is wasted and high power is required for pumping water.

In a surface condenser, there is no direct contact between cooling water and exhausted steam. It consists of a bank of horizontal tubes enclosed in a cast iron shell. The cooling water flows through the tubes and exhausted steam over the surface of the tubes. The steam gives up its heat to water and is itself condensed.

Advantages of this type of condenser are: condensate can be used as feed water, less pumping power required and creation of better vacuum at the turbine exhaust.

However, disadvantages of this type of condenser are: high initial cost requires large floor area and high maintenance charges.

3. **Prime movers**. The prime mover converts steam energy into mechanical energy. There are two types of steam prime movers viz., steam engines and steam turbines. A steam turbine has several advantages over a steam engine as a prime mover viz., high efficiency, simple construction, higher speed, less floor area requirement and low maintenance cost. Therefore, all modern steam power stations employ steam turbines as prime movers.

Steam turbines are generally classified into two types according to the action of steam on moving blades viz.

(i) Impulse turbines (ii) Reactions turbines

In an impulse turbine, the steam expands completely in the stationary nozzles (or fixed blades), the pressure over the moving blades remaining constant. In doing so, the steam attains a high velocity and impinges against the moving blades. This results in the impulsive force on the moving blades which sets the rotor rotating. In a reaction turbine, the steam is partially expanded in the stationary nozzles; the remaining expansion takes place during its flow over the moving blades. The result is that the momentum of the steam causes a reaction force on the moving blades which sets the rotor in motion.

4. **Water treatment plant**. Boilers require clean and soft water for longer life and better efficiency. However, the source of boiler feed water is generally a river or lake which may contain suspended and dissolved impurities, dissolved gases etc. Therefore, it is very important that water is first purified and softened by chemical treatment and then delivered to the boiler. The water from the source of supply is stored in storage tanks. The suspended impurities are removed through sedimentation, coagulation and filtration. Dissolved gases are removed by aeration and degasification. The water is then ‘softened’ by removing temporary and permanent hardness through different chemical processes. The pure and soft water thus available is fed to the boiler for steam generation.

5. **Electrical equipment**. A modern power station contains numerous electrical equipment. However, the most important items are:

(i) **Alternators**. Each alternator is coupled to a steam turbine and converts mechanical energy of the turbine into electrical energy. The alternator may be hydrogen or air cooled. The necessary excitation is provided by means of main and pilot exciters directly coupled to the alternator shaft.

(ii) **Transformers**. A generating station has different types of transformers, viz.,

(a) Main step-up transformers which step-up the generation voltage for transmission of power.

(b) Station transformers which are used for general service (e.g., lighting) in the power station.

(c) Auxiliary transformers which supply to individual unit-auxiliaries.

(iii) **Switchgear**. It houses such equipment which locates the fault on the system and isolates the faulty part from the healthy section. It contains circuit breakers, relays, switches and other control devices.

Nuclear Power Station

A generating station in which nuclear energy is converted into electrical energy is known as a nuclear power station.

In nuclear power station, heavy elements such as Uranium (U) or Thorium (Th) are subjected to nuclear fission in a special apparatus known as a reactor. The heat energy thus released is utilized in raising steam at high temperature and pressure. The steam runs the steam turbine which converts steam energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy.

The most important feature of a nuclear power station is that huge amount of electrical energy can be produced from a relatively small amount of nuclear fuel as compared to other conventional types of power stations. It has been found that complete fission of 1 kg of Uranium (U) can produce as much energy as can be produced by the burning of 4,500 tons of high grade coal. Although the recovery of principal nuclear fuels (i.e., Uranium and Thorium) is difficult and expensive, yet the total energy content of the estimated world reserves of these fuels are considerably higher than those of conventional fuels, viz., coal, oil and gas. At present, energy crisis is gripping us and, therefore, nuclear energy can be successfully employed for producing low cost electrical energy on a large scale to meet the growing commercial and industrial demands.

Advantages:

I. The amount of fuel required is quite small. Therefore, there is a considerable saving in the cost of fuel transportation.

II. A nuclear power plant requires less space as compared to any other type of the same size.

III. It has low running charges as a small amount of fuel is used for producing bulk electrical energy.

IV. This type of plant is very economical for producing bulk electric power.

V. It can be located near the load centers because it does not require large quantities of water and need not be near coal mines. Therefore, the cost of primary distribution is reduced.

VI. There are large deposits of nuclear fuels available all over the world. Therefore, such plants can ensure continued supply of electrical energy for thousands of years.

VII. It ensures reliability of operation.

Disadvantages:

I. The fuel used is expensive and is difficult to recover.

II. The capital cost on a nuclear plant is very high as compared to other types of plants.

III. The erection and commissioning of the plant requires greater technical know-how.

IV. The fission by-products are generally radioactive and may cause a dangerous amount of radioactive pollution.

V. Maintenance charges are high due to lack of standardization. Moreover, high salaries of specially trained personnel employed to handle the plant further raise the cost.

VI. Nuclear power plants are not well suited for varying loads as the reactor does not respond to the load fluctuations efficiently.

VII. The disposal of the by-products, which are radioactive, is a big problem. They have either to be disposed off in a deep trench or in a sea away from sea-shore.

Schematic Arrangement of Nuclear Power Station:

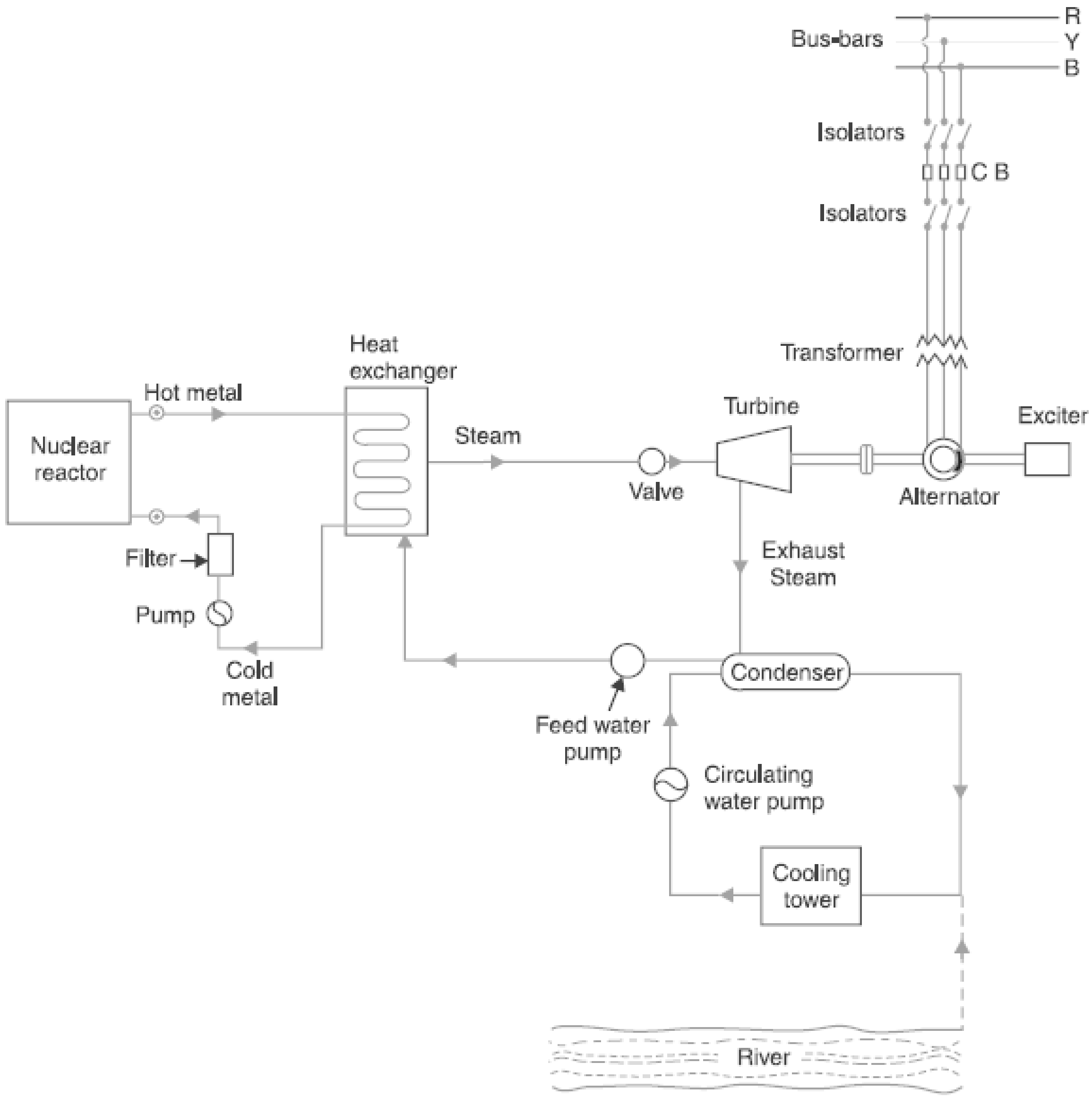
The schematic arrangement of a nuclear power station is shown in Fig; the whole arrangement can be divided into the following main stages:

(i) Nuclear reactor

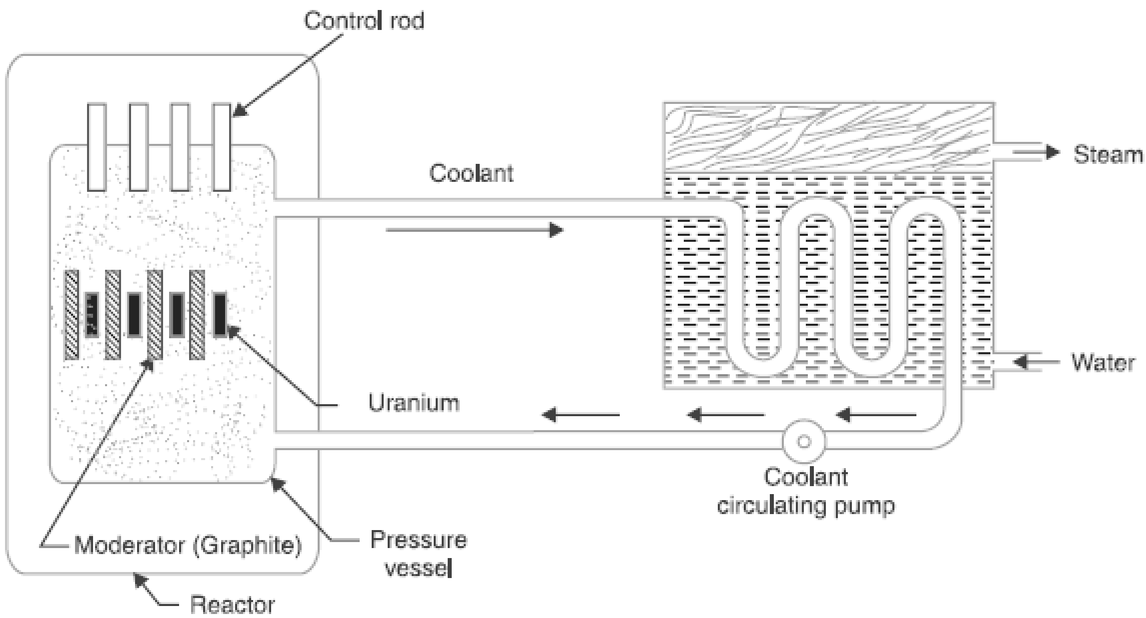
(ii) Heat exchanger

(iii) Steam turbine

(iv) Alternator.



(i) Nuclear reactor. It is an apparatus in which nuclear fuel (U) is subjected to nuclear fission. It controls the chain reaction* that starts once the fission is done. If the chain reaction is not controlled, the result will be an explosion due to the fast increase in the energy released. A nuclear reactor is a cylindrical stout pressure vessel and houses fuel rods of Uranium, moderator and control rods (See Fig.) The fuel rods constitute the fission material and release huge amount of energy when bombarded with slow moving neutrons. The moderator consists of graphite rods which enclose the fuel rods. The moderator slows down the neutrons before they bombard the fuel rods. The control rods are of cadmium and are inserted into the reactor. Cadmium is strong neutron absorber and thus regulates the supply of neutrons for fission. When the control rods are pushed in deep enough, they absorb most of fission neutrons and hence few are available for chain reaction which, therefore, stops. However, as they are being withdrawn, more and more of these fission neutrons cause fission and hence the intensity of chain reaction (or heat produced) is increased. Therefore, by pulling out the control rods, power of the nuclear reactor is increased, whereas by pushing them in, it is reduced. In actual practice, the lowering or raising of control rods is accomplished automatically according to the requirement of load. The heat produced in the reactor is removed by the coolant, generally a sodium metal. The coolant carries the heat to the heat exchanger.



Nuclear Reactor

(ii) Heat exchanger: The coolant gives up heat to the heat exchanger which is utilized in raising the steam. After giving up heat, the coolant is again fed to the reactor.

(iii) Steam turbine: The steam produced in the heat exchanger is led to the steam turbine through a valve. After doing a useful work in the turbine, the steam is exhausted to condenser. The condenser condenses the steam which is fed to the heat exchanger through feed water pump.

(iv) Alternator: The steam turbine drives the alternator which converts mechanical energy into electrical energy. The output from the alternator is delivered to the bus-bars through transformer, circuit breakers and isolators.

Selection of Site for Nuclear Power Station:

The following points should be kept in view while selecting the site for a nuclear power station:

(i) **Availability of water**. As sufficient water is required for cooling purposes, therefore, theplant site should be located where ample quantity of water is available, e.g., across a river or by sea-side.

(ii) **Disposal of waste**. The waste produced by fission in a nuclear power station is generally radioactive which must be disposed off openly to avoid health hazards. The waste should either be buried in a deep trench or disposed off in sea quite away from the sea shore. Therefore, the site selected for such a plant should have adequate arrangement for the disposal of radioactive waste.

(iii) **Distance from populated areas**. The site selected for a nuclear power station should be quite away from the populated areas as there is a danger of presence of radioactivity in the atmosphere near the plant. However, as a precautionary measure, a dome is used in the plant which does not allow the radioactivity to spread by wind or underground waterways.

(iv) **Transportation facilities**: The site selected for a nuclear power station should have adequate facilities in order to transport the heavy equipment during erection and to facilitate the movement of the workers employed in the plant. From the above mentioned factors it becomes apparent that ideal choice for a nuclear power station would be near sea or river and away from thickly populated areas.

Gas Turbine Power Plant

Gas Turbine:A gas turbine is also known as combustion turbine. It is an internal type of combustion engine. In the downstream turbine upstream rotating compressor is coupled in-between combustion chamber also.

Gas Turbine power plant:It is defined as the principal prime mover which is of the turbine type and the medium of working is permanent gas”.

Components present in the gas turbine power plant:

- Compressor
- Intercooler
- Regenerator
- Combustion chamber
- Gas turbine
- Reheating unit

Compressor: IN most of the cases centrifugal and axial turbines are used in the gas turbine power plants. Two compressors are used in the gas turbine power plant. In that one of them is low pressure compressor and the other one is high pressure compressor. Through the filer the atmospheric air must be drawn into the compressor by using the low pressure compressor. The developed power must be used to run the compressor. It uses nearly 66% of the power source. With the help of the intercooler low pressure air, and is moved into the high pressure compressor. Then immediately the high pressure air must be moves in to the regenerator.

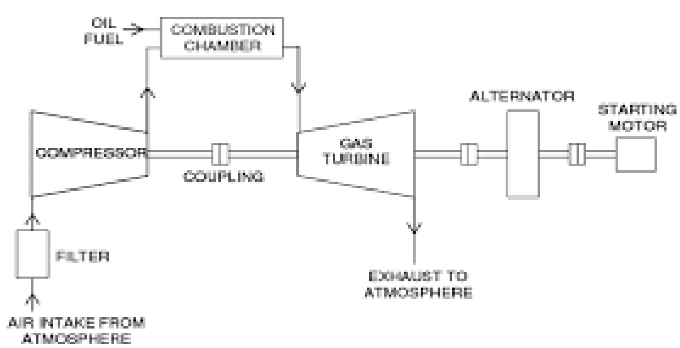
Intercooler: The main aim of the intercooler is to reduce the compressor work and it is to be placed between the low pressure and high pressure compressors. Where the pressure ratio must be high then intercoolers are used. The energy required to compress the air must be proportional to the inlet air pressure. The compressed air cooling in the intercooler is complete by water.

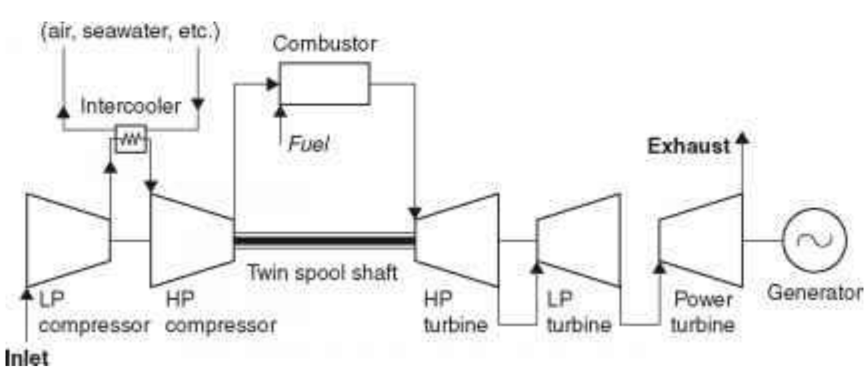
Regenerator: When the air is entering to the regenerator then preheating is doen to reduce the fuel consumption in the combustion chamber, where the efficiency needs to be increased. This is done by heat of hot exhaust gases coming out of the turbine.

Combustion chamber: From the regenerator hot air must be allowed to flow into the combustion chamber. The fuel like natural gas, coal and kerosene are inserted into the combustion chamber. So the high temperature and high pressure products of combustion must be passes through the turbine.

Working of gas turbine power plant:

From the atmosphere the air must be drawn into the low presser compressor with the help of the air filter and then it must be compressed. The compressed low pressure air must come out into the compressor which contains high pressure through the intercooler. So the heat compressed air must be removed. Then the compressed air which consists of high presser must be allowed to go into the combustion chamber with the help of the regenerator. The fuel must be added to the compressor air with the help of the combustion chamber, and then the fuel combustion needs to takes place. So the products obtained from the combustion must be allowed into the high pressure turbine. The exhaust present the high pressure turbine must be enters in to another combustion chamber. In which the additional fuel must be added then it moves through the low pressure turbine. In the low pressure turbine after completion of expansion the exhaust must be used as heat the sir coming out with high pressure. Then it moves to the combustion chamber followed by the regenerator. Then the exhaust must be released in to the atmosphere.





Advantage of gas turbine power plant:

- In gas turbine power plant natural gas is suitable as the fuel. Depends up the available of the natural gas turbine must be installed.
- Gas turbine power plants can effort carefully for small organization hours.
- Loading of fuel needs less capacity and handling is stress-free.
- Gas turbine power plant is minor and close in size when compared with the steam power plants
- It can be started fast and can be place on load in an identical small interval time
- The maintenance cost is less
- It is simple in construction compare to the remaining power plants
- In case of the steam power plants there is no requirement for boiler, condenser
- The gas turbine can function at high speed meanwhile there is no reciprocating part
- Cheaper fuel such as paraffin, kerosene, powdered coal and benzene can be used
- Gas turbine power plants can be used in water shortage areas
- Less pollution is noticed
- A smaller amount of water is necessary for the method

Disadvantage of gas turbine power plant:

- To effort the compressor 66% of the developed source is recycled
- The gas turbine unit has a small thermal efficiency
- The running speed of the gas turbine is in the range from 40k to 100k rpm

- The working temperature is as great as 2000 C, for this reason different alloys and metals are used for the several components of the turbine
- Special cooling techniques are necessary for cooling the turbine blades
- It is hard to start a gas turbine as associated to a diesel engine in a diesel power plant
- The life span of a gas turbine plant is up to 10 years, after which its efficiency declines to less than 10 percent

Application of gas turbine power plant:

- To drive generators and supply loads in steam, diesel or hydro plants
- To work with conventional steam boilers as combination plants
- Thermal process industries
- Petro chemical industries
- Power generation in aircraft and ships for their propulsion.
- They are not suitable for cars because of their high speeds

Hydro-electric Power Station:

A generating station which utilizes the potential energy of water at a high level for the generation of electrical energy is known as a hydro-electric power station.

Hydro-electric power stations are generally located in hilly areas where dams can be built conveniently and large water reservoirs can be obtained. In a hydro-electric power station, water head is created by constructing a dam across a river or lake. From the dam, water is led to a water turbine. The water turbine captures the energy in the falling water and changes the hydraulic energy (i.e., product of head and flow of water) into mechanical energy at the turbine shaft. The turbine drives the alternator which converts mechanical energy into electrical energy. Hydro-electric power stations are becoming very popular because the reserves of fuels (i.e., coal and oil) are depleting day by day. They have the added importance for flood control, storage of water for irrigation and water for drinking purposes.

Advantages

(i) It requires no fuel as water is used for the generation of electrical energy.

(ii) It is quite neat and clean as no smoke or ash is produced.

(iii) It requires very small running charges because water is the source of energy which is available free of cost.

(iv) It is comparatively simple in construction and requires less maintenance.

(v) It does not require a long starting time like a steam power station. In fact, such plants can be put into service instantly.

(vi) It is robust and has a longer life.

(vii) Such plants serve many purposes. In addition to the generation of electrical energy, they also help in irrigation and controlling floods.

(viii) Although such plants require the attention of highly skilled persons at the time of construction, yet for operation, a few experienced persons may do the job well.

Disadvantages

(i) It involves high capital cost due to construction of dam.

(ii) There is uncertainty about the availability of huge amount of water due to dependence on weather conditions.

(iii) Skilled and experienced hands are required to build the plant.

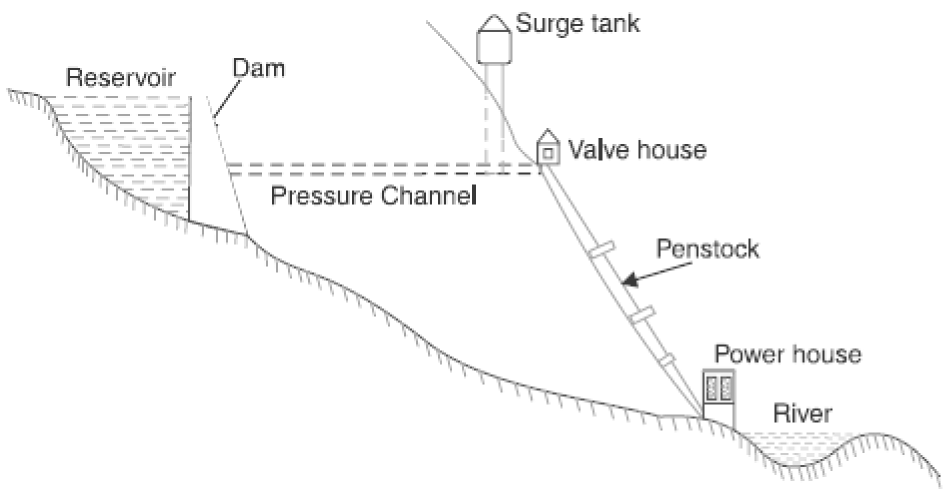
(iv) It requires high cost of transmission lines as the plant is located in hilly areas which are quite away from the consumers.

Schematic Arrangement of Hydro-electric Power Station

Although a hydro-electric power station simply involves the conversion of hydraulic energy into electrical energy, yet it embraces many arrangements for proper working and efficiency. The schematic arrangement of a modern hydro-electric plant is shown in Fig. 2.2.

The dam is constructed across a river or lake and water from the catchment area collects at the back of the dam to form a reservoir. A pressure tunnel is taken off from the reservoir and water brought to the valve house at the start of the penstock. The valve house contains main sluice valves and automatic isolating valves. The former controls the water flow to the power house and the latter cuts off supply of water when the penstock bursts. From the valve house, water is taken to water turbine through a huge steel pipe known as penstock. The water turbine converts hydraulic energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy.

A surge tank (open from top) is built just before the valve house and protects the penstock from bursting in case the turbine gates suddenly close* due to electrical load being thrown off. When the gates close, there is a sudden stopping of water at the lower end of the penstock and consequently the penstock can burst like a paper log. The surge tank absorbs this pressure swing by increase in its level of water



Schematic arrangement of a Hydro-electric plant

Fig. 2.2

Choice of Site for Hydro-electric Power Stations

The following points should be taken into account while selecting the site for a hydro-electric power station:

(i) **Availability of water**. Since the primary requirement of a hydro-electric power station is the availability of huge quantity of water, such plants should be built at a place (e.g., river, canal) where adequate water is available at a good head.

(ii) **Storage of water**. There are wide variations in water supply from a river or canal during the year. This makes it necessary to store water by constructing a dam in order to ensure the generation of power throughout the year. The storage helps in equalizing the flow of water so that any excess quantity of water at a certain period of the year can be made available during times of very low flow in the river. This leads to the conclusion that site selected for a hydro-electric plant should provide adequate facilities for erecting a dam and storage of water.

(iii) **Cost and type of land**. The land for the construction of the plant should be available at a reasonable price. Further, the bearing capacity of the ground should be adequate to withstand the weight of heavy equipment to be installed.

(iv) **Transportation facilities**. The site selected for a hydro-electric plant should be accessible by rail and road so that necessary equipment and machinery could be easily transported. It is clear from the above mentioned factors that ideal choice of site for such a plant is near a river in hilly areas where dam can be conveniently built and large reservoirs can be obtained.

Elements of hydroelectric power stations:

The constituents of a hydro-electric plant are (1) hydraulic structures (2) water turbines and (3) electrical equipment. We shall discuss these items in turn.

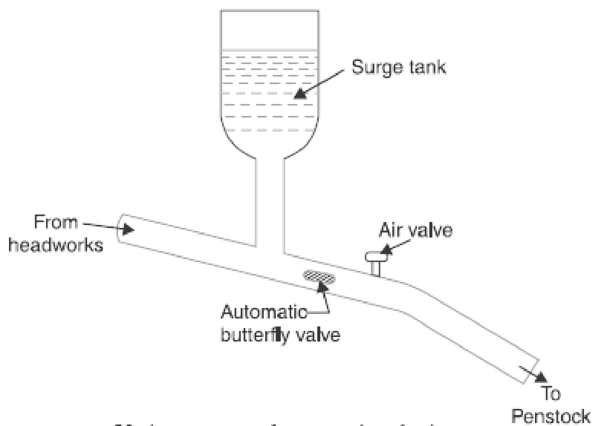
1. Hydraulic structures: Hydraulic structures in a hydro-electric power station include dam, spillways, head works, surge tank, penstock and accessory works.

(i) **Dam**: A dam is a barrier which stores water and creates water head. Dams are built of concrete or stone masonry, earth or rock fill. The type and arrangement depends upon the topography of the site. A masonry dam may be built in a narrow canyon. An earth dam may be best suited for a wide valley. The type of dam also depends upon the foundation conditions, local materials and transportation available, occurrence of earthquakes and other hazards. At most of sites, more than one type of dam may be suitable and the one which is most economical is chosen.

(ii)**Spillways**: There are times when the river flow exceeds the storage capacity of the reservoir. Such a situation arises during heavy rainfall in the catchment area. In order to discharge the surplus water from the storage reservoir into the river on the down-stream side of the dam, spillways are used. Spillways are constructed of concrete piers on the top of the dam. Gates are provided between these piers and surplus water is discharged over the crest of the dam by opening these gates.

(iii) **Headworks**: The head works consists of the diversion structures at the head of an intake. They generally include booms and racks for diverting floating debris, sluices for by-passing debris and sediments and valves for controlling the flow of water to the turbine. The flow of water into and through head works should be as smooth as possible to avoid head loss and cavitation. For this purpose, it is necessary to avoid sharp corners and abrupt contractions or enlargements.

(iv)**Surge tank**: Open conduits leading water to the turbine require no* protection. However, when closed conduits are used, protection becomes necessary to limit the abnormal pressure in the conduit. For this reason, closed conduits are always provided with a surge tank. A surge tank is a small reservoir or tank (open at the top) in which water level rises or falls to reduce the pressure swings in the conduit. A surge tank is located near the beginning of the conduit. When the turbine is running at a steady load, there are no surges in the flow of water through the conduit i.e., the quantity of water flowing in the conduit is just sufficient to meet the turbine requirements. However, when the load on the turbine decreases, the governor closes the gates of turbine, reducing water supply to the turbine. The excess water at the lower end of the conduit rushes back to the surge tank and increases its water level. Thus the conduit is prevented from bursting. On the other hand, when load on the turbine increases, additional water is drawn from the surge tank to meet the increased load requirement. Hence, a surge tank overcomes the abnormal pressure in the conduit when load on the turbine falls and acts as a reservoir during increase of load on the turbine. (v)Penstocks: Penstocks are open or closed conduits which carry water to the turbines. They are generally made of reinforced concrete or steel. Concrete penstocks are suitable for low heads (< 30 m) as greater pressure causes rapid deterioration of concrete. The steel pen stocks can be designed for any head; the thickness of the penstock increases with the head or working pressure.



Various penstock protective devices

Fig. 2.3

Various devices such as automatic butterfly valve, air valve and surge tank (See Fig. 2.3) are provided for the protection of penstocks. Automatic butterfly valve shuts off water flow through the penstock promptly if it ruptures. Air valve maintains the air pressure inside the penstock equal to outside atmospheric pressure. When water runs out of a penstock faster than it enters, a vacuum is created which may cause the penstock to collapse. Under such situations, air valve opens and admits air in the penstock to maintain inside air pressure equal to the outside air pressure.

2. Water turbines: Water turbines are used to convert the energy of falling water into mechanical energy. The principal types of water turbines are:

(i) Impulse turbines (ii) Reaction turbines

(i) Impulse turbines. Such turbines are used for high heads. In an impulse turbine, the entire pressure of water is converted into kinetic energy in a nozzle and the velocity of the jet drives the wheel. The example of this type of turbine is the Pelton wheel (See Fig. 2.4). It consists of a wheel fitted with elliptical buckets along its periphery. The force of water jet striking the buckets on the wheel drives the turbine. The quantity of water jet falling on the turbine is controlled by means of a needle or spear (not shown in the figure) placed in the tip of the nozzle. The movement ofthe needle is controlled by the governor. If the load on the turbine decreases, the governor pushes the needle into the nozzle, thereby reducing the quantity of water striking the buckets. Reverse action takes place if the load on the turbine increases.

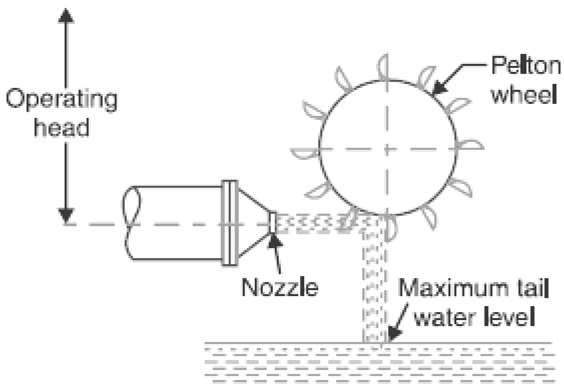


Fig. 2.4 Pelton Wheel

(ii) Reaction turbines. Reaction turbines are used for low and medium heads. In a reaction turbine, water enters the runner partly with pressure energy and partly with velocity head. The important types of reaction turbines are:

(a) Francis turbines (b) Kaplan turbines

A Francis turbine is used for low to medium heads. It consists of an outer ring of stationary guide blades fixed to the turbine casing and an inner ring of rotating blades forming the runner. The guide blades control the flow of water to the turbine. Water flows radially inwards and changes to a downward direction while passing through the runner. As the water passes over the “rotating blades” of the runner, both pressure and velocity of water are reduced. This causes a reaction force which drives the turbine.

A Kaplan turbine is used for low heads and large quantities of water. It is similar to Francis turbine except that the runner of Kaplan turbine receives water axially water flows through regulating gates all around the sides, changing direction in the runner to axial flow. This causes a reaction force which drives the turbine.

3. Electrical equipment: The electrical equipment of a hydro-electric power station includes alternators, transformers, circuit breakers and other switching and protective devices.

Selection of site for Hydro Power Stations:

The important factors governing selection are as follows.

1. Location of Dam:From the cost point of view, the smaller the length of dam, the lower will be the cost of construction. Therefore the site has to be where the river valley has a neck formation. In order to have capacity a valley which has a large storage capacity on the upstream side of the proposed dam site is probably the best. It is desirable to locate a dam after the confluence of two rivers, so that advantage of both the valleys to provide large storage capacity is available.

2. Choice of Dam: The most important consideration in the choice of dam is safety and economy. Failure of dam may result in substantial loss of life and property. The proposed dam must satisfy the test of stability for (i) Shock loads which may be due to earth quakes or sudden changes in reservoir levels and (ii) unusually high floods.The dam should, as far as possible be close to the turbines and should have the shortest length of conduit.

3. Quantity of water Available:This can be estimated on the basis of measurements of stream flow over as long as period as possible.Storage of water is necessary for maintaining continuity of power supply throughout the year. Sufficient storage of water should be available since rainfall is not uniform throughout the year and from one year to another.

4. Accessibility of site:The site should be accessible from the view point of transportations of man and material, so that the overall cost for construction of project is kept low.

5. Distance from the load center:The distance should be as small as possible so that the cost of transmission of power is minimum. Availability of construction material and general know how, should above considered in site selection.

Classification of Hydro Power Plants

1. Classification Based on capacity :

    a) Micro Hydel plant — less than 5 MW
    b) Medium Hydel plant — 5 - 100 MW
    c) High Capacity Hydel plant — 101 – 1000 MW
    d) Very High Capacity Hydel plant — above 1000 MW

2. Classification Based on construction:

Run off river plant without pondage: A run-off river plant is one in which a dam is constructed across a river and the low head thereby created is used to generate power. It is typically a low head plant is generally provided with an overflow weir, the power station being an integral part of the dam structure. In many plants of this type, it is necessary to provide locks for the passage of ships, so that navigation may continue without hinderance. Water passes to the power station through racks made of steel bars to keep out all foreign bodies which might damage the turbine; there racks must be cleared periodically. These plants thus use water as and when it is available. The firm capacity of such plants is very low if the supply of water is not uniform throughout the year.

Run-off-river with pondage: The pondage increases the usefulness of this type of plant. The main requirement for the plant is that the tail race should be such that floods do not raise the trail race water level;otherwise the operation will be affected adversely with pondage it is possible to meet hour to hour fluctuations of load throughout a week or larger periods depending upon its size.

Valley dam plant: The main feature of a valley dam plant is a dam in the river which creates a storage reservoir that develops the necessary head regulated for the turbines. The power plant is located right at the tow of the dam. Water flows through penstocks embedded in the dam to the power house and joins the main river course directly at the outlet of the power house. The plant can be used efficiently throughout the year as it has a storage capacity. Its firm capacity is relatively high. The following are the main components of a valley dam.

(a) The dam with its appurtenant structure like spillways etc.

(b) The intake with gate, stop logs and racks etc.

(c) The main power plant with its components.

Diversion canal plant: The characteristics of this plant are that the waters of the river are diverted away from the main channel through a diversion canal, known as power canal. A power plant is located at a suitable point along the length of the canal. The water after passing through the power plant joins the parent river. These plants are usually low head or medium head plants. They do not have any storage reservoir. The power house requirements of pondage are met through a pool called forebay which is located just before the power plant. The main components of a diversion canal plant are

(a) Diversion weir

(b) Diversion canal Intake with its ancillary works

(c) Bridges of culverts etc. of the diversion canal and

(d) Forebay and its appurtenances.

High head diversion plant: The main feature of this plant is the development of high head resulting from the diversion of water. The diversion of water can be achieved in two ways. (a) through a system of channels and tunnels to another neighboring river or basin which is at a much lower level as compared to the level of the parent river.

(b) Along the tunnels from an upstream point of the river to a downstream point of the parent river.

The main point of difference between high head and low head diversion plant is the elaborate conveyance system for the high head plants. The main components of this type of plant are as follows

(a) Deversion weir (b) the canal tunner intake (c) The head race (d) surge tank (e) penstock (f) tailrace

3. Classification based on operation:

Base load plant: These plants operate on the base portion of the load curve of the power system if they are of large capacity. Plant with large storage can best be used as base load plants especially in rainy seasons when the water level of the reservoir will be raised by rain water. As these loads operate throughout the year at approximately full capacity, the load factor of such plants is high

Peak load plants: These plants supply power to the system corresponding to the load at the top portion of the load curve. Run-off river plant with pondage can be used for such purposes. The load factor of such plant is relatively low as they operate only for a short period of the total operating time.

Classification based on head:

Another way of classifying hydro stations is based on the hydraulic heads available:

Low head plants with head less than 70m

Medium head plants between 70m and 300m

Classification of turbines:

Mainly, there are four types of turbines

(i) Francis Turbine – Francis in 1849

(ii) Pelton Turbine – Pelton in 1889

(iii) Propeller and Kaplan Turbine – Kaplan in 1913

(iv) Deriaz Turbine – Deriaz in 1945

1. Classification based on head:

Low head 2-15m - propeller or Kaplan turbines

Medium head 15 – 70m – Kaplan or Francis turbines

High head 70 – 500m –Francis or pelton turbines

Very high head 500m and above, - Pelton turbines

Deriaz turbines have been used upto a head of 300m, but they are normally used under reversible flow conditions e.g. pumpedstorage plants where a turbine acts both as a prime mover and a pump.

2. Classification based on Discharge:

Low discharge – Pelton turbines

Medium discharge – Francis turbines

High discharge – Kaplan turbines

3. Classification based on Direction of flow:

Axial flow: Propeller and Kaplan turbines

Tangential flow: Pelton turbines

Radial inward flow or mixed flow: Francis turbine

Diagonal flow: Deriaz turbine.

Classification based on pressure: If the pressure of water corresponds to atmosphere before and after striking the blades, such a design of turbine is known as pressure less or impulse turbine. Pelton turbine corresponds to this category. On the other hand if a turbine is made to rotate under the action of water flowing under pressure (greater than atmospheric), the water enters all-round the periphery of the wheel and the energy in the form of bothe pressure and kinetic is utilized by the wheel. Such turbines are known as pressure or reaction turbines. Propeller, Kaplan, Francis and Deriaz belong to this category of turbines

Impulse turbine: Pelton

Reaction turbine: Propeller, Kaplan, Francis and Deriaz

Classification based on specific speed:

Turbines are never classified based on their actual speed but always on the basis of their specific speed which is defined as the speed at which the machine produces,h.P. under a head of 1m. It is an important quantity as it involves the three basic parameters, the speed, power and the head.

Slow specific speed 4 to 70 r.p.m :Pelto turbine

Medium Specific speed 70 to 400 r.p.m : Francis turbine

Fast specific speed 350 to 1100 r.p.m : Kaplan turbine

Francis turbines are used for high power output upto and above 8,00,000h.p, Pelton for medium up to 3,30,000h.p and Kaplan up to 1,50,000h.p.

Power potential studies:

Water power equation or output equation

Let H = head of water in meters (between the water level at inlet and tail race)

Q = Quantity of water in m^3/sec or lit/sec

W = Specific gravity of water

= 1kg/lit when Q is represented in lit/sec

= 1000kg/m^3 when Q is represented in m^3/sec

ή = efficiency of the system

If ‘Q’ Quantity of water falls through ‘H’ m theoretical work done = WQH Kg-m/sec

Effective work done or output of the system = WQH * ήkg-m/sec.

Metrix output = WQH* ή /75 H.P (1 H.P. = 75 kg-m/sec)

Metrix output in watts $= \frac{WQH*n}{75} * 735.5$ Watts

Metrix output in Kilowatts $= \frac{WQH*n}{75*1000} * 735.5$

$= \frac{WQH*n}{75} * 0.735$

Output = $\frac{WQH*n}{102}$ KW

Forebay: A fore bay s an enlarged body of water just above the intake and is used as a regulating reservoir. The river water is distributed to various penstocks, leading to the turbines through the fore bay. If the load on the turbine decreases as a result of reduction in system load. The water is stored in the forebay temporarily and is withdrawn from it when the load on the turbine increases. A forebay is, therefore a naturally provided storage which is able to absorb the flow variations due to variations in system loads. Forebay is also known as head pond.

Draft Tube: The draft tubes are either straight conical draft tubes with a circular section or they are elbow – shaped tubes with gradually increasing areas, the shape changing from circular at the runner section to rectangular at the outlet section. Draft tubes are used for reaction turbines i.e. for Frances and Kaplan turbines and serve mainly two functions.

(i) They achieve the recovery of velocity head at runner outlet which otherwise would have gone waste as an exit loss.

(ii) It permits the setting of the runner of the turbine wheel at a level above that of the water in the tail-race under high water and flood condition without losing the advantage of the elevation difference. The weight of the draft tube is decided by the need to avoid cavitation. Cavitation occurs in flowing water when a cavity or void filled with air and water vapor is formed. Cavitation is harmful as it causes pitting of the turbine runners.

Hydro Graph: It is a graphical representation between discharge and time. For a hydrograph the ordinates may be plotted in terms of the gange height, the number of cubic meters per second per square kilometer, the power in kilowatts that can be developed theoretically per meter of fall or the energy in kilowatt-hours recorded as the switch board exile the abscissa may be in terms of hours, days or weeks. In short a hydro graph shows the variations of flow with time. It also indicates power available from the stream at different times of the day or year.

Mass curve: A mass curve is a plot of cumulative volume of water that can be stored from stream flow versus time in days, weeks or months. The units used for indicating storage are the cubic meter or the day –second –meter. A day-second meter is the flow at the rate or 1 m^3/sec for one day and is equal to 60*60*24 = 86400m^3

By storage the flow of water can be modified according to the plant requirements and hence the generating capacity of plant for the same mass flow can be increased. Water behind the dam at the plant is pondage. Water held in upstream reservoirs is storage. The purpose of a reservoir is to conserve water which may be used during the period of deficiency. The capacity of a reservoir to make available the flow of water at a required rate is studied by means of a mass curve.

Ocean Energy:

Tidal energy:

Tides are defined as the rise and fall of sea level caused by the gravitational pull of the moon and the sun on the Earth. They are not only limited to the oceans, but can also occur in other systems whenever a gravitational field exists. In addition, while the majority of the Earth is affected by the gravitational force of the sun, this is not as easily visible on water. The moon itself has a more prominent effect on the tides, as it is much closer to the Earth when compared to the sun. Shorelines experience either a daily diurnal or semi-diurnal tide consisting of one or two high and low tides respectively.

Wave energy:

Wave energy, also known as ocean energy is defined as energy harnessed from oceanic waves. As the wind blows across the surface of the ocean, it creates waves and thus they can also be referred to as energy moving across the surface of the water. Waves created as a result of wind are usually referred to as wind waves and they occurs most effectively on water surfaces as there are no land masses to resist the power of the wind [2]. These waves while commonly seen on the ocean surface also occur freely on lakes, rivers and canals and can be defined as either being capillary waves, ripples, seas or swells. No two waves are the same with each wave differing in height and distance between the crests and troughs.

Tides formation:

As the moon rotates around the earth, it exerts a gravitational pull creating a tide that moves across the earth. As the moon circles the earth, the earth itself moves in a slight circle too and this inertia causes a tide on the opposite side of the earth. This is known as the two high tides in between which the low tides will occur.

Waves formation:

The changing patterns of the speed, duration and distance with which the wind blows will affect the shape of the formed waves. In addition, the shape and size of respective waves formed will also depend on the resulting affecting system and can easily aid in narrowing down the origins of the waves. For example, high, steep waves that rise and fall quickly are newly formed and often the result of nearby weather systems like local storms while long steady waves are usually formed from extreme weather conditions occurring much further away, sometimes from storms that may even be in another hemisphere.

Wave energy technologies:

To date, there are three main types of wave energy technologies. The first uses floats or buoys to generate electricity from oceanic swells which drive hydraulic pumps. The second type uses an oscillating water column to generate electricity from the rise and fall of water inside a cylindrical shaft. This is usually done at the shore. The water drives air out of the shaft which in turns powers an air driven turbine. The third type utilizes a tapered channel with is located either on or offshore. This technology concentrates waves and drives them into an elevated reservoir where power is generated using a turbine.

Harnessing tidal energy:

While all coastal areas experience high and low tides, this energy can only be harnessed and used for electricity production if the difference between the high and low tides is large enough. The main types of tidal energy include 1) kinetic energy obtained from the currents of changing tides and 2) potential energy obtained from changing heights between the high and low tide. One of the advantages of using tides as a source of energy is that it is more reliable since it is based on the gravitational pull of the moon and can thus be predicted. That being said, while it can be predicted, one of the disadvantages is that this source will only generate energy for 6 – 12 hours at a time thereby reducing the prolonged availability. This intermittent energy production creates a less reliable energy source. Harnessing this energy can disrupt natural migrating routes for marine animals and regular boating pathways. Turbines used for energy generation can kill a large amount of fish in the area. That being said, the ability to uses tidal energy as a source of electricity may subsequently decrease reliance on coal driven generating sources which will in turn reduce the amount of CO_2 emissions.

Tidal energy technologies

Commonly used technologies for tidal energy generation include tidal dams or barrages which contain a sluice across the water body. Beyond the sluice are hydro turbines. As the tide changes, the uneven water levels pushes through past the sluice and powers the turbine. Over time however, a great deal of downstream effects on the both the shoreline and surrounding marine ecosystems were noticed resulting in the development of a range of newer, more environmentally friendly models. These include tidal lagoons, tidal fences and underwater tidal turbines.

Difference between tidal energy and wave energy

We have already defined that tides and waves are formed under completely different conditions. Tides are the rise and fall of the ocean caused by the gravitational pull of the moon and sun on the earth while waves are the wind energy moving across the surface of the ocean thereby making waves much easier to measure as when compared to tides. Tides are less noticeable as when compared to waves and can most commonly be seen on the shorelines affecting the amount of visible water and sand. Waves on the other hand can be seen on the surface of the ocean rising and falling. While tidal power fluctuates daily and wave power may be a more sustained source of energy, it not widely used as only a small number of test sites exist globally.

Summary of differences:

Tidal Energy	Wave Energy
Harnessed from the rise and fall of sea levels	Harnessed from waves moving along the surface of the
Caused by the gravitational pull of the moon and sun on the Earth	Caused by wind
Intensity is affected by location and position of the Earth	Intensity is affected by wind strength
	Often referred to as wave power
Types of tidal energy include kinetic and potential energy	Types of wave energy include kinetic energy
Harnessed using barrages, dams, tidal fences and tidal turbines	Harnessed using offshore and onshore systems
More reliable since it is based on the gravitational pull of the moon and sun	Less reliable since it is based on the effect of the streng the wind on the surface of the water
Discontinuous source of energy that is generated for about 6 – 12 hours at a time	Continuous source of energy
Can disrupt migrating routes of birds and boating pathways and result in large amounts of fish kill	Effect on surrounding environments, ecosystems and communities are low
High construction costs but low maintenance costs	Extremely high start-up costs to design and develop the technology required

WIND ENERGY:

Wind energy is a form of solar energy.[1] Wind energy (or wind power) describes the process by which wind is used to generate electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. A generator can convert mechanical power into electricity. Mechanical power can also be utilized directly for specific tasks such as pumping water.

Wind Energy Basics:

Wind is caused by the uneven heating of the atmosphere by the sun, variations in the earth's surface, and rotation of the earth. Mountains, bodies of water, and vegetation all influence wind flow pattern. Wind turbines convert the energy in wind to electricity by rotating propeller-like blades around a rotor. The rotor turns the drive shaft, which turns an electric generator. Three key factors affect the amount of energy a turbine can harness from the wind: wind speed, air density, and swept area.

Wind speed:

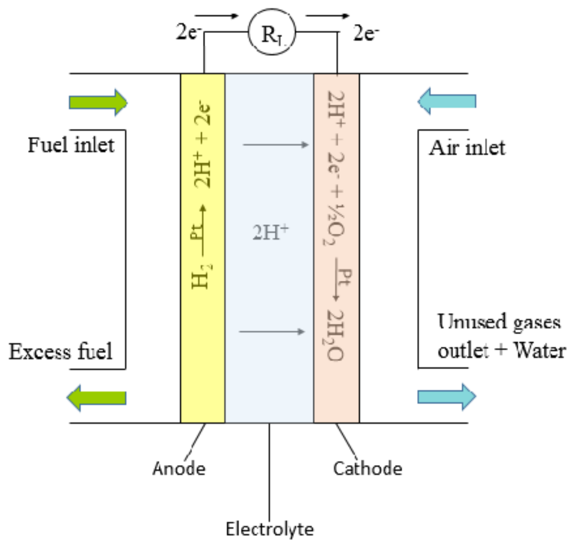
The amount of energy in the wind varies with the cube of the wind speed, in other words, if the wind speed doubles, there is eight times more energy in the wind. Small changes in wind speed have a large impact on the amount of power available in the wind.

- Density of the air

  The more dense the air, the more energy received by the turbine. Air density varies with elevation and temperature. Air is less dense at higher elevations than at sea level, and warm air is less dense than cold air. All else being equal, turbines will produce more power at lower elevations and in locations with cooler average temperatures.

Fuel cells:

These are devices which take stored chemical energy and converts it to electrical energy directly. Essentially it takes the chemical energy that is stored within whatever energy source you have such as hydrogen, gasoline or methane and then through two electrochemical reactions it converts it directly to electricity.



Components of Fuel Cells

Much like a battery, a cell creates energy by converting chemical energy into electrical energy. Unlike a battery, it produces electricity from external supplies of fuel (on the anode side) and oxidant (on the cathode side). These react in the presence of an electrolyte. Generally, the reactants flow in and reaction products flow out while the electrolyte remains in the cell. Cells can operate virtually continuously as long as the necessary flows persist.

The major components of the fuel cell are electrolytes, which is also reactor so it keeps the reagents from mixing together. The next pieces are electrodes, these are pieces that act as catalysts for electrical chemical reaction. Generally what happens is that the reactants flow in and the reaction products flow out while the electrolyte remains in the cell. Then there is a bi-polar plate which is also called a separator, this is a way to collect the current and build voltage from cells.

Fuel for fuel cells

Fuel cells can use a variety of fuels including hydrogen, ethanol, methanol, and various acids and alkalines (bases).

The cells run best on hydrogen but hydrogen is not something you can dig out of the ground. You can dig out a fossil fuel and convert it into hydrogen rich stream. But to do that for a fuel cell, you need to reform it and clean up the gases quite a bit. Hydrogen is abundant in water.

Fuel Cell Efficiency

Fuel cells are theoretically much more efficient than conventional power generation.

Example of energy conversions for a coal fired power station:

- Chemical energy in coal converts to heat
- Heat (in the form of steam driving a turbine) converts into mechanical energy
- The mechanical energy converts to electrical energy

Each conversion has its own inefficiencies, so the overall process is very inefficient.

A fuel cell converts chemical energy directly into electrical energy and is, in theory, much more efficient.

Solar energy:

It is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaic, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis. It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air.

The Earth receives 174 petawatts (PW) of incoming solar radiation (insulation) at the upper atmosphere.[5] Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet.[6] Most of the world's population live in areas with insulation levels of 150–300 watts/m², or 3.5–7.0 kWh/m² per day. Solar radiation is absorbed by the Earth's land surface, oceans – which cover about 71% of the globe – and atmosphere. Warm air containing evaporated water from the oceans rises, causing atmospheric circulation or convection. When the air reaches a high altitude, where the temperature is low, water vapor condenses into clouds, which rain onto the Earth's surface, completing the water cycle. The latent heat of water condensation amplifies convection, producing atmospheric phenomena such as wind, cyclones and anti-cyclones. Sunlight absorbed by the oceans and land masses keeps the surface at an average temperature of 14 °C. By photosynthesis, green plants convert solar energy into chemically stored energy, which produces food, wood and the biomass from which fossil fuels are derived.

The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 hex joules (EJ) per year. In 2002, this was more energy in one hour than the world used in one year. Photosynthesis captures approximately 3,000 EJ per year in biomass. The amount of solar energy reaching the surface of the planet is so vast that in one year it is about twice as much as will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined

Solar technologies are characterized as either passive or active depending on the way they capture, convert and distribute sunlight and enable solar energy to be harnessed at different levels around the world, mostly depending on distance from the equator. Although solar energy refers primarily to the use of solar radiation for practical ends, all renewable energies, other than geothermal power and Tidal power, derive their energy either directly or indirectly from the Sun.

Active solar techniques use photovoltaic, concentrated solar power, solar thermal collectors, pumps, and fans to convert sunlight into useful outputs. Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the Sun. Active solar technologies increase the supply of energy and are considered supply side technologies, while passive solar technologies reduce the need for alternate resources and are generally considered demand side technologies.

Cogeneration (CHP and CCP):

Cogeneration consists of the simultaneous production of two different energy forms from a single resource. CHP is the most common application: the heat produced during power production is recovered, for instance by a heat exchanger, and can then be used to produce steam, hot water, hot air or another hot fluid. Combined Cold and Power (CCP) exists as well: cooling is produced along with electricity from the recovered heat. In order to promote heat production, the CHP scheme can also produce heat first and then use a part of it to produce power. Later in this Informatory Note, we will focus on the most common cogeneration type: the recovery of thermal wastes during power production.

For this purpose, a heat and cold storage system can be set up (sensible or latent heat storage, chemical storage...). To match the cooling production with the needs, complementary cooling can also be produced from power or from fuel combustion. 3 International Institute of Refrigeration - Informatory Note Figure 1: CCHP principle In buildings, the heat demand is usually higher in winter than in summer and vice versa for cooling, except in tropical regions where the cooling demand is extended all year long.

Used fuels:

Several fuels are used as the primary energy for cogeneration and trigeneration. Natural gas is the most commonly used fuel for cogeneration and trigeneration (around 40% in the European Union (EU) between 2005 and 2013 for example). Moreover, solid fossil fuels (such as coal and peat), which emit more CO_2, are being gradually replaced by renewable energies. As far as cogeneration is concerned, their consumption dropped from 35% in 2005 to 21% in 2013 in EU countries, whereas the consumption of renewable energies has doubled at the same time (from 10% to 18%). Oil and oil-based products are also used as fuel for co/trigeneration and accounted for 4% in 2013, whereas other fuels account for 12% in the European Union.

Main prime movers:

Different technologies are used and developed to convert primary energy into power. The main ones are thermal engines, which convert the thermal energy of fuel combustion into mechanical energy. In the following paragraph, we will consider that each prime mover is coupled with an alternator to convert the resulting mechanical energy into power. Thus, in order to compare these technologies, we will discuss electrical efficiency (conversion factor of consumed primary energy into power), thermal efficiency (conversion factor of consumed primary energy into heat) and about overall efficiency (conversion factor of consumed primary energy into useful energy, i.e. power and heat). The power/heat ratio (ratio between power and heat produced by the cogeneration system) is also a useful parameter to choose the most suitable technology according to the required energy form.

Internal combustion engines (ICEs):

using gas or gasoil. Heat is recovered from the exhaust gases at a high temperature (around 450 °C) and from cooling liquid (mainly water and oil) at a low temperature (around 95 °C). Their electrical efficiency is high but they require regular maintenance (Table 1), including monitoring and periodic change of lubricating oil. Furthermore, they are noisy, they vibrate strongly and emit greenhouse gases.

External combustion engines:

They use different fuels and emit less greenhouse gases than internal combustion engines. They are less noisy but they are less efficient and more expensive.

Combustion turbines (gas turbines):

These are ICEs whose exhaust gases are expanded in a turbine, and their heat is then recovered at a high temperature (over 500 °C). A post-combustion system can be used downstream of the turbine, in order to raise the temperature of exhaust gases up to 900 °C.

Steam turbines:

Their thermodynamic cycle is based on an external combustion, and operates on the principle of the Hirn cycle. In this technology, the working fluid is steam and not an organic fluid as for the organic Rankine cycle, which can also be used for thermal engines. The high pressure vapour produced by a boiler is expanded in the turbine, and the heat is then available as low pressure steam. Several primary energies can be used in the boiler: fuels from the recovery of industrial waste, from the incineration of Municipal Solid Waste (MSW) or from biomass.

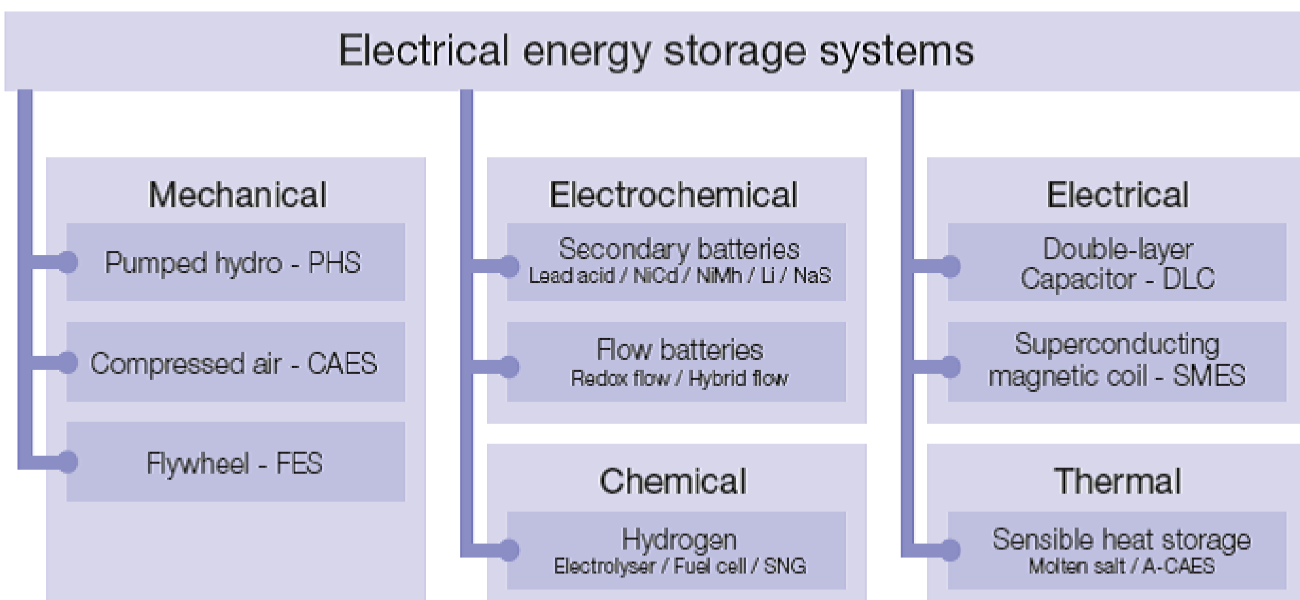
Electrical Energy Storage (EES):

Till about a few years ago, we thought that electricity cannot be stored and needs to be consumed as and when it is generated. Times are changing; today electricity can be stored in megawatt scale thanks to developments made in storage technologies and solutions. These electricity energy storage (EES) applications are increasingly becoming viable around the world.

The smart grids are expected to be the biggest achievement of the 21st century! And energy storage technologies are going to be an important part of it.

The EES technologies around the world:

Energy storage technologies encompass a large set of diverse technologies. They are broadly classified into mechanical, electrochemical, chemical, electrical and thermal energy storage systems as shown in the figure below.



Globally there is about 202 GW of grid connected storage systems of which 135 GW is pumped hydro and 65 GW is UPS systems, rest about 2677MW being new storage technologies:

Technology	MW
Thermal	1000
Solar thermal	601
Batteries	594
Compressed air	440
Flywheels	42

1. **Pumped storage hydro** – the most successful energy storage systems due to their fast response and storage capacity, pumped storage hydro have been proven to be excellent reserves. The world installed capacity is about 135GW. Conventionally, two water reservoirs at different elevations are used to pump water during off peak hours from the lower to the upper reservoir (charging) and the water flows back to move a turbine and generate electricity (discharging) when required. Their long lifetimes and stability are what makes them ideal storage systems. However technical and commercial issues have prevented their large scale adoption.

2. **Compressed air energy storage (CAES)** – 440MW of installations exist around the world. This technology is based on the conventional gas turbines and stores energy by compressing air in an underground storage cavern. Electricity is used to compress air and when needed the compressed air is mixed with natural gas, burned and expanded in a modified gas turbine. The turbine produces the same amount of output power as conventional gas turbines but uses only 40% of the gas. Round trip efficiencies of up to 70% are reached. Undersea insulated airbags based systems are the latest under trials. The advantage of CAES is its large capacity; disadvantages are low round-trip efficiency and geographic limitation of locations.

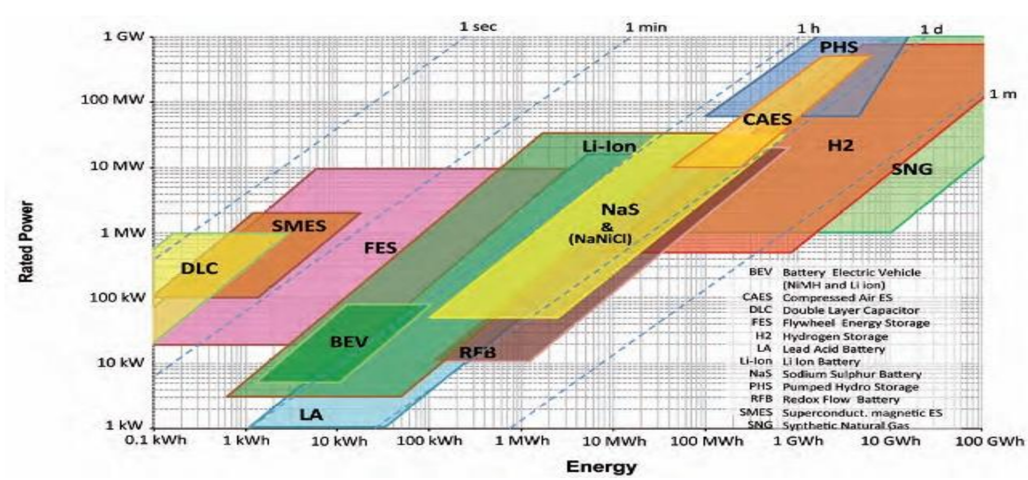
3. **Flywheels** – rotational energy is stored in a large rotational cylinder where the energy is maintained by keeping its speed constant. A transmission device is used to accelerate or decelerate the flywheel by supplying and extracting electricity. When the speed is increased higher amounts of energy are stored. A vacuum chamber is used to reduce friction, and the rotors are made of carbon fibre composites suspended by magnetic bearings. Flywheels are extensively used for space applications. Latest generation flywheels are reported to be suitable for grid applications. Beacon Power commissioned a 20MW FES plant in New York in 2011 with storage capabilities of up to 5 MWh in 15 mins. Experiments with wind farms in California have also shown encouraging results. Total installations of 42MW exist in the world. The long life of this technology with relatively less maintenance requirements and excellent cycle stability make it an ideal storage solution, however the high levels of self-discharge due to air resistance and bearing losses make it less efficient.

4. **Batteries** - originally invented by Italian scientist Alessandro Volta in early 1800s – batteries were essentially zinc and copper electrodes in sulphuric acid. Those days there was no need for electricity! In 1859, lead acid battery emerged as a power source for automobiles. In 1888 alkaline batteries were invented. Next major breakthrough was in 1970s with nickel- cadmium cells that set off the electronic boom, walkman's and power tools became popular inventions. The next major turning point was 1991 with the commercialization of Lithium batteries (LIB) which actually revolutionized the portable electronic gadgets industry. Nickel-Metal Hydride (Ni-MH) batteries emerged in 1997 in Toyota and Honda cars while mass production of LIBs in Korea started in the 2000s, mass production of LIBs by LG Chemicals and Hyundai for Electric Vehicles have been in production since 2009.

Batteries have distinctly different market segments: Appliances - electric and electronic devices; EVs - two wheelers and 4 wheelers; home applications and MW scale grid integrated applications. Requirement for each of these domains being very different, the size, capabilities and technologies can be different. So, different technologies can and will co-exist in battery technologies. However all of them need to mature to higher efficiencies and capacities. The various battery technologies available are:

NaS - by far sodium sulphur batteries are considered the most matured technology. Main manufacturer is NGK Insulators, Japan. About 300MW of installed capacity exist around the world. However fire in the NGK factory in Sep 2011 put a strong question mark on the future of NaS. Despite that in December 2012 a 1MW NaS battery park was installed in Berlin by Yunicos in association with Vattenfall for frequency regulation which flattens fluctuations within milliseconds. Yunicos installs battery parks with 20 years guarantees. In the Web to energy project they recently put on line the LIBs to communicate on the 61850 protocol. Closer to home, at Mitsui House in Delhi they have recently completed a microgrid with NaS battery.

LIB - rechargeable Lithium Bromide has changed our daily life. This technology has products for all the four industry segments- electronics, EVs, home applications and grid connected applications. Li is a comparatively light metal and is very active. Developments in material sciences have allowed for improvements in their density and the advanced LIBs under development are targeting 300wh/kg and 1$/Wh which will be non-flammable. Next generation by 2020 is expected to reach 700wh/kg and 50 cents/Wh which may be fully solid state. Current generation numbers are 140wh/kg and 3.2 $/Wh. Without prejudice to the great leaps made by LIBs the recent Dream Liners troubles have put doubts on LIBs scalability to megawatt levels. Heat dissipation might warrant active cooling. That is a whole lot expensive as temperature sensors and cooling systems are going to be expensive.



Lead Acid - Lead acid batteries are the world's most widely used battery type and have been commercially deployed since about 1890. Their usability decreases when high power is discharged and this makes them unviable as MW scale solutions.

Vanadium redox - this technology is a flow type battery that is emerging as a dark horse. Flow batteries use PEM fuel cell technology. UTC Labs in Hartford, Connecticut have a 20kw flow battery with vanadium redox. UTC is ready for commercialization of this technology and intends to manufacture it in India considering the huge market potential here.

5. **Electric Double layer capacitors -** EDLC are super/ultra capacitors that were invented by GE in 1957. Standard oil developed it in the 1960s and sold it to NEC who commercialized it in 1970s as super capacitors to provide backup for computer memory. Later used in space applications, aircrafts etc, these EES have very long life and can withstand lakhs of cycles.

6. **Super conducting magnetic energy storage -** very much in its infancy stage, it has a superconducting coil and a cryogenically cooled refrigeration system that once charged stores the energy in the magnetic field created in the coil for an indefinite period of time. 1MWh systems used for grid applications, 20MWh systems than can provide 40MW for 30mins or 10MW for 2 hrs are under development.

7. **Thermal storage** – systems use cold water, hot water or ice storage to store the heat and use for later. The efficiencies vary with the material. They are important for integrating large scale renewable energy as concentrated solar thermal technology can be used as a reliable and despicable source of energy to balance the supply and demand.

UNIT-IV

A.C DISTRIBUTION & D.C DISTRIBUTION

In general, the distribution system is the electrical system between the sub-station fed by the transmission system and the consumers meters. It generally consists of *feeders, distributors* and the *service mains.* Fig. 12.1 shows the single line diagram of a typical low tension distribution system.

(*i*) *Feeders.* A feeder is a conductor which connects the sub-station (or localised generating station) to the area where power is to be distributed. Generally, no tappings 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.

(*ii*) *Distributor.* A distributor is a conductor from which tappings are taken for supply to the consumers. In Fig. 12.1, *A B*, *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 ± 6% of rated value at the consumers' terminals.

(*iii*) *Service mains.* A service mains is generally a small cable which connects the distributor to the consumers' terminals.

12.2 Classification of Distribution Systems

A distribution system may be classified according to ;

(*i*) *Nature of current.* According to nature of current, distribution system may be classified as (*a*) d.c. distribution system (*b*) a.c. distribution system. Now-a-days, a.c. system is universally adopted for distribution of electric power as it is simpler and more economical than direct current method.

(*ii*) *Type of construction.* According to type of construction, distribution system may be classified as (*a*) overhead system (*b*) 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.

(*iii*) *Scheme of connection.* According to scheme of connection, the distribution system may be classified as (*a*) radial system (*b*) ring main system (*c*) inter-connected system. Each scheme has its own advantages and disadvantages and those are discussed in Art.12.7.

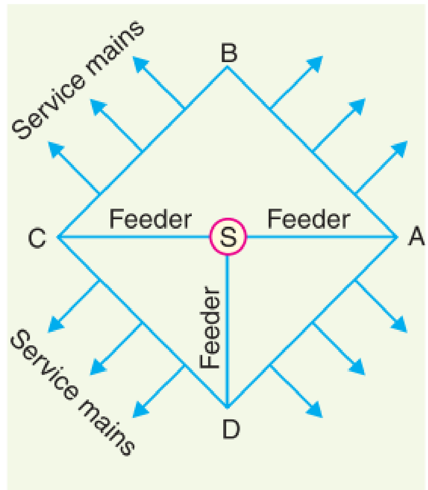


Fig. 12.1

7.3 Comparison of D.C. and A.C. Transmission

The electric power can be transmitted either by means of d.c. or a.c. Each system has its own merits and demerits. It is, therefore, desirable to discuss the technical advantages and disadvantages of the two systems for transmission of electric power.

1. D.C. transmission. For some years past, the transmission of electric power by d.c. has been receiving the active consideration of engineers due to its numerous advantages.

Advantages. The high voltage d.c. transmission has the following advantages over high voltage a.c. transmission :

(*i*) It requires only two conductors as compared to three for a.c. transmission.

(*ii*) There is no inductance, capacitance, phase displacement and surge problems in d.c. transmission.

(*iii*) Due to the absence of inductance, the voltage drop in a d.c. transmission line is less than the a.c. line for the same load and sending end voltage. For this reason, a d.c. transmission line has better voltage regulation.

(*iv*) There is no skin effect in a d.c. system. Therefore, entire cross-section of the line conductor is utilised.

(*v*) For the same working voltage, the potential stress on the insulation is less in case of d.c. system than that in a.c. system. Therefore, a d.c. line requires less insulation.

(*vi*) A d.c. line has less corona loss and reduced interference with communication circuits.

(*vii*) The high voltage d.c. transmission is free from the dielectric losses, particularly in the case of cables.

(*viii*) In d.c. transmission, there are no stability problems and synchronising difficulties.

Disadvantages

(*i*) Electric power cannot be generated at high d.c. voltage due to commutation problems.

(*ii*) The d.c. voltage cannot be stepped up for transmission of power at high voltages.

(*iii*) The d.c. switches and circuit breakers have their own limitations.

2. A.C. transmission. Now-a-days, electrical energy is almost exclusively generated, transmitted and distributed in the form of a.c.

Advantages

(*i*) The power can be generated at high voltages.

(*ii*) The maintenance of a.c. sub-stations is easy and cheaper.

(*iii*) The a.c. voltage can be stepped up or stepped down by transformers with ease and efficiency. This permits to transmit power at high voltages and distribute it at safe potentials.

Disadvantages

(*i*) An a.c. line requires more copper than a d.c. line.

(*ii*) The construction of a.c. transmission line is more complicated than a d.c. transmission line.

(*iii*) Due to skin effect in the a.c. system, the effective resistance of the line is increased.

(*iv*) An a.c. line has capacitance. Therefore, there is a continuous loss of power due to charging current even when the line is open.

12.6 Overhead Versus Underground System

The distribution system can be overhead or underground. Overhead lines are generally mounted on wooden, concrete or steel poles which are arranged to carry distribution transformers in addition to the conductors. The underground system uses conduits, cables and manholes under the surface of streets and sidewalks. The choice between overhead and underground system depends upon a number of widely differing factors. Therefore, it is desirable to make a comparison between the two.

(*i*) *Public safety.* The underground system is more safe than overhead system because all distribution wiring is placed underground and there are little chances of any hazard.

(*ii*) *Initial cost.* The underground system is more expensive due to the high cost of trenching, conduits, cables, manholes and other special equipment. The initial cost of an underground system may be five to ten times than that of an overhead system.

(*iii*) *Flexibility.* The overhead system is much more flexible than the underground system. In the latter case, manholes, duct lines etc., are permanently placed once installed and the load expansion can only be met by laying new lines. However, on an overhead system, poles, wires, transformers etc., can be easily shifted to meet the changes in load conditions.

(*iv*) *Faults.* The chances of faults in underground system are very rare as the cables are laid underground and are generally provided with better insulation.

(*v*) *Appearance.* The general appearance of an underground system is better as all the distribution lines are invisible. This factor is exerting considerable public pressure on electric supply companies to switch over to underground system.

(*vi*) *Fault location and repairs.* In general, there are little chances of faults in an underground system. However, if a fault does occur, it is difficult to locate and repair on this system. On an overhead system, the conductors are visible and easily accessible so that fault locations and repairs can be easily made.

(*vii*) *Current carrying capacity and voltage drop.* An overhead distribution conductor has a considerably higher current carrying capacity than an underground cable conductor of the same material and cross-section. On the other hand, underground cable conductor has much lower inductive reactance than that of an overhead conductor because of closer spacing of conductors.

(*viii*) *Useful life.* The useful life of underground system is much longer than that of an overhead system. An overhead system may have a useful life of 25 years, whereas an underground system may have a useful life of more than 50 years.

(*ix*) *Maintenance cost.* The maintenance cost of underground system is very low as compared with that of overhead system because of less chances of faults and service interruptions from wind, ice, lightning as well as from traffic hazards.

(*x*) *Interference with communication circuits.* An overhead system causes electromagnetic interference with the telephone lines. The power line currents are superimposed on speech currents, resulting in the potential of the communication channel being raised to an undesirable level. However, there is no such interference with the underground system.

It is clear from the above comparison that each system has its own advantages and disadvantages. However, comparative economics (*i.e.*, annual cost of operation) is the most powerful factor influencing the choice between underground and overhead system. The greater capital cost of underground system prohibits its use for distribution. But sometimes non-economic factors (*e.g.*, general appearance, public safety etc.) exert considerable influence on choosing underground system. In general, overhead system is adopted for distribution and the use of underground system is made only where overhead construction is impracticable or prohibited by local laws.

12.4 D.C. Distribution

It is a common knowledge that electric power is almost exclusively generated, transmitted and distributed as a.c. However, for certain applications, d.c. supply is absolutely necessary. For instance, d.c. supply is required for the operation of variable speed machinery (*i.e.*, d.c. motors), for electrochemical work and for congested areas where storage battery reserves are necessary. For this purpose, a.c. power is converted into d.c. power at the substation by using converting machinery *e.g.*, mercury arc rectifiers, rotary converters and motor-generator sets. The d.c. supply from the substation may be obtained in the form of (*i*) 2-wire or (*ii*) 3-wire for distribution.

(*i*) *2-wire d.c. 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 etc. are connected in parallel between the two wires as shown in Fig. 12.4. This system is never used for transmission purposes due to low efficiency but may be employed for distribution of d.c. power.

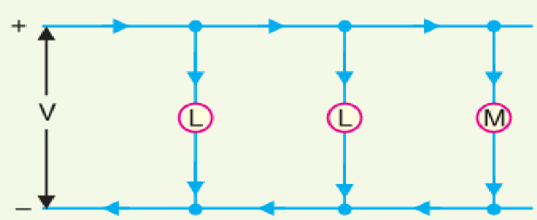


Fig. 12.4

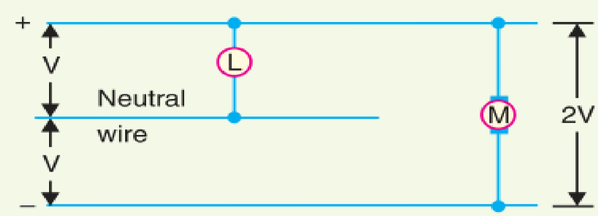


Fig. 12.5

(*ii*) *3-wire d.c. 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. 12.5. The principal advantage of this system is that it makes available two voltages at the consumer terminals *viz.*, *V* between any outer and the neutral and 2V between the outers. Loads requiring high voltage (*e.g.*, motors) 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.

12.5 Methods of Obtaining 3-wire D.C. System

There are several methods of obtaining 3-wire d.c. system. However, the most important ones are:

(*i*) *Two generator method.* In this method, two shunt wound d.c. generators G_1 and G_2 are connected in series and the neutral is obtained from the common point between generators as shown in Fig. 12.6 (*i*). Each generator supplies the load on its own side. Thus generator G_1 supplies a load current of I_1, whereas generator G_2 supplies a load current of I_2. The difference of load currents on the two sides, known as out of balance current $(I_1 - I_2)$ flows through the neutral wire. The principal disadvantage of this method is that two separate generators are required.

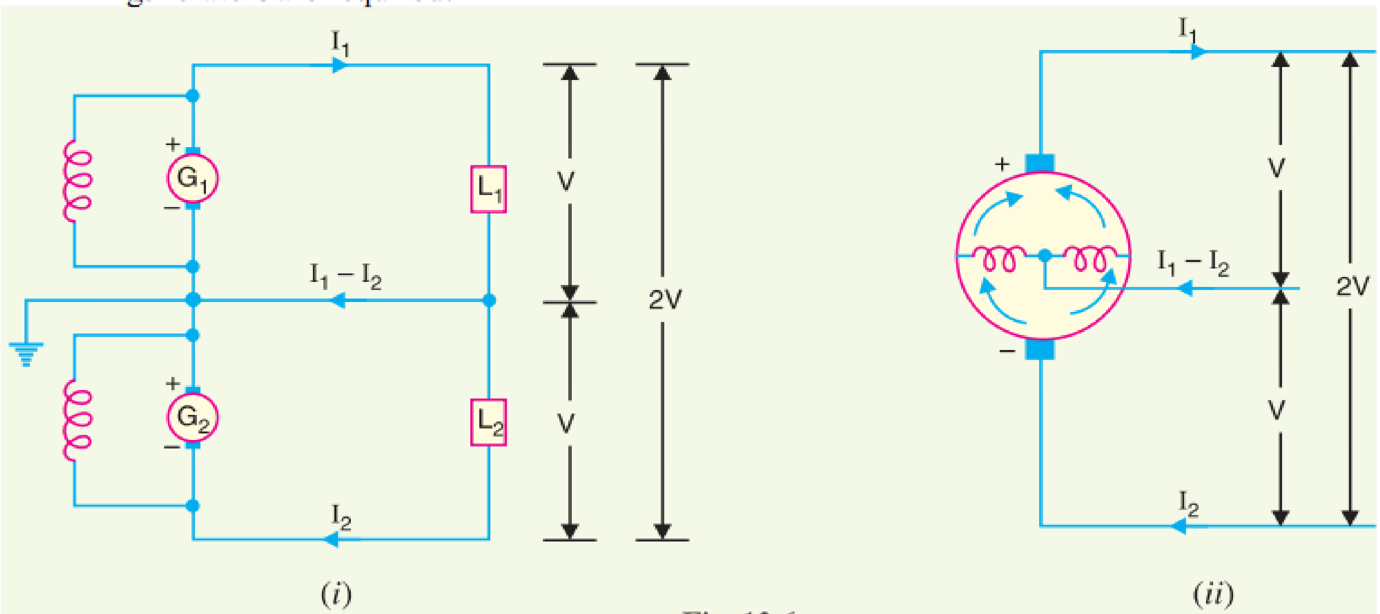


Fig. 12.6

(*ii*) *3-wire d.c. generator.* The above method is costly on account of the necessity of two generators. For this reason, 3-wire d.c. generator was developed as shown in Fig. 12.6 (*ii*). It consists of a standard 2-wire machine with one or two coils of high reactance and low resistance, connected permanently to diametrically opposite points of the armature winding. The neutral wire is obtained from the common point as shown.

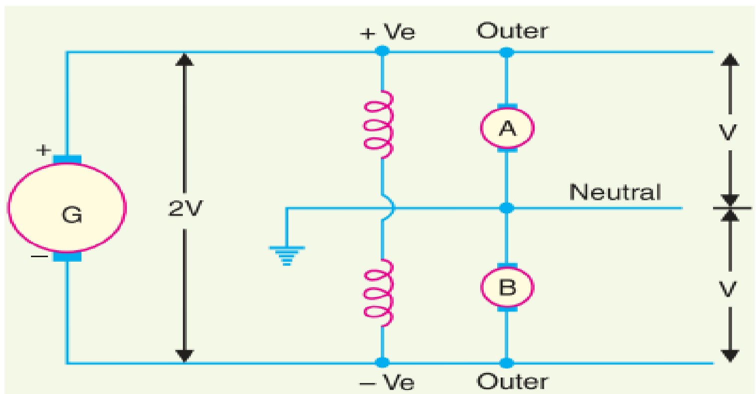


Fig. 12.7

(*iii*) *Balancer set.* The 3-wire system can be obtained from 2-wire d.c. system by the use of balancer set as shown in Fig. 12.7. *G* is the main 2-wire d.c. generator and supplies power to the whole system. The balancer set consists of two identical d.c shunt machines A and B coupled mechanically with their armatures and field windings joined in series across the outers. The junction of their armatures is earthed and neutral wire is taken out from here. The balancer set has the additional advantage that it maintains the potential difference on two sides of neutral equal to each other. This method is discussed in detail in the next chapter.

12.7 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 :

(*i*) Radial System. In this system, separate feeders radiate from a single substation and feed the distributors at one end only. Fig. 12.8 (*i*) shows a single line diagram of a radial system for d.c. distribution where a feeder OC supplies a distributor $A\,B$ at point A. Obviously, the distributor is fed at one end only *i.e.*, point A is this case. Fig. 12.8 (*ii*) shows a single line diagram of radial system for a.c. distribution. The radial system is employed only when power is generated at low voltage and the substation is located at the centre of the load.

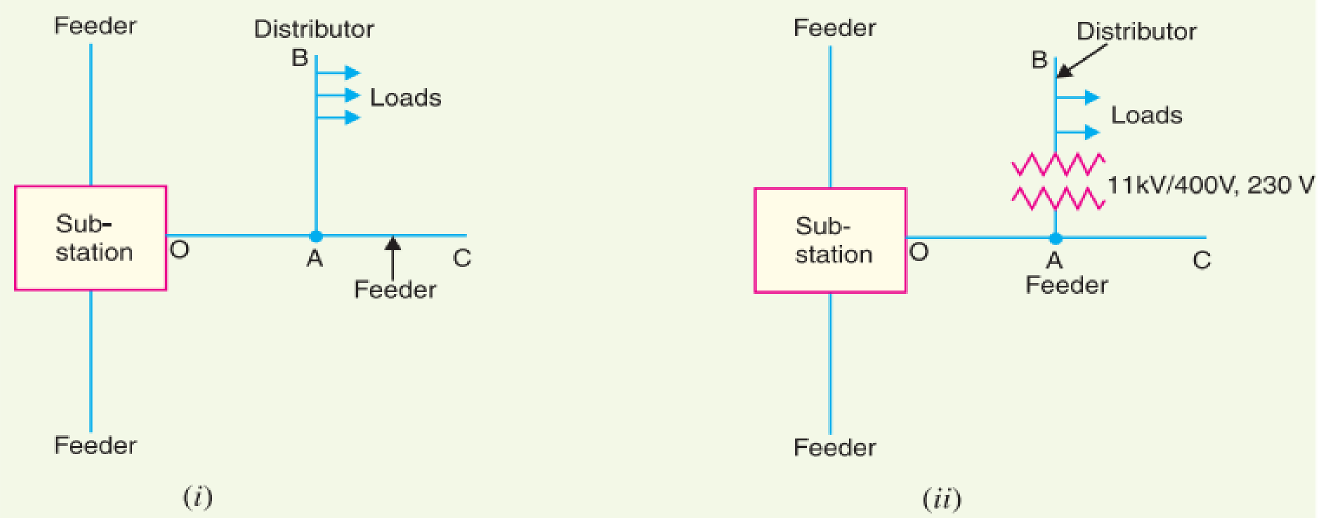


Fig. 12.8

This is the simplest distribution circuit and has the lowest initial cost. However, it suffers from the following drawbacks :

(*a*) The end of the distributor nearest to the feeding point will be heavily loaded.

(*b*) The consumers are dependent on a single feeder and single distributor. Therefore, any fault on the feeder or distributor cuts off supply to the consumers who are on the side of the fault away from the substation.

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

Due to these limitations, this system is used for short distances only.

(*ii*) **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. Fig. 12.9 shows the single line diagram of ring main system for a.c. distribution where substation supplies to the closed feeder LMNOPQRS. The distributors are tapped from different points *M*, *O* and *Q* of the feeder through distribution transformers. The ring main system has the following advantages :

(*a*) There are less voltage fluctuations at consumer's terminals.

(*b*) The system is very reliable as each distributor is fed *via* *two feeders. In the event of fault on any section of the feeder, the continuity of supply is maintained. For example, 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 *via* the feeder *SRQPONM*.

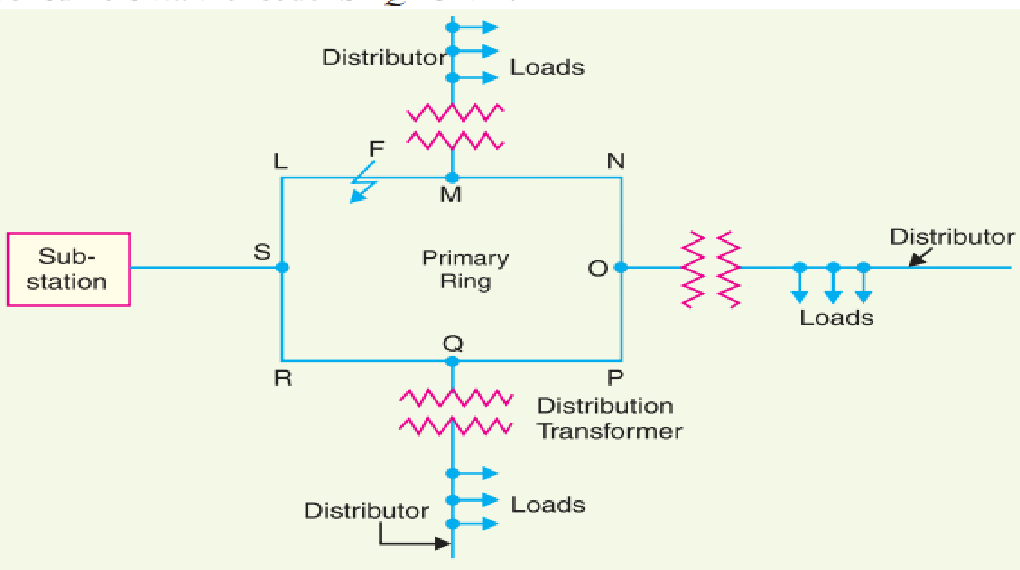


Fig. 12.9

(*iii*) **Interconnected system.** When the feeder ring is energised by two or more than two generating stations or substations, it is called inter-connected system. Fig. 12.10 shows the single line diagram of interconnected system where the closed feeder ring $ABCD$ is supplied by two substations S_1 and S_2 at points D and C respectively. Distributors are connected to

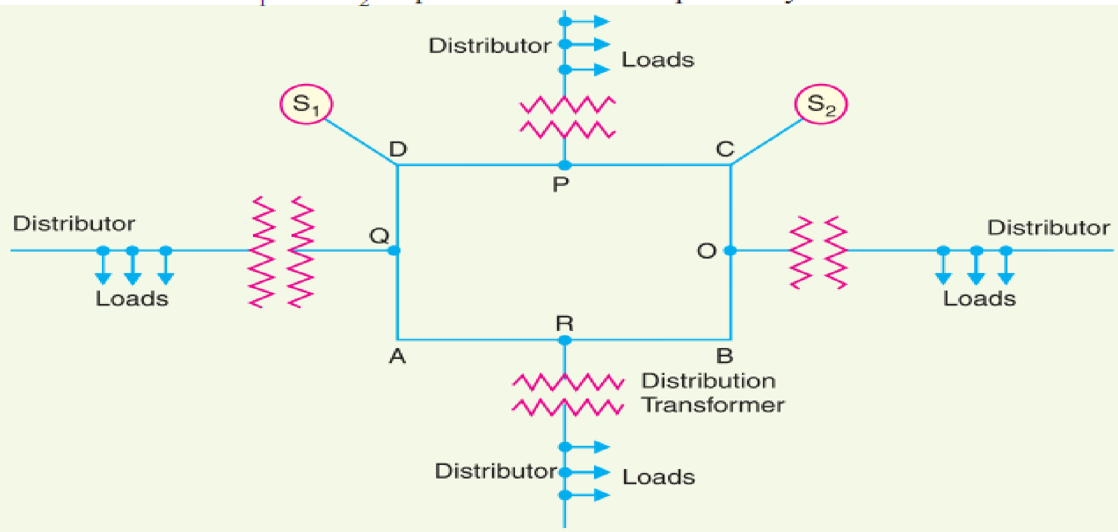


Fig. 12.10

* Thus the distributor from point M is supplied by the feeders SLM and SRQPONM.

points O, P, Q and R of the feeder ring through distribution transformers. The interconnected system has the following advantages :

(*a*) It increases the service reliability.

(*b*) 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.

12.8 Requirements of a Distribution System

A considerable amount of effort is necessary to maintain an electric power supply within the requirements of various types of consumers. Some of the requirements of a good distribution system are : proper voltage, availability of power on demand and reliability.

(*i*) **Proper voltage.** One important requirement of a distribution system is that voltage variations at consumer's terminals should be as low as possible. The changes in voltage are generally caused due to the variation of load on the system. Low voltage causes loss of revenue, inefficient lighting and possible burning out of motors. High voltage causes lamps to burn out permanently and may cause failure of other appliances. Therefore, a good distribution system should ensure that the voltage variations at consumers terminals are within permissible limits. The statutory limit of voltage variations is ± 6% of the rated value at the consumer's terminals. Thus, if the declared voltage is 230 V, then the highest voltage of the consumer should not exceed 244 V while the lowest voltage of the consumer should not be less than 216 V.

(*ii*) **Availability of power on demand.** Power must be available to the consumers in any amount that they may require from time to time. For example, motors may be started or shut down, lights may be turned on or off, without advance warning to the electric supply company. As electrical energy cannot be stored, therefore, the distribution system must be capable of supplying load demands of the consumers. This necessitates that operating staff must continuously study load patterns to predict in advance those major load changes that follow the known schedules.

(*iii*) **Reliability.** Modern industry is almost dependent on electric power for its operation. Homes and office buildings are lighted, heated, cooled and ventilated by electric power. This calls for reliable service. Unfortunately, electric power, like everything else that is man-made, can never be absolutely reliable. However, the reliability can be improved to a considerable extent by (*a*) interconnected system (*b*) reliable automatic control system (*c*) providing additional reserve facilities.

12.9 Design Considerations in Distribution System

Good voltage regulation of a distribution network is probably the most important factor responsible for delivering good service to the consumers. For this purpose, design of feeders and distributors requires careful consideration.

(*i*) *Feeders.* A feeder is designed from the point of view of its current carrying capacity while the voltage drop consideration is relatively unimportant. It is because voltage drop in a feeder can be compensated by means of voltage regulating equipment at the substation.

(*ii*) *Distributors.* A distributor is designed from the point of view of the voltage drop in it. It is because a distributor supplies power to the consumers and there is a statutory limit of voltage variations at the consumer's terminals (± 6% of rated value). The size and length of the distributor should be such that voltage at the consumer's terminals is within the permissible limits.

13.1 Types of D.C. Distributors

The most general method of classifying d.c. distributors is the way they are fed by the feeders. On this basis, d.c. distributors are classified as:

(*i*) Distributor fed at one end

(*ii*) Distributor fed at both ends

(*iii*) Distributor fed at the centre

(*iv*) Ring distributor.

(*i*) **Distributor fed at one end.** In this type of feeding, the distributor is connected to the supply at one end and loads are taken at different points along the length of the distributor. Fig. 13.1 shows the single line diagram of a d.c. distributor *A B* fed at the end *A* (also known as *singly fed distributor*) and loads I_1, I_2 and I_3 tapped off at points *C*, *D* and *E* respectively.

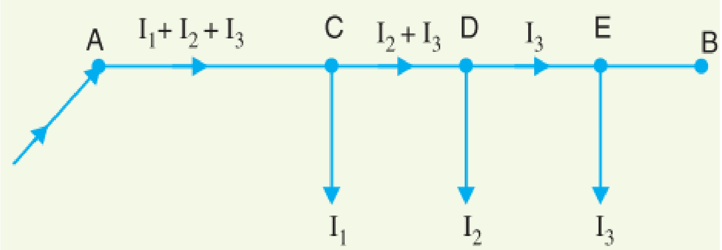


Fig. 13.1

The following points are worth noting in a singly fed distributor :

(*a*) The current in the various sections of the distributor away from feeding point goes on decreasing. Thus current in section *AC* is more than the current in section *CD* and current in section *CD* is more than the current in section *DE*.

(*b*) The voltage across the loads away from the feeding point goes on decreasing. Thus in Fig. 13.1, the minimum voltage occurs at the load point *E*.

(*c*) In case a fault occurs on any section of the distributor, the whole distributor will have to be disconnected from the supply mains. Therefore, continuity of supply is interrupted.

(*ii*) **Distributor fed at both ends.** In this type of feeding, the distributor is connected to the supply mains at both ends and loads are tapped off at different points along the length of the distributor. The voltage at the feeding points may or may not be equal. Fig. 13.2 shows a distributor *A B* fed at the ends *A* and *B* and loads of I_1, I_2 and I_3 tapped off at points *C*, *D* and *E* respectively. Here, the load voltage goes on decreasing as we move away from one feeding point *say A*, reaches minimum value and then again starts rising and reaches maximum value when we reach the other feeding point *B*. The minimum voltage occurs at some load point and is never fixed. It is shifted with the variation of load on different sections of the distributor.

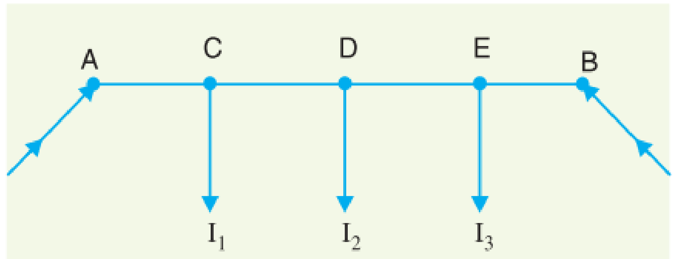


Fig. 13.2

Advantages

(*a*) If a fault occurs on any feeding point of the distributor, the continuity of supply is maintained from the other feeding point.

(*b*) In case of fault on any section of the distributor, the continuity of supply is maintained from the other feeding point.

(*c*) The area of X-section required for a doubly fed distributor is much less than that of a singly fed distributor.

(*c*) The area of X-section required for a doubly fed distributor is much less than that of a singly fed distributor.

(*iii*) **Distributor fed at the centre.** In this type of feeding, the centre of the distributor is connected to the supply mains as shown in Fig. 13.3. It is equivalent to two singly fed distributors, each distributor having a common feeding point and length equal to half of the total length.

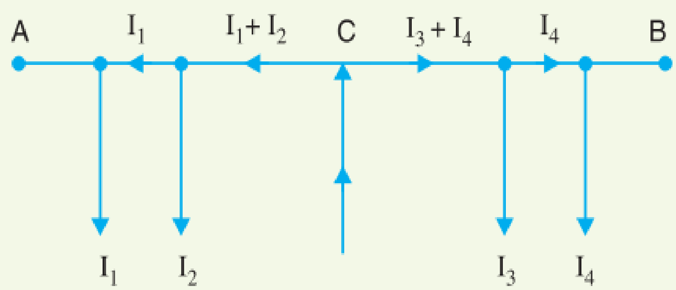


Fig. 13.3

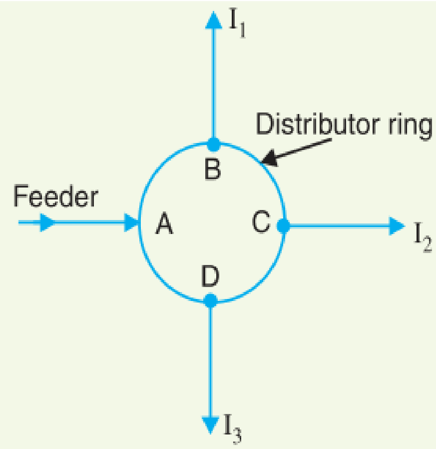


Fig. 13.4

(*iv*) **Ring mains.** In this type, the distributor is in the form of a closed ring as shown in Fig.13.4. It is equivalent to a straight distributor fed at both ends with equal voltages, the two ends being brought together to form a closed ring. The distributor ring may be fed at one or more than one point.

In d.c. distribution calculations, one important point of interest is the determination of point of minimum potential on the distributor. The point where it occurs depends upon the loading conditions and the method of feeding the distributor. The distributor is so designed that the minimum potential on it is not less than 6% of rated voltage at the consumer's terminals. In the next sections, we shall discuss some important cases of d.c. distributors separately.

13.3 D.C. Distributor Fed at one End—Concentrated Loading

Fig. 13.5 shows the single line diagram of a 2-wire d.c. distributor AB fed at one end A and having concentrated loads I_1, I_2, I_3 and I_4 tapped off at points C, D, E and F respectively.

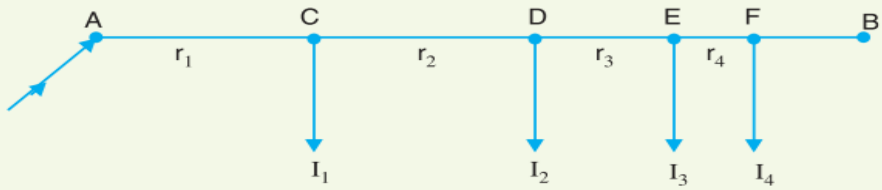


Fig. 13.5

Let r_1, r_2, r_3 and r_4 be the resistances of both wires (go and return) of the sections AC, CD, DE and EF of the distributor respectively.

Current fed from point A $= I_1 + I_2 + I_3 + I_4$

Current in section AC $= I_1 + I_2 + I_3 + I_4$

Current in section CD $= I_2 + I_3 + I_4$

Current in section DE $= I_3 + I_4$

Current in section EF $= I_4$

Voltage drop in section AC $= r_1 (I_1 + I_2 + I_3 + I_4)$

Voltage drop in section CD $= r_2 (I_2 + I_3 + I_4)$

Voltage drop in section DE $= r_3 (I_3 + I_4)$

Voltage drop in section EF $= r_4 I_4$

$\therefore$ Total voltage drop in the distributor

$$= r_1 (I_1 + I_2 + I_3 + I_4) + r_2 (I_2 + I_3 + I_4) + r_3 (I_3 + I_4) + r_4 I_4$$

It is easy to see that the minimum potential will occur at point F which is farthest from the feeding point A.

Example 13.1. *A 2-wire d.c. distributor cable AB is 2 km long and supplies loads of 100A, 150A, 200A and 50A situated 500 m, 1000 m, 1600 m and 2000 m from the feeding point A. Each conductor has a resistance of 0·01 Ω per 1000 m. Calculate the p.d. at each load point if a p.d. of 300 V is maintained at point A.*

Solution. Fig. 13.6 shows the single line diagram of the distributor with its tapped currents.

Resistance per 1000 m of distributor $= 2 \times 0{\cdot}01 = 0{\cdot}02\,\Omega$

Resistance of section AC, R_{AC} $= 0{\cdot}02 \times 500/1000 = 0{\cdot}01\,\Omega$

Resistance of section CD, R_{CD} $= 0{\cdot}02 \times 500/1000 = 0{\cdot}01\,\Omega$

Resistance of section DE, R_{DE} $= 0{\cdot}02 \times 600/1000 = 0{\cdot}012\,\Omega$

Resistance of section EB, R_{EB} $= 0{\cdot}02 \times 400/1000 = 0{\cdot}008\,\Omega$

Referring to Fig. 13.6, the currents in the various sections of the distributor are :

$I_{EB} = 50$ A ; $I_{DE} = 50 + 200 = 250$ A

$I_{CD} = 250 + 150 = 400$ A ; $I_{AC} = 400 + 100 = 500$ A

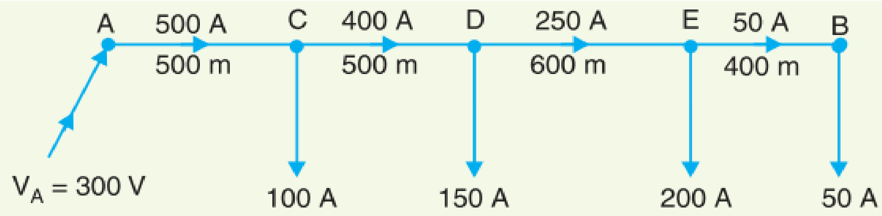


Fig. 13.6

P.D. at load point C, V_C = Voltage at A − Voltage drop in AC

$$= V_A - I_{AC} R_{AC}$$

$$= 300 - 500 \times 0{\cdot}01 = \mathbf{295\ V}$$

P.D. at load point D, $V_D = V_C - I_{CD} R_{CD}$

$$= 295 - 400 \times 0{\cdot}01 = \mathbf{291\ V}$$

P.D. at load point E, $V_E = V_D - I_{DE} R_{DE}$

$$= 291 - 250 \times 0{\cdot}012 = \mathbf{288\ V}$$

P.D. at load point B, $V_B = V_E - I_{EB} R_{EB}$

$$= 288 - 50 \times 0{\cdot}008 = \mathbf{287{\cdot}6\ V}$$

Example 13.2. *A 2-wire d.c. distributor AB is 300 metres long. It is fed at point A. The various loads and their positions are given below :*

At point	*distance from A in metres*	*concentrated load in amperes*
C	*40*	*30*
D	*100*	*40*
E	*150*	*100*
F	*250*	*50*

If the maximum permissible voltage drop is not to exceed 10 V, find the cross-sectional area of the distributor. Take $\rho = 1{\cdot}78 \times 10^{-8}\ \Omega m$.

Solution. The single line diagram of the distributor along with its tapped currents is shown in Fig. 13.7. Suppose that resistance of 100 m length of the distributor is r ohms. Then resistance of various sections of the distributor is :

$$R_{AC} = 0{\cdot}4\,r\,\Omega \quad ; \quad R_{CD} = 0{\cdot}6\,r\,\Omega \quad ; \quad R_{DE} = 0{\cdot}5\,r\,\Omega \quad ; \quad R_{EF} = r\,\Omega$$

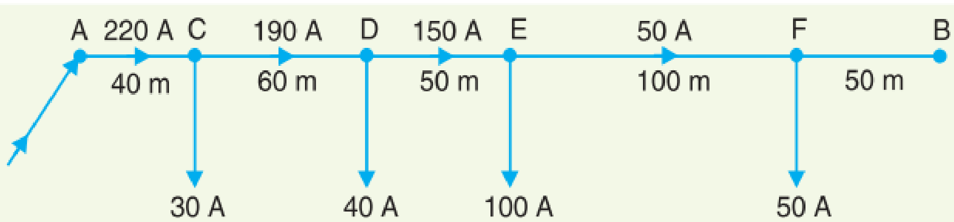


Fig. 13.7

Referring to Fig. 13.7, the currents in the various sections of the distributor are :

$I_{AC} = 220$ A ; $I_{CD} = 190$ A ; $I_{DE} = 150$ A ; $I_{EF} = 50$ A

Total voltage drop over the distributor

$$= I_{AC} R_{AC} + I_{CD} R_{CD} + I_{DE} R_{DE} + I_{EF} R_{EF}$$
$$= 220 \times 0{\cdot}4r + 190 \times 0{\cdot}6r + 150 \times 0{\cdot}5r + 50 \times r$$
$$= 327\ r$$

As the maximum permissible drop in the distributor is 10 V,

$$\therefore \quad 10 = 327\ r$$

or $r = 10/327 = 0{\cdot}03058\ \Omega$

X-sectional area of conductor $= \dfrac{{}^*\rho l}{r/2} = \dfrac{1{\cdot}78 \times 10^{-8} \times 100}{\dfrac{0{\cdot}03058}{2}} = 116{\cdot}4 \times 10^{-6}\ \text{m}^2 =$ **$1{\cdot}164\ \text{cm}^2$**

Example 13.3. *Two tram cars (A & B) 2 km and 6 km away from a sub-station return 40 A and 20 A respectively to the rails. The sub-station voltage is 600 V d.c. The resistance of trolley wire is 0·25 Ω/km and that of track is 0·03 Ω/km. Calculate the voltage across each tram car.*

Solution. The tram car operates on d.c. supply. The positive wire is placed overhead while the rail track acts as the negative wire. Fig. 13.8 shows the single line diagram of the arrangement.

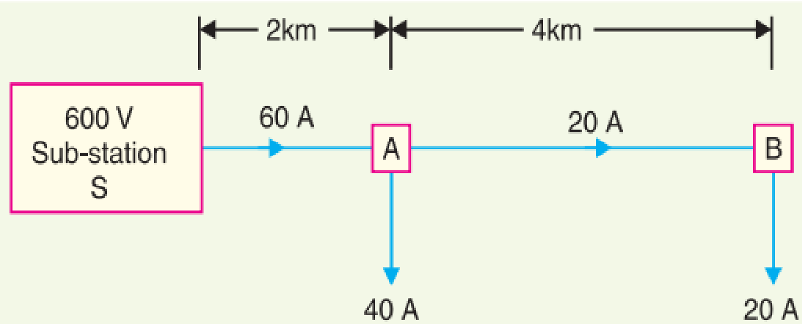


Fig. 13.8

Resistance of trolley wire and track/km

$$= 0{\cdot}25 + 0{\cdot}03 = 0{\cdot}28\Omega$$

Current in section $SA = 40 + 20 = 60$ A

Current in section $AB = 20$ A

Voltage drop in section $SA = 60 \times 0{\cdot}28 \times 2 = 33{\cdot}6$ V

Voltage drop in section $AB = 20 \times 0{\cdot}28 \times 4 = 22{\cdot}4$ V

$\therefore$ Voltage across tram $A = 600 - 33{\cdot}6 =$ **566·4 V**

Voltage across tram $B = 566{\cdot}4 - 22{\cdot}4 =$ **544 V**

Example 13.4. *The load distribution on a two-wire d.c. distributor is shown in Fig. 13.9. The cross-sectional area of each conductor is 0·27 cm². The end A is supplied at 250 V. Resistivity of the wire is ρ = 1·78 μ Ω cm. Calculate (i) the current in each section of the conductor (ii) the two-core resistance of each section (iii) the voltage at each tapping point.*

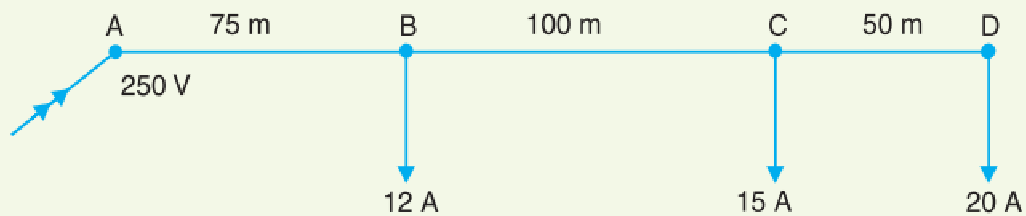


Fig. 13.9

Solution.

(*i*) Currents in the various sections are :

$$\text{Section } CD, I_{CD} = \mathbf{20\ A}\ ; \text{ section } BC, I_{BC} = 20 + 15 = \mathbf{35\ A}$$

$$\text{Section } AB, I_{AB} = 20 + 15 + 12 = \mathbf{47\ A}$$

(*ii*) Single-core resistance of the section of 100 m length

$$= \rho\frac{l}{a} = 1{\cdot}78 \times 10^{-6} \times \frac{100 \times 100}{0{\cdot}27} = 0{\cdot}066\,\Omega$$

* Note that resistance of each conductor of l = 100 m is $r/2$.

The resistances of the various sections are :

$$R_{AB} = 0{\cdot}066 \times 0{\cdot}75 \times 2 = \mathbf{0{\cdot}099\,\Omega}\ ; R_{BC} = 0{\cdot}066 \times 2 = \mathbf{0{\cdot}132\,\Omega}$$

$$R_{CD} = 0{\cdot}066 \times 0{\cdot}5 \times 2 = \mathbf{0{\cdot}066\,\Omega}$$

(*iii*) Voltage at tapping point *B* is

$$V_B = V_A - I_{AB} R_{AB} = 250 - 47 \times 0{\cdot}099 = \mathbf{245{\cdot}35\ V}$$

Voltage at tapping point *C* is

$$V_C = V_B - I_{BC} R_{BC} = 245{\cdot}35 - 35 \times 0{\cdot}132 = \mathbf{240{\cdot}73\ V}$$

Voltage at tapping point *D* is

$$V_D = V_C - I_{CD} R_{CD} = 240{\cdot}73 - 20 \times 0{\cdot}066 = \mathbf{239{\cdot}41\ V}$$

13.4 Uniformly Loaded Distributor Fed at One End

Fig 13.11 shows the single line diagram of a 2-wire d.c. distributor *A B* fed at one end *A* and loaded uniformly with *i* amperes per metre length. It means that at every 1 m length of the distributor, the load tapped is *i* amperes. Let *l* metres be the length of the distributor and *r* ohm be the resistance per metre run.

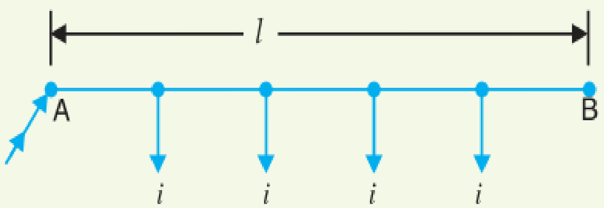


Fig. 13.11

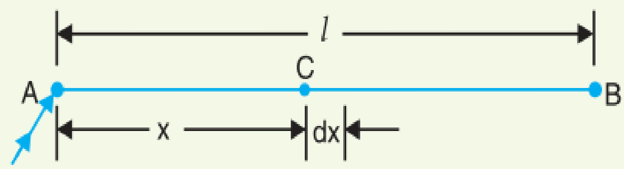


Fig. 13.12

Consider a point *C* on the distributor at a distance *x* metres from the feeding point *A* as shown in Fig. 13.12. Then current at point *C* is

$$= i\,l - i\,x \text{ amperes} = i\,(l - x) \text{ amperes}$$

Now, consider a small length *dx* near point *C*. Its resistance is *r dx* and the voltage drop over length *dx* is

$$dv = i\,(l - x)\,r\,dx = i\,r\,(l - x)\,dx$$

Total voltage drop in the distributor upto point *C* is

$$v = \int_0^x i\,r\,(l - x)\,dx = i\,r\left(l\,x - \frac{x^2}{2}\right)$$

The voltage drop upto point *B* (*i.e.* over the whole distributor) can be obtained by putting $x = l$ in the above expression.

∴ Voltage drop over the distributor *AB*

$$= i\,r\left(l \times l - \frac{l^2}{2}\right)$$

$$= \tfrac{1}{2}\,i\,r\,l^2 = \tfrac{1}{2}\,(i\,l)\,(r\,l)$$

$$= \tfrac{1}{2}\,I\,R$$

where $i\,l = I$, the total current entering at point *A*

$r\,l = R$, the total resistance of the distributor

Thus, in a uniformly loaded distributor fed at one end, the total voltage drop is equal to that produced by the whole of the load assumed to be concentrated at the middle point.

Example 13.5. *A 2-wire d.c. distributor 200 metres long is uniformly loaded with 2A/metre. Resistance of single wire is 0·3 Ω/km. If the distributor is fed at one end, calculate :*

(*i*) *the voltage drop upto a distance of 150 m from the feeding point*

(*ii*) *the maximum voltage drop*

Solution.

Current loading, $i = 2$ A/m

Resistance of distributor per metre run,

$$r = 2 \times 0{\cdot}3/1000 = 0{\cdot}0006\,\Omega$$

Length of distributor, $l = 200$ m

(*i*) Voltage drop upto a distance *x* metres from feeding point

$$= i\,r\left(l\,x - \frac{x^2}{2}\right) \quad \text{[See Art. 13·4]}$$

Here, $x = 150$ m

∴ Desired voltage drop $= 2 \times 0{\cdot}0006\left(200 \times 150 - \frac{150 \times 150}{2}\right) = $ **22·5 V**

(*ii*) Total current entering the distributor,

$$I = i \times l = 2 \times 200 = 400 \text{ A}$$

Total resistance of the distributor,

$$R = r \times l = 0{\cdot}0006 \times 200 = 0{\cdot}12\,\Omega$$

∴ Total drop over the distributor

$$= \frac{1}{2}\,I\,R = \frac{1}{2} \times 400 \times 0{\cdot}12 = \textbf{24 V}$$

Example 13.6. *A uniform 2-wire d.c. distributor 500 metres long is loaded with 0.4 ampere metre and is fed at one end. If the maximum permissible voltage drop is not to exceed 10 V, find the cross-sectional area of the distributor conductor. Take ρ = 1·7 × 10*$^{-6}$ *Ω cm.*

Solution.

Current entering the distributor, $I = i \times l = 0{\cdot}4 \times 500 = 200$ A

Max. permissible voltage drop $= 10$ V

Let *r* ohm be the resistance per metre length of the distributor (both wires).

Max. voltage drop $= \frac{1}{2}\,I\,R$

or $10 = \frac{1}{2}\,I\,r\,l$ $\quad [\because R = r\,l]$

or $$r = \frac{2 \times 10}{I \times l} = \frac{2 \times 10}{200 \times 500} = 0{\cdot}2 \times 10^{-3}\,\Omega$$

∴ Area of cross-section of the distributor conductor is

$$a = \frac{\rho\,l}{r/2} = \frac{1{\cdot}7 \times 10^{-6} \times 100^{*} \times 2}{0{\cdot}2 \times 10^{-3}} = \textbf{1·7 cm}^2$$

Example 13.7. *A 250 m , 2-wire d.c. distributor fed from one end is loaded uniformly at the rate of 1·6 A/metre. The resistance of each conductor is 0·0002 Ω per metre. Find the voltage necessary at feed point to maintain 250 V (i) at the far end (ii) at the mid-point of the distributor.*

Solution.

Current loading, $i = 1 \cdot 6 \text{A/m}$

Current entering the distributor, $I = i \times l = 1 \cdot 6 \times 250 = 400 \text{ A}$

Resistance of the distributor per metre run

$$r = 2 \times 0 \cdot 0002 = 0 \cdot 0004 \, \Omega$$

Total resistance of distributor, $R = r \times l = 0 \cdot 0004 \times 250 = 0 \cdot 1 \, \Omega$

(*i*) Voltage drop over the entire distributor

$$= \frac{1}{2} \, I R = \frac{1}{2} \times 400 \times 0 \cdot 1 = 20 \text{ V}$$

∴ Voltage at feeding point $= 250 + 20 =$ **270 V**

(*ii*) Voltage drop upto a distance of x metres from feeding point

$$= i \, r \left(l \, x - \frac{x^2}{2} \right)$$

Here $x = l/2 = 250/2 = 125$ m

∴ Voltage drop $= 1 \cdot 6 \times 0 \cdot 0004 \left(250 \times 125 - \frac{(125)^2}{2} \right) = 15 \text{ V}$

∴ Voltage at feeding point $= 250 + 15 =$ **265 V**

Example 13.8. *Derive an expression for the power loss in a uniformly loaded distributor fed at one end.*

Solution. Fig. 13.13 shows the single line diagram of a 2-wire d.c. distributor AB fed at end A and loaded uniformly with i amperes per metre length.

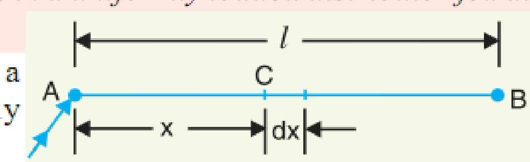


Fig. 13.13

Let l = length of the distributor in metres

r = resistance of distributor (both conductors) per metre run

Consider a small length dx of the distributor at point C at a distance x from the feeding end A. The small length dx will carry current which is tapped in the length CB.

∴ Current in $dx = i \, l - i \, x = i \, (l - x)$

* Because we have assumed that r ohm is the resistance of 1m (= 100 cm) length of the distributor.

$$\text{Power loss in length } dx = (\text{current in length } dx)^2 \times \text{Resistance of length } dx$$
$$= [i\,(l - x)]^2 \times r\,dx$$

Total power loss P in the whole distributor is

$$P = \int_0^l [i\,(l - x)]^2\; r\,dx = \int_0^l i^2\left(l^2 + x^2 - 2\,lx\right)\, r\,dx$$
$$= i^2 r \int_0^l \left(l^2 + x^2 - 2\,lx\right) dx = i^2 r \left[l^2 x + \frac{x^3}{3} - \frac{2lx^2}{2}\right]_0^l$$
$$= i^2 r \left[l^3 + \frac{l^3}{3} - l^3\right] = i^2 \times \frac{r\,l^3}{3}$$

$$\therefore \quad P = \frac{i^2\, r\, l^3}{3}$$

Example 13.9. *Calculate the voltage at a distance of 200 m of a 300 m long distributor uniformly loaded at the rate of 0.75 A per metre. The distributor is fed at one end at 250 V. The resistance of the distributor (go and return) per metre is 0·00018 Ω. Also find the power loss in the distributor.*

Solution.

Voltage drop at a distance x from supply end

$$= i\,r\left(l\,x - \frac{x^2}{2}\right)$$

Here $i = 0{\cdot}75$ A/m; $l = 300$ m ; $x = 200$ m ; $r = 0{\cdot}00018\ \Omega$/m

$$\therefore \quad \text{Voltage drop} = 0{\cdot}75 \times 0{\cdot}00018\left[300 \times 200 - \frac{(200)^2}{2}\right] = 5.4 \text{ V}$$

Voltage at a distance of 200 m from supply end

$$= 250 - 5{\cdot}4 = \mathbf{244{\cdot}6\ V}$$

Power loss in the distributor is

$$P = \frac{i^2\, r\, l^3}{3} = \frac{(0\cdot 75)^2 \times 0\cdot 00018 \times (300)^3}{3} = \mathbf{911{\cdot}25\ W}$$

13.5 Distributor Fed at Both Ends — Concentrated Loading

Whenever possible, it is desirable that a long distributor should be fed at both ends instead of at one end only, since total voltage drop can be considerably reduced without increasing the cross-section of the conductor. The two ends of the distributor may be supplied with **(*i*)** equal voltages **(*ii*)** unequal voltages.

(*i*) Two ends fed with equal voltages. Consider a distributor *A B* fed at both ends with equal voltages *V* volts and having concentrated loads I_1, I_2, I_3, I_4 and I_5 at points *C*, *D*, *E*, *F* and *G* respectively as shown in Fig. 13.14. As we move away from one of the feeding points, *say A*, p.d. goes on decreasing till it reaches the minimum value at some load point, *say E*, and then again starts rising and becomes *V* volts as we reach the other feeding point *B*.

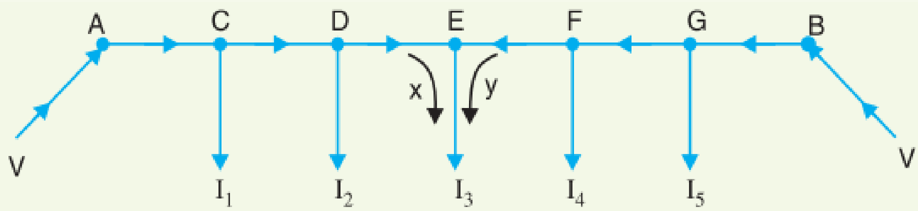


Fig. 13.14

All the currents tapped off between points *A* and *E* (minimum p.d. point) will be supplied from the feeding point *A* while those tapped off between *B* and *E* will be supplied from the feeding point *B*. The current tapped off at point *E* itself will be partly supplied from *A* and partly from *B*. If these currents are *x* and *y* respectively, then,

$$I_3 = x + y$$

Therefore, we arrive at a very important conclusion that at the point of minimum potential, current comes from both ends of the distributor.

Point of minimum potential. It is generally desired to locate the point of minimum potential. There is a simple method for it. Consider a distributor *A B* having three concentrated loads I_1, I_2 and I_3 at points *C*, *D* and *E* respectively. Suppose that current supplied by feeding end *A* is I_A. Then current distribution in the various sections of the distributor can be worked out as shown in Fig. 13.15

(*i*). Thus

$$I_{AC} = I_A \; ; \qquad I_{CD} = I_A - I_1$$

$$I_{DE} = I_A - I_1 - I_2 \; ; \qquad I_{EB} = I_A - I_1 - I_2 - I_3$$

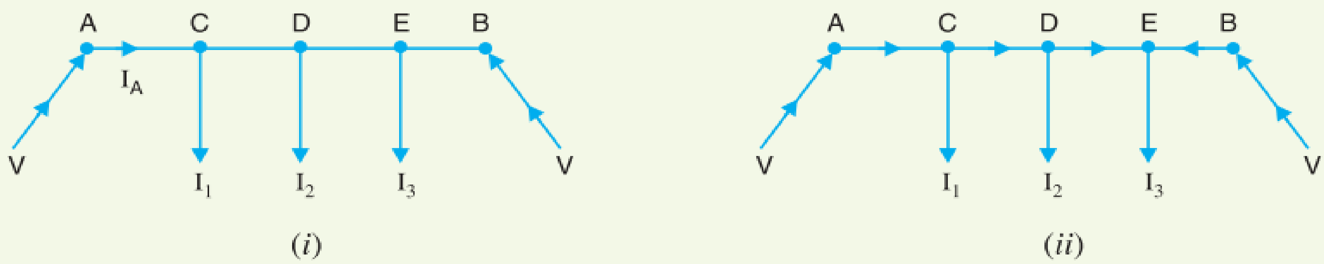


Fig. 13.15

Voltage drop between A and B = Voltage drop over $A\,B$

or $\quad V - V = I_A R_{AC} + (I_A - I_1) R_{CD} + (I_A - I_1 - I_2) R_{DE} + (I_A - I_1 - I_2 - I_3) R_{EB}$

From this equation, the unknown I_A can be calculated as the values of other quantities are generally given. Suppose *actual* directions of currents in the various sections of the distributor are indicated as shown in Fig. 13.15 (*ii*). The load point where the currents are coming from both sides of the distributor is the point of minimum potential *i.e.* point E in this case

(*ii*) Two ends fed with unequal voltages. Fig. 13.16 shows the distributor $A\,B$ fed with unequal voltages ; end A being fed at V_1 volts and end B at V_2 volts. The point of minimum potential can be found by following the same procedure as discussed above. Thus in this case,

Voltage drop between A and B = Voltage drop over $A\,B$

or $\quad V_1 - V_2$ = Voltage drop over $A\,B$

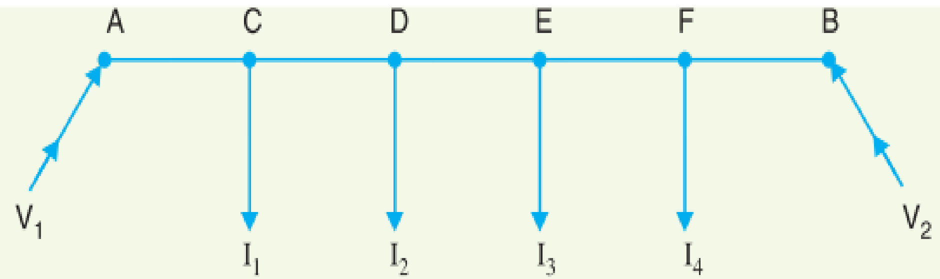


Fig. 13.16

Example 13.10. *A 2-wire d.c. street mains AB, 600 m long is fed from both ends at 220 V. Loads of 20 A, 40 A, 50 A and 30 A are tapped at distances of 100m, 250m, 400m and 500 m from the end A respectively. If the area of X-section of distributor conductor is 1cm², find the minimum consumer voltage. Take* $\rho = 1{\cdot}7 \times 10^{-6}\ \Omega$ *cm.*

Solution. Fig. 13.17 shows the distributor with its tapped currents. Let I_A amperes be the current supplied from the feeding end A. Then currents in the various sections of the distributor are as shown in Fig. 13.17.

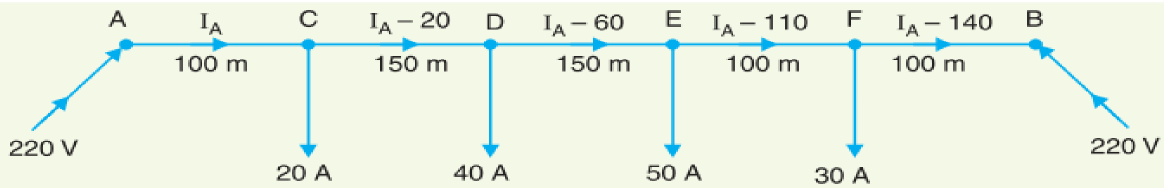


Fig. 13.17

Resistance of 1 m length of distributor

$$= 2 \times \frac{1{\cdot}7 \times 10^{-6} \times 100}{1} = 3{\cdot}4 \times 10^{-4}\ \Omega$$

Resistance of section AC, R_{AC} $= (3{\cdot}4 \times 10^{-4}) \times 100 = 0{\cdot}034\ \Omega$

Resistance of section CD, R_{CD} $= (3{\cdot}4 \times 10^{-4}) \times 150 = 0{\cdot}051\ \Omega$

Resistance of section DE, R_{DE} $= (3{\cdot}4 \times 10^{-4}) \times 150 = 0{\cdot}051\ \Omega$

Resistance of section EF, R_{EF} $= (3{\cdot}4 \times 10^{-4}) \times 100 = 0{\cdot}034\ \Omega$

Resistance of section FB, R_{FB} $= (3{\cdot}4 \times 10^{-4}) \times 100 = 0{\cdot}034\ \Omega$

$$\text{Voltage at } B = \text{Voltage at } A - \text{Drop over length } AB$$

or

$$V_B = V_A - [I_A R_{AC} + (I_A - 20) R_{CD} + (I_A - 60) R_{DE} + (I_A - 110) R_{EF} + (I_A - 140) R_{FB}]$$

or

$$220 = 220 - [0{\cdot}034 I_A + 0{\cdot}051 (I_A - 20) + 0{\cdot}051 (I_A - 60) + 0{\cdot}034 (I_A - 110) + 0{\cdot}034 (I_A - 140)]$$

$$= 220 - [0{\cdot}204 I_A - 12{\cdot}58]$$

or

$$0{\cdot}204 I_A = 12{\cdot}58$$

$\therefore$

$$I_A = 12{\cdot}58/0{\cdot}204 = 61{\cdot}7 \text{ A}$$

The *actual distribution of currents in the various sections of the distributor is shown in Fig. 13.18. It is clear that currents are coming to load point E from both sides *i.e.* from point D and point F. Hence, E is the point of minimum potential.

$\therefore$ Minimum consumer voltage,

$$V_E = V_A - [I_{AC} R_{AC} + I_{CD} R_{CD} + I_{DE} R_{DE}]$$

* Knowing the value of I_A, current in any section can be determined. Thus,

Current in section CD, $I_{CD} = I_A - 20 = 61{\cdot}7 - 20 = 41{\cdot}7 A$ from C to D

Current in section EF, $I_{EF} = I_A - 110 = 61{\cdot}7 - 110 = -48{\cdot}3$ A from E to F

$= 48{\cdot}3$ A from F to E

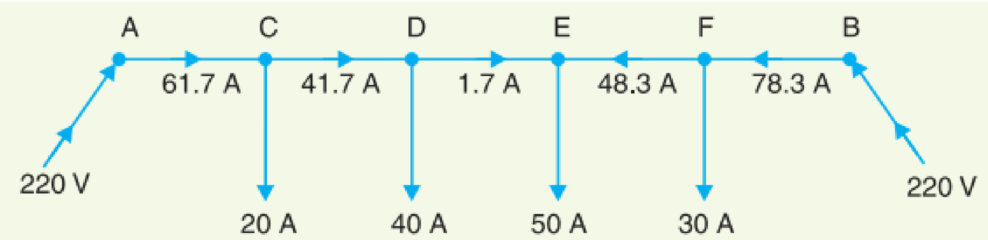


Fig. 13.18

$$= 220 - [61{\cdot}7 \times 0{\cdot}034 + 41{\cdot}7 \times 0{\cdot}051 + 1{\cdot}7 \times 0{\cdot}051]$$

$$= 220 - 4{\cdot}31 = \mathbf{215{\cdot}69 \text{ V}}$$

Example 13.11. *A 2-wire d.c. distributor AB is fed from both ends. At feeding point A, the voltage is maintained as at 230 V and at B 235 V. The total length of the distributor is 200 metres and loads are tapped off as under :*

25 A at 50 metres from A ; 50 A at 75 metres from A

30 A at 100 metres from A ; 40 A at 150 metres from A

The resistance per kilometre of one conductor is 0·3 Ω. Calculate :

(*i*) *currents in various sections of the distributor*

(*ii*) *minimum voltage and the point at which it occurs*

Solution. Fig. 13.19 shows the distributor with its tapped currents. Let I_A amperes be the current supplied from the feeding point A. Then currents in the various sections of the distributor are as shown in Fig 13.19.

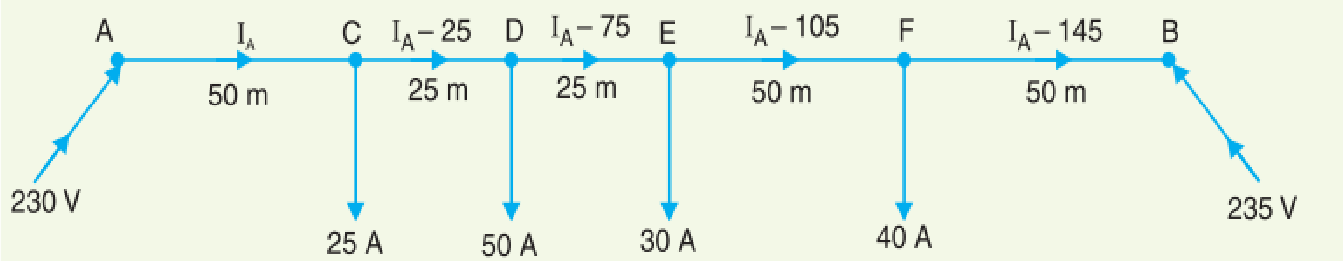


Fig. 13.19

Resistance of 1000 m length of distributor (both wires)

$$= 2 \times 0{\cdot}3 = 0{\cdot}6\,\Omega$$

Resistance of section AC, R_{AC} $= 0{\cdot}6 \times 50/1000 = 0{\cdot}03\,\Omega$

Resistance of section CD, R_{CD} $= 0{\cdot}6 \times 25/1000 = 0{\cdot}015\,\Omega$

Resistance of section DE, R_{DE} $= 0{\cdot}6 \times 25/1000 = 0{\cdot}015\,\Omega$

$$\text{Resistance of section } EF, R_{EF} = 0 \cdot 6 \times 50/1000 = 0 \cdot 03\ \Omega$$

$$\text{Resistance of section } FB, R_{FB} = 0 \cdot 6 \times 50/1000 = 0 \cdot 03\ \Omega$$

$$\text{Voltage at } B = \text{Voltage at } A - \text{Drop over } AB$$

or

$$V_B = V_A - [I_A R_{AC} + (I_A - 25) R_{CD} + (I_A - 75) R_{DE} + (I_A - 105) R_{EF} + (I_A - 145) R_{FB}]$$

or

$$235 = 230 - [0 \cdot 03 I_A + 0 \cdot 015 (I_A - 25) + 0 \cdot 015 (I_A - 75) + 0 \cdot 03 (I_A - 105) + 0 \cdot 03 (I_A - 145)]$$

or

$$235 = 230 - [0 \cdot 12 I_A - 9]$$

$$\therefore \quad I_A = \frac{239 - 235}{0 \cdot 12} = 33 \cdot 34 \text{ A}$$

(*i*) $\therefore$ Current in section AC, $I_{AC} = I_A =$ **33·34 A**

Current in section CD, $I_{CD} = I_A - 25 = 33 \cdot 34 - 25 =$ **8·34 A**

Current in section DE, $I_{DE} = I_A - 75 = 33 \cdot 34 - 75 = -41 \cdot 66$ A *from D to E*

$=$ **41·66 A** *from E to D*

Current in section EF, $I_{EF} = I_A - 105 = 33 \cdot 34 - 105 = -71 \cdot 66$ A *from E to F*

$=$ **71·66 A** *from F to E*

Current in section FB, $I_{FB} = I_A - 145 = 33 \cdot 34 - 145 = -111 \cdot 66$ A *from F to B*

$=$ **111·66 A** *from B to F*

(*ii*) The actual distribution of currents in the various sections of the distributor is shown in Fig. 13.20. The currents are coming to load point *D* from both sides of the distributor. Therefore, load point *D* is the point of minimum potential.

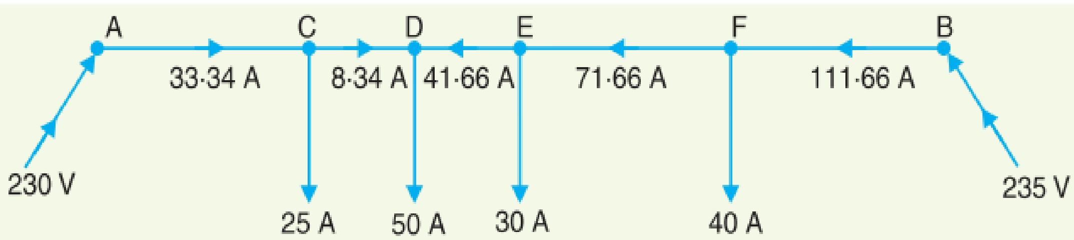


Fig. 13.20

$$\text{Voltage at } D, V_D = V_A - [I_{AC} R_{AC} + I_{CD} R_{CD}]$$

$$= 230 - [33 \cdot 34 \times 0 \cdot 03 + 8 \cdot 34 \times 0 \cdot 015]$$

$$= 230 - 1 \cdot 125 = \mathbf{228 \cdot 875\ V}$$

$$\text{Voltage at } B = \text{Voltage at } A - \text{Drop over } AB$$

or

$$V_B = V_A - [I_A R_{AC} + (I_A - 100) R_{CD} + (I_A - 300) R_{DE} + (I_A - 550) R_{EF} + (I_A - 850) R_{FB}]$$

Example 13.12. *A two-wire d.c. distributor AB, 600 metres long is loaded as under :*

Distance from A (metres) :	*150*	*300*	*350*	*450*
Loads in Amperes :	*100*	*200*	*250*	*300*

The feeding point A is maintained at 440 V and that of B at 430 V. If each conductor has a resistance of 0·01 Ω per 100 metres, calculate :

(i) the currents supplied from A to B, (ii) the power dissipated in the distributor.

Solution. Fig. 13.21 shows the distributor with its tapped currents. Let I_A amperes be the current supplied from the feeding point A. Then currents in the various sections of the distributor are as shown in Fig.13.21.

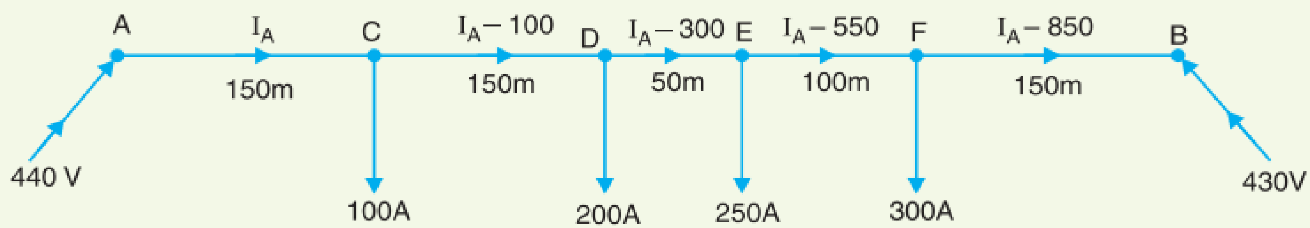


Fig. 13.21

Resistance of 100 m length of distributor (both wires)

$$= 2 \times 0{\cdot}01 = 0{\cdot}02\,\Omega$$

Resistance of section AC, R_{AC} $= 0{\cdot}02 \times 150/100 = 0{\cdot}03\,\Omega$

Resistance of section CD, R_{CD} $= 0{\cdot}02 \times 150/100 = 0{\cdot}03\,\Omega$

Resistance of section DE, R_{DE} $= 0{\cdot}02 \times 50/100 = 0{\cdot}01\,\Omega$

Resistance of section EF, R_{EF} $= 0{\cdot}02 \times 100/100 = 0{\cdot}02\,\Omega$

Resistance of section FB, R_{FB} $= 0{\cdot}02 \times 150/100 = 0{\cdot}03\,\Omega$

or $430 = 440 - [0 \cdot 03\, I_A + 0 \cdot 03\, (I_A - 100) + 0 \cdot 01\, (I_A - 300) + 0 \cdot 02\, (I_A - 550) + 0 \cdot 03\, (I_A - 850)]$

or $430 = 440 - [0 \cdot 12\, I_A - 42 \cdot 5]$

$\therefore \quad I_A = \dfrac{482 \cdot 5 - 430}{0 \cdot 12} = 437 \cdot 5 \text{ A}$

The actual distribution of currents in the various sections of the distributor is shown in Fig.13.22. Incidentally, E is the point of minimum potential.

(*i*) Referring to Fig. 13.22, it is clear that

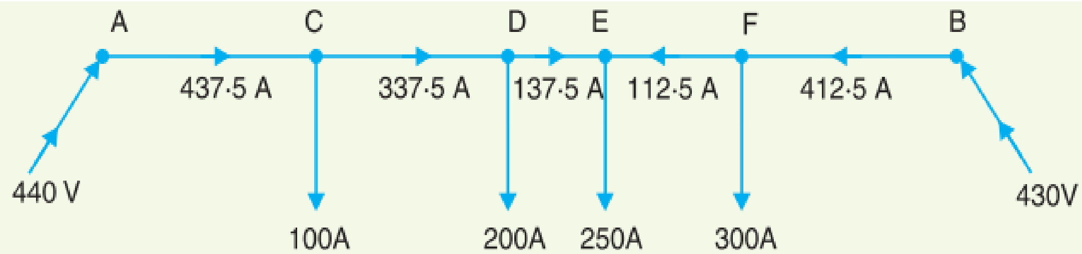


Fig. 13.22

Current supplied from end A, I_A = **437·5 A**

Current supplied from end B, I_B = **412·5 A**

(*ii*) Power loss in the distributor

$= I_{AC}^2 R_{AC} + I_{CD}^2 R_{CD} + I_{DE}^2 R_{DE} + I_{EF}^2 R_{EF} + I_{FB}^2 R_{FB}$

$= (437 \cdot 5)^2 \times 0 \cdot 03 + (337 \cdot 5)^2 \times 0 \cdot 03 + (137 \cdot 5)^2 \times 0 \cdot 01 + (112 \cdot 5)^2 \times 0 \cdot 02 + (412 \cdot 5)^2 \times 0 \cdot 03$

$= 5742 + 3417 + 189 + 253 + 5104 = 14{,}705$ watts = **14·705 kW**

Example 13.13. *An electric train runs between two sub-stations 6 km apart maintained at voltages 600 V and 590 V respectively and draws a constant current of 300 A while in motion. The track resistance of go and return path is 0·04 Ω/km. Calculate :*

(*i*) *the point along the track where minimum potential occurs*

(*ii*) *the current supplied by the two sub-stations when the train is at the point of minimum potential*

Solution. The single line diagram is shown in Fig. 13.23 where substation A is at 600 V and sub-station B at 590 V. Suppose that minimum potential occurs at point M at a distance x km from the substation A. Let I_A amperes be the current supplied by the sub-station A. Then current supplied by sub-station B is $300 - I_A$ as shown in Fig 13.23.

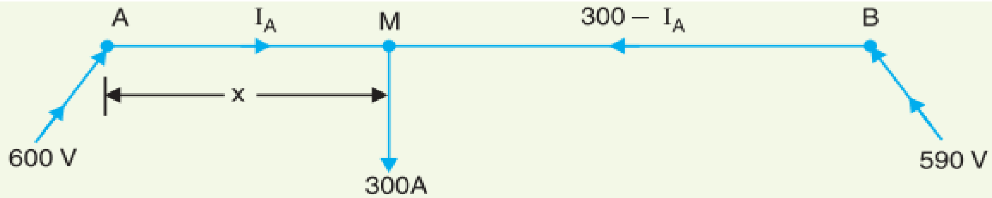


Fig. 13.23

Resistance of track (go and return path) per km

$$= 0 \cdot 04\ \Omega$$

Track resistance for section AM, $R_{AM} = 0 \cdot 04\, x\ \Omega$

Track resistance for section MB, $R_{MB} = 0 \cdot 04\,(6 - x)\Omega$

Potential at M, $V_M = V_A - I_A R_{AM}$ ... (*i*)

Also, Potential at M, $V_M = V_B - (300 - I_A) R_{MB}$ ... (*ii*)

From equations (*i*) and (*ii*), we get,

$$V_A - I_A R_{AM} = V_B - (300 - I_A) R_{MB}$$

or $$600 - 0\cdot04\,x\,I_A = 590 - (300 - I_A) \times 0\cdot04\,(6 - x)$$

or $$600 - 0\cdot04\,x\,I_A = 590 - 0\cdot04\,(1800 - 300\,x - 6\,I_A + I_A \times x)$$

or $$600 - 0\cdot04\,x\,I_A = 590 - 72 + 12\,x + 0\cdot24\,I_A - 0\cdot04\,xI_A$$

or $$0\cdot24\,I_A = 82 - 12\,x$$

or $$I_A = 341\cdot7 - 50\,x$$

Substituting the value of I_A in eq. (*i*), we get,

$$V_M = V_A - (341\cdot7 - 50\,x) \times 0\cdot04\,x$$

$\therefore$ $$V_M = 600 - 13\cdot7\,x + 2x^2 \qquad \ldots(iii)$$

(*i*) For V_M to be minimum, its differential coefficient *w.r.t.* x must be zero *i.e.*

$$\frac{d}{dx}(600 - 13\cdot7\,x + 2x^2) = 0$$

or $$0 - 13\cdot7 + 4x = 0$$

$\therefore$ $$x = 13\cdot7/4 = \mathbf{3\cdot425\ km}$$

i.e. minimum potential occurs at a distance of $3\cdot425$ km from the sub-station A.

(*ii*) $\therefore$ Current supplied by sub-station A

$$= 341\cdot7 - 50 \times 3\cdot425 = 341\cdot7 - 171\cdot25 = \mathbf{170\cdot45\ A}$$

Current supplied by sub-station B $= 300 - I_A = 300 - 170\cdot45 = \mathbf{129\cdot55\ A}$

13.6 Uniformly Loaded Distributor Fed at Both Ends

We shall now determine the voltage drop in a uniformly loaded distributor fed at both ends. There can be two cases *viz.* the distributor fed at both ends with (*i*) equal voltages (*ii*) unequal voltages. The two cases shall be discussed separately.

(*i*) **Distributor fed at both ends with equal voltages.** Consider a distributor AB of length l metres, having resistance r ohms per metre run and with uniform loading of i amperes per metre run as shown in Fig. 13.24. Let the distributor be fed at the feeding points A and B at equal voltages, say V volts. The total current supplied to the distributor is $i\,l$. As the two end voltages are equal, therefore, current supplied from each feeding point is $i\,l/2$ *i.e.*

Current supplied from each feeding point

$$= \frac{i\,l}{2}$$

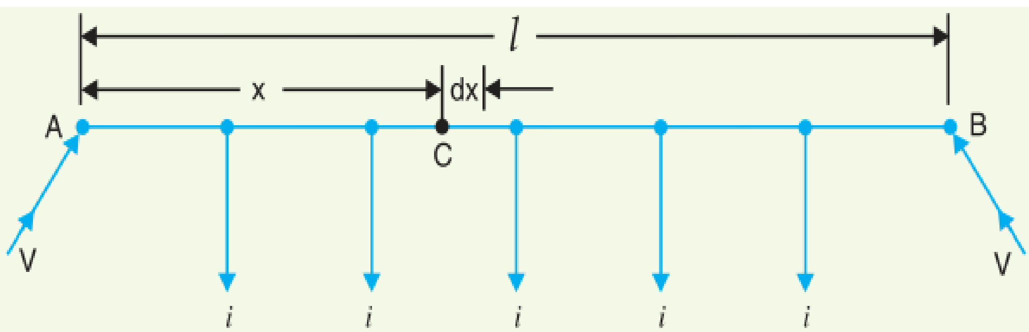


Fig. 13.24

Consider a point C at a distance x metres from the feeding point A. Then current at point C is

$$= \frac{i\,l}{2} - i\,x = i\left(\frac{l}{2} - x\right)$$

Now, consider a small length dx near point C. Its resistance is $r\,dx$ and the voltage drop over length dx is

$$dv = i\left(\frac{l}{2} - x\right) r\,dx = i\,r\left(\frac{l}{2} - x\right) dx$$

$$\therefore \quad \text{Voltage drop upto point } C = \int_0^x i\,r\left(\frac{l}{2}-x\right)dx = i\,r\left(\frac{l\,x}{2}-\frac{x^2}{2}\right)$$

$$= \frac{i\,r}{2}\left(l\,x - x^2\right)$$

Obviously, the point of minimum potential will be the mid-point. Therefore, maximum voltage drop will occur at mid-point *i.e.* where $x = l/2$.

$$\therefore \quad \text{Max. voltage drop} = \frac{i\,r}{2}\left(l\,x - x^2\right)$$

$$= \frac{i\,r}{2}\left(l \times \frac{l}{2} - \frac{l^2}{4}\right) \qquad \text{[Putting } x = l/2\text{]}$$

$$= \frac{1}{8}\,i\,r\,l^2 = \frac{1}{8}(i\,l)(r\,l) = \frac{1}{8}\,I\,R$$

where $i\,l = I$, the total current fed to the distributor from both ends

$r\,l = R$, the total resistance of the distributor

$$\text{Minimum voltage} = V - \frac{I\,R}{8} \text{ volts}$$

(*ii*) Distributor fed at both ends with unequal voltages. Consider a distributor AB of length l metres having resistance r ohms per metre run and with a uniform loading of i amperes per metre run as shown in Fig. 13.25. Let the distributor be fed from feeding points A and B at voltages V_A and V_B respectively.

Suppose that the point of minimum potential C is situated at a distance x metres from the feeding point A. Then current supplied by the feeding point A will be *$i\,x$.

* As C is at minimum potential, therefore, there is no current at this point. Consequently, current in section AC (*i.e.* $i\,x$) will be the current supplied by feeding point A.

$\therefore$ Voltage drop in section $AC = \frac{i\,r\,x^2}{2}$ volts

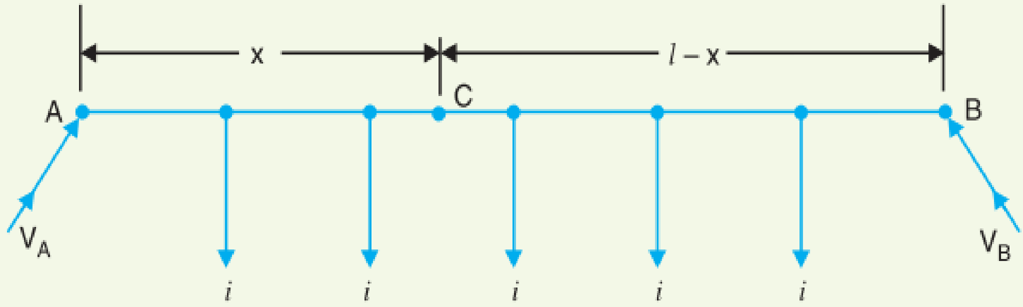


Fig. 13.25

As the distance of C from feeding point B is $(l - x)$, therefore, current fed from B is $i\,(l - x)$.

$\therefore$ Voltage drop in section $BC = \frac{i\,r\,(l-x)^2}{2}$ volts

$$\text{Voltage at point } C,\ V_C = V_A - \text{Drop over } AC$$

$$= V_A - \frac{i\,r\,x^2}{2} \qquad ...(i)$$

$$\text{Also, voltage at point } C,\ V_C = V_B - \text{Drop over } BC$$

$$= V_B - \frac{i\,r\,(l-x)^2}{2} \qquad ...(ii)$$

From equations (i) and (ii), we get,

$$V_A - \frac{i\,r\,x^2}{2} = V_B - \frac{i\,r\,(l-x)^2}{2}$$

Solving the equation for x, we get,

$$x = \frac{V_A - V_B}{i\,r\,l} + \frac{l}{2}$$

As all the quantities on the right hand side of the equation are known, therefore, the point on the distributor where minimum potential occurs can be calculated.

Example 13.14. *A two-wire d.c. distributor cable 1000 metres long is loaded with 0·5 A/metre. Resistance of each conductor is 0·05 Ω/km. Calculate the maximum voltage drop if the distributor is fed from both ends with equal voltages of 220 V. What is the minimum voltage and where it occurs ?*

Solution.

Current loading, $i = 0 \cdot 5$ A/m

Resistance of distributor/m, $r = 2 \times 0 \cdot 05/1000 = 0 \cdot 1 \times 10^{-3}\ \Omega$

Length of distributor, $l = 1000$ m

Total current supplied by distributor, $I = i\,l = 0 \cdot 5 \times 1000 = 500$ A

Total resistance of the distributor, $R = r\,l = 0 \cdot 1 \times 10^{-3} \times 1000 = 0 \cdot 1\ \Omega$

$\therefore$ Max. voltage drop $= \dfrac{I\,R}{8} = \dfrac{500 \times 0 \cdot 1}{8} = $ **6·25 V**

Minimum voltage will occur at the mid-point of the distributor and its value is

$= 220 - 6 \cdot 25 = $ **213·75 V**

Example 13.15. *A 2-wire d.c. distributor AB 500 metres long is fed from both ends and is loaded uniformly at the rate of 1·0 A/metre. At feeding point A, the voltage is maintained at 255 V and at B at 250 V. If the resistance of each conductor is 0·1 Ω per kilometre, determine :*

(*i*) *the minimum voltage and the point where it occurs*

(*ii*) *the currents supplied from feeding points A and B*

Solution. Fig. 13.26 shows the single line diagram of the distributor.

Voltage at feeding point *A*, $V_A = 255$ V

Voltage at feeding point *B*, $V_B = 250$ V

Length of distributor, $l = 500$ m

Current loading, $i = 1$ *A*/m

Resistance of distributor/m, $r = 2 \times 0{\cdot}1/1000 = 0{\cdot}0002\,\Omega$

(*i*) Let the minimum potential occur at a point *C* distant *x* metres from the feeding point *A*. As proved in Art. 13.6,

$$x = \frac{V_A - V_B}{i\,r\,l} + \frac{l}{2} = \frac{255 - 250}{1 \times 0 \cdot 0002 \times 500} + 500/2$$

$$= 50 + 250 = \mathbf{300\ m}$$

i.e. minimum potential occurs at 300 m from point *A*.

Minimum voltage, $$V_C = V_A - \frac{ir\,x^2}{2} = 255 - \frac{1 \times 0 \cdot 0002 \times (300)^2}{2}$$

$$= 255 - 9 = \mathbf{246\ V}$$

(*ii*) Current supplied from *A* $= i\,x = 1 \times 300 = \mathbf{300\ A}$

Current supplied from *B* $= i\,(l - x) = 1\,(500 - 300) = \mathbf{200\ A}$

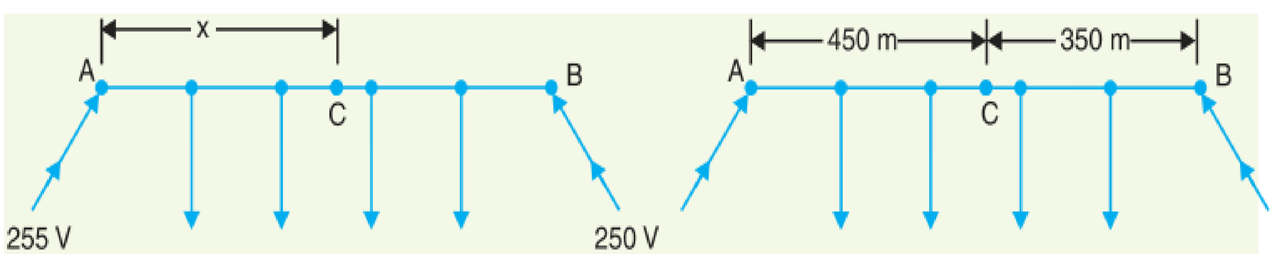


Fig. 13.26 Fig. 13.27

Example 13.16. *A 800 metres 2-wire d.c. distributor AB fed from both ends is uniformly loaded at the rate of 1·25 A/metre run. Calculate the voltage at the feeding points A and B if the minimum potential of 220 V occurs at point C at a distance of 450 metres from the end A. Resistance of each conductor is 0·05 Ω/km.*

Solution. Fig. 13.27 shows the single line diagram of the distributor.

Current loading, $i = 1{\cdot}25$ A/m

Resistance of distributor/m, $r = 2 \times 0{\cdot}05/1000 = 0{\cdot}0001\ \Omega$

Voltage at C, $V_C = 220$ V

Length of distributor, $l = 800$ m

Distance of point C from A, $x = 450$ m

$$\text{Voltage drop in section } AC = \frac{i\,r\,x^2}{2} = \frac{1\cdot 25 \times 0\cdot 0001 \times (450)^2}{2} = 12\cdot 65 \text{ V}$$

∴ Voltage at feeding point A, $V_A = 220 + 12{\cdot}65 =$ **232·65 V**

$$\text{Voltage drop in section } BC = \frac{i\,r\,(l-x)^2}{2} = \frac{1\cdot 25 \times 0\cdot 0001 \times (800-450)^2}{2}$$

$$= 7\cdot 65 \text{ V}$$

∴ Voltage at feeding point B, $V_B = 220 + 7{\cdot}65 =$ **227·65 V**

Example 13.17.

(*i*) *A uniformly loaded distributor is fed at the centre. Show that maximum voltage drop = I R/8 where I is the total current fed to the distributor and R is the total resistance of the distributor.*

(*ii*) *A 2-wire d.c. distributor 1000 metres long is fed at the centre and is loaded uniformly at the rate of 1·25 A/metre. If the resistance of each conductor is 0·05 Ω/km, find the maximum voltage drop in the distributor.*

Solution. (*i*) Fig. 13.28 shows distributor AB fed at centre C and uniformly loaded with i amperes/metre. Let l metres be the length of the distributor and r ohms be the resistance per metre run. Obviously, maximum voltage drop will occur at either end.

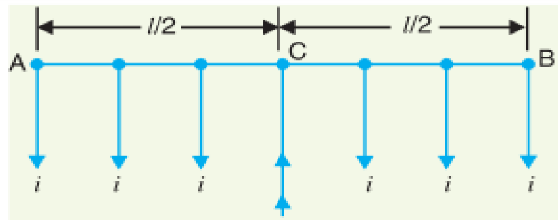


Fig. 13.28

$\therefore$ Max. voltage drop = Voltage drop in half distributor

$$= \frac{1}{2}\left(\frac{i\,l}{2}\right)\left(\frac{r\,l}{2}\right) = \frac{1}{8}(i\,l)(r\,l)$$

$$= \frac{1}{8}\,I\,R$$

where $i\,l = I$, the total current fed to the distributor

$r\,l = R$, the total resistance of the distributor

(*ii*) Total current fed to the distributor is

$$I = i\,l = 1{\cdot}25 \times 1000 = 1250 \text{ A}$$

Total resistance of the distributor is

$$R = r\,l = 2 \times 0{\cdot}05 \times 1 = 0{\cdot}1\ \Omega$$

$$\text{Max. voltage drop} = \frac{1}{8}\,I\,R = \frac{1}{8} \times 1250 \times 0{\cdot}1 = \mathbf{15.62\ V}$$

Example 13.18. *Derive an expression for the power loss in a uniformly loaded distributor fed at both ends with equal voltages.*

Solution. Consider a distributor *AB* of length *l* metres, having resistance *r* ohms per metre run with uniform loading of *i* amperes per metre run as shown in Fig.13.29. Let the distributor be fed at the feeding points *A* and *B* at equal voltages, say V volts. The total current supplied by the distributor is *i l*. As the two end voltages are equal, therefore, current supplied from each feeding point is *i l*/2.

$$\text{Current supplied from each feeding point} = \frac{i\,l}{2}$$

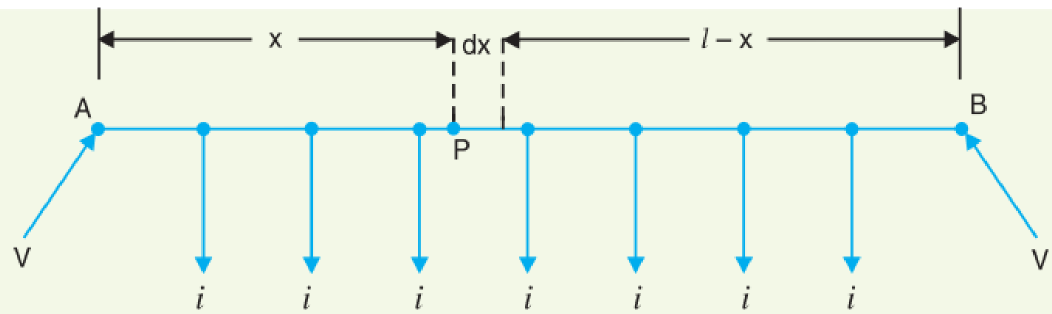


Fig. 13.29

Consider a small length *dx* of the distributor at point *P* which is at a distance *x* from the feeding end *A*.

$$\text{Resistance of length } dx = r\,dx$$

$$\text{Current in length } dx = \frac{i\,l}{2} - i\,x = i\left(\frac{l}{2} - x\right)$$

$$\text{Power loss in length } dx = (\text{current in } dx)^2 \times \text{Resistance of } dx$$

$$= \left[i\left(\frac{l}{2} - x\right)\right]^2 \times r\,dx$$

Total power loss in the distributor is

$$P = \int_0^l \left[i\left(\frac{l}{2} - x\right)\right]^2 r\,dx = i^2 r \int_0^l \left(\frac{l^2}{4} - l\,x + x^2\right) dx$$

$$= i^2 r\left[\frac{l^2 x}{4} - \frac{l\,x^2}{2} + \frac{x^3}{3}\right]_0^l = i^2 r\left[\frac{l^3}{4} - \frac{l^3}{2} + \frac{l^3}{3}\right]$$

$$\therefore \quad P = \frac{i^2\,r\,l^3}{12}$$

13.7 Distributor with Both Concentrated and Uniform Loading

There are several problems where a distributor has both concentrated and uniform loadings. In such situations, the total drop over any section of the distributor is equal to the sum of drops due to concentrated and uniform loading in that section. We shall solve a few problems by way of illustration.

Example 13.19. *A 2-wire d.c. distributor AB, 900 metres long is fed at A at 400 V and loads of 50 A, 100 A and 150 A are tapped off from C, D and E which are at a distance of 200 m, 500 m and 800 m from point A respectively. The distributor is also loaded uniformly at the rate of 0.5 A/m. If the resistance of distributor per metre (go and return) is 0.0001 Ω, calculate voltage (i) at point B and (ii) at point D.*

Solution. This problem can be solved in two stages. First, the drop at any point due to concentrated loading is found. To this is added the voltage drop due to uniform loading.

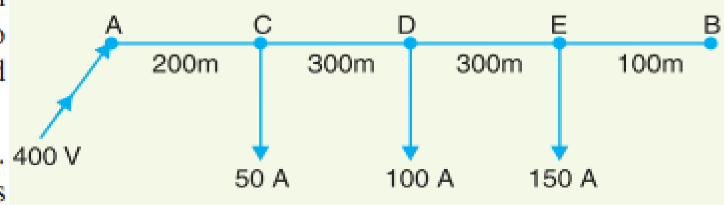


Fig. 13.30

Drops due to concentrated loads. Fig. 13.30 shows only the concentrated loads tapped off from the various points. The currents in the various sections are :

$$I_{AC} = 300 \text{ A} ; I_{CD} = 250 \text{ A} ; I_{DE} = 150 \text{ A}$$

$$\text{Drop in section } AC = I_{AC} R_{AC} = 300 \times (200 \times 0{\cdot}0001) = 6 \text{ V}$$

$$\text{Drop in section } CD = 250 \times (300 \times 0{\cdot}0001) = 7{\cdot}5 \text{ V}$$

$$\text{Drop in section } DE = 150 \times (300 \times 0{\cdot}0001) = 4{\cdot}5 \text{ V}$$

$$\text{Total drop over } AB = 6 + 7{\cdot}5 + 4{\cdot}5 = 18 \text{ V}$$

Drops due to uniform loading

$$\text{Drop over } AB = \frac{i\,r\,l^2}{2} = \frac{0{\cdot}5 \times 0{\cdot}0001 \times (900)^2}{2} = 20{\cdot}25 \text{ V}$$

$$\text{Drop over } AD = i\,r\left(l\,x - \frac{x^2}{2}\right)$$

Here, $l = 900 \text{ m} ; x = 500 \text{ m}$

$$\therefore \quad \text{Drop over } AD = 0{\cdot}5 \times 0{\cdot}0001\left(900 \times 500 - \frac{500^2}{2}\right) = 16{\cdot}25 \text{ V}$$

(*i*) Voltage at point $B = V_A$ – Drop over AB due to conc. and uniform loadings

$= 400 - (18 + 20{\cdot}25) =$ **361·75 V**

(*ii*) Voltage at point $D = V_A$ – Drop over AD due to conc. and uniform loadings

$= 400 - (6 + 7{\cdot}5 + 16{\cdot}25) =$ **370·25 V**

Example 13.20. *Two conductors of a d.c. distributor cable AB 1000 m long have a total resistance of 0·1 Ω. The ends A and B are fed at 240 V. The cable is uniformly loaded at 0·5 A per metre length and has concentrated loads of 120 A, 60 A, 100 A and 40 A at points distant 200 m, 400 m, 700 m and 900 m respectively from the end A. Calculate (i) the point of minimum potential (ii) currents supplied from ends A and B (iii) the value of minimum potential.*

Solution.

Distributor resistance per metre length, $r = 0{\cdot}1/1000 = 10^{-4}\ \Omega$

Uniform current loading, $i = 0{\cdot}5$ A/m

(*i*) Point of minimum potential. The point of minimum potential is not affected by the uniform loading of the distributor. Therefore, let us consider the concentrated loads first as shown in Fig. 13.31. Suppose the current supplied by end *A* is *I*. Then currents in the various sections will be as shown in Fig. 13.31.

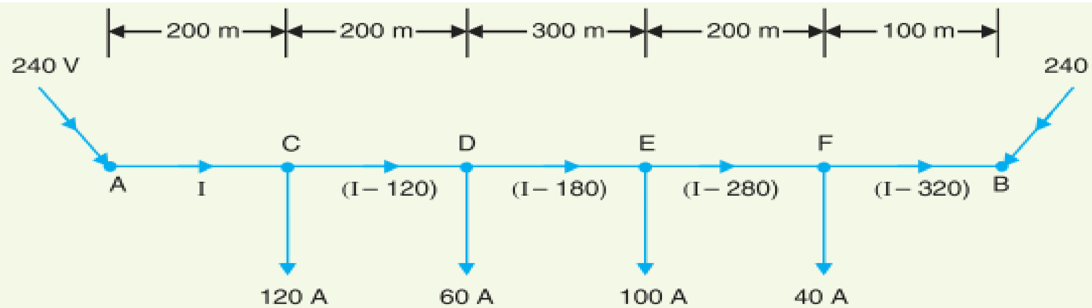


Fig. 13.31

$$V_A - V_B = \text{Drop over the distributor } AB$$

$$240 - 240 = I_{AC} R_{AC} + I_{CD} R_{CD} + I_{DE} R_{DE} + I_{EF} R_{EF} + I_{FB} R_{FB}$$

or $$0 = 10^{-4} [I \times 200 + (I - 120)\, 200 + (I - 180)\, 300 + (I - 280)\, 200 + (I - 320) \times 100]$$

or $$0 = 1000\, I - 166000 \quad \therefore \quad I = 166000/1000 = 166 \text{ A}$$

The actual distribution of currents in the various sections of the distributor due to concentrated loading is shown in Fig. 13.32. It is clear from this figure that *D is the point of minimum potential.*

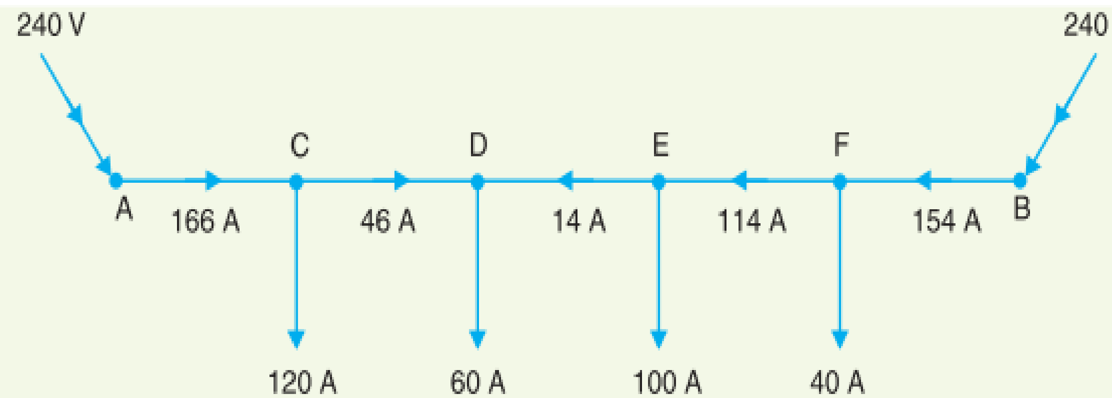


Fig. 13.32

(*ii*) The feeding point A will supply 166 A due to concentrated loading *plus* $0{\cdot}5 \times 400 = 200$ A due to uniform loading.

$\therefore$ Current supplied by A, I_A = 166 + 200 = **366 A**

The feeding point B will supply a current of 154 A due to concentrated loading *plus* 0·5 × 600 = 300 A due to uniform loading.

$\therefore$ Current supplied by B, I_B = 154 + 300 = **454 A**

(*iii*) As stated above, D is the point of minimum potential.

$\therefore$ Minimum potential, V_D = V_A – Drop in AD due to conc. loading – Drop in AD due to uniform loading

Now, Drop in AD due to conc. loading

$$= I_{AC}\,R_{AC} + I_{CD}\,R_{CD}$$
$$= 166 \times 10^{-4} \times 200 + 46 \times 10^{-4} \times 200$$
$$= 3{\cdot}32 + 0{\cdot}92 = 4{\cdot}24 \text{ V}$$

Drop in AD due to uniform loading $= \dfrac{i\,r^*\,l^2}{2} = \dfrac{0{\cdot}5 \times 10^{-4} \times (400)^2}{2} = 4\,V$

$\therefore$ $V_D = 240 - 4{\cdot}24 - 4$ = **231·76 V**

Example 13.21. *A d.c. 2-wire distributor AB is 500m long and is fed at both ends at 240 V. The distributor is loaded as shown in Fig 13.33. The resistance of the distributor (go and return) is 0·001Ω per metre. Calculate (i) the point of minimum voltage and (ii) the value of this voltage.*

Solution. Let *D* be the point of **minimum potential and let *x* be the current flowing in section *CD* as shown in Fig 13.33. Then current supplied by end *B* will be (60 − *x*).

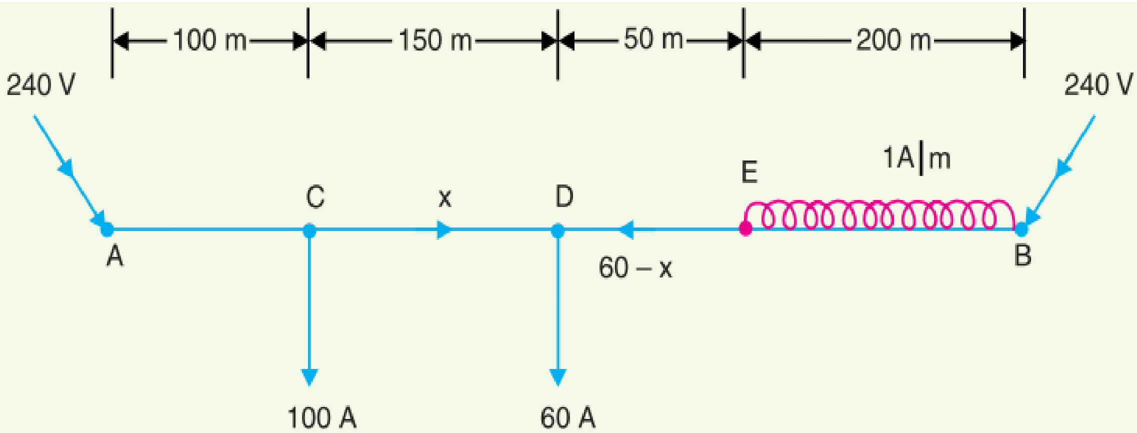


Fig. 13.33

(*i*) If *r* is the resistance of the distributor (go and return) per metre length, then,

$$\text{Voltage drop in length } AD = I_{AC}\, R_{AC} + I_{CD}\, R_{CD}$$

$$= (100 + x) \times 100\, r + x \times 150\, r$$

$$\text{Voltage drop in length } BD = \frac{i\, r\, l^2}{2} + (60 - x) \times 250\, r$$

$$= \frac{1 \times r \times (200)^2}{2} + (60 - x) \times 250\, r$$

Since the feeding points A and B are at the same potential,

$$\therefore \quad (100 + x) \times 100\, r + x \times 150\, r = \frac{1 \times r \times (200)^2}{2} + (60 - x)\, 250\, r$$

or $$100x + 10000 + 150x = 20000 + 15000 - 250x$$

or $$500x = 25000 \quad \therefore\ x = 50 \text{ A}$$

* Drop due to uniform loading can be determined by imagining that the distributor is cut into two at point D so that AD can be thought as a distributor fed at one end and loaded uniformly.

** You may carry out the calculation by assuming C to be point of minimum potential. The answer will be unaffected.

The actual directions of currents in the various sections of the distributor are shown in Fig. 13.34. Note that currents supplied by A and B meet at D. *Hence point D is the point of minimum potential.*

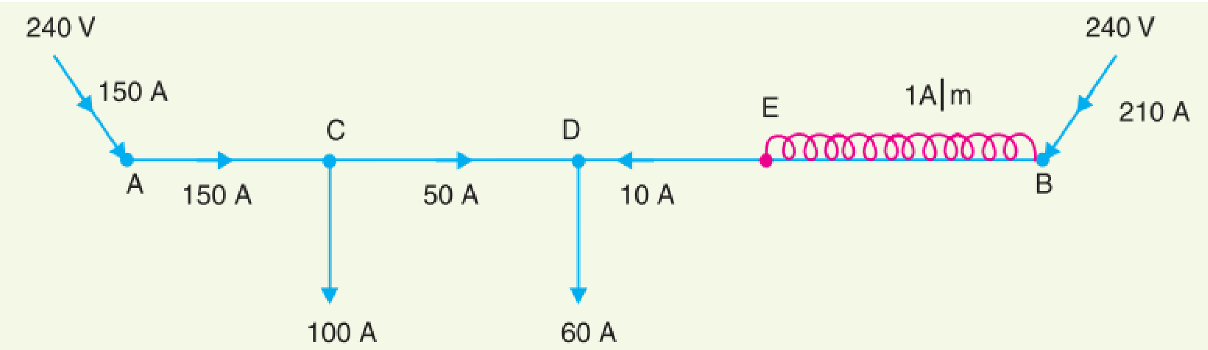


Fig. 13.34

(ii)

$$\text{Total current} = 160 + 1 \times 200 = 360 \text{ A}$$

$$\text{Current supplied by } A,\ I_A = 100 + x = 100 + 50 = 150 \text{ A}$$

$$\text{Current supplied by } B,\ I_B = 360 - 150 = 210 \text{ A}$$

$$\text{Minimum potential, } V_D = V_A - I_{AC} R_{AC} - I_{CD} R_{CD}$$

$$= 240 - 150 \times (100 \times 0{\cdot}001) - 50 \times (150 \times 0{\cdot}001)$$

$$= 240 - 15 - 7{\cdot}5 = \mathbf{217{\cdot}5\ V}$$

13.8 Ring Distributor

A distributor arranged to form a closed loop and fed at one or more points is called a *ring distributor*. Such a distributor starts from one point, makes a loop through the area to be served, and returns to the original point. For the purpose of calculating voltage distribution, the distributor can be considered as consisting of a series of open distributors fed at both ends. The principal advantage of ring distributor is that by proper choice in the number of feeding points, great economy in copper can be affected.

The most simple case of a ring distributor is the one having only one feeding point as shown in Fig. 13.36(*ii*). Here A is the feeding point and tappings are taken from points B and C. For the purpose of calculations, it is equivalent to a straight distributor fed at both ends with equal voltages.

13.9 Ring Main Distributor with Interconnector

Sometimes a ring distributor has to serve a large area. In such a case, voltage drops in the various sections of the distributor may become excessive. In order to reduce voltage drops in various sections, distant points of the distributor are joined through a conductor called *interconnector*. Fig. 13.38 shows the ring distributor *ABCDEA*. The points *B* and *D* of the ring distributor are joined through an interconnector *BD*. There are several methods for solving such a network. However, the solution of such a network can be readily obtained by applying Thevenin's theorem. The steps of procedure are :

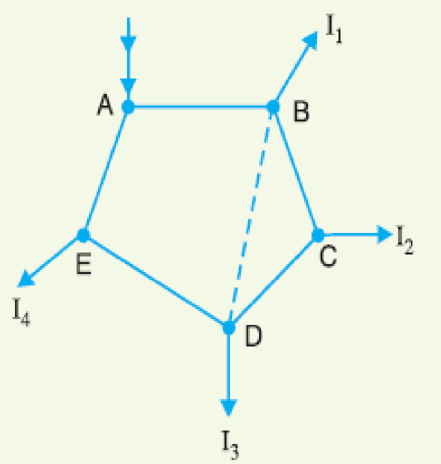


Fig. 13.38

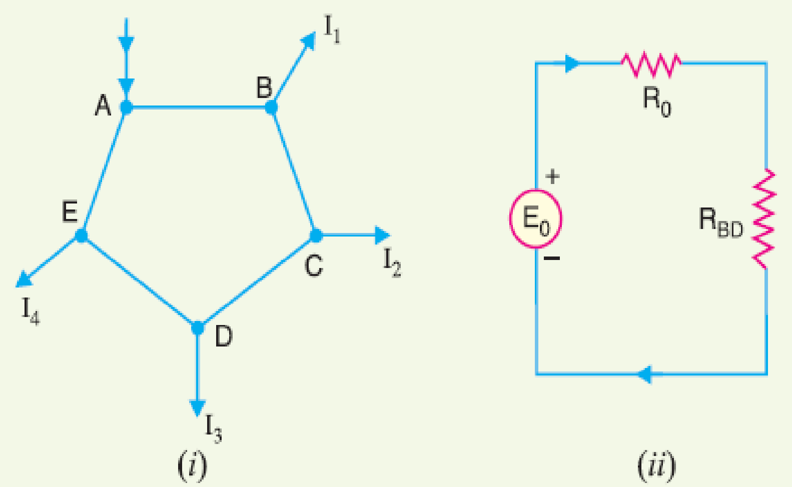


Fig. 13.39

(*i*) Consider the interconnector *BD* to be disconnected [See Fig. 13.39 (*i*)] and find the potential difference between *B* and *D*. This gives Thevenin's equivalent circuit voltage E_0.

(*ii*) Next, calculate the resistance viewed from points *B* and *D* of the network composed of distribution lines only. This gives Thevenin's equivalent circuit series resistance R_0.

(*iii*) If R_{BD} is the resistance of the interconnector *BD*, then Thevenin's equivalent circuit will be as shown in Fig. 13.39 (*ii*).

$$\therefore \quad \text{Current in interconnector } BD = \frac{E_0}{R_0 + R_{BD}}$$

Therefore, current distribution in each section and the voltage of load points can be calculated.

Example 13.22. *A 2-wire d.c. ring distributor is 300 m long and is fed at 240 V at point A. At point B, 150 m from A, a load of 120 A is taken and at C, 100 m in the opposite direction, a load of 80 A is taken. If the resistance per 100 m of single conductor is 0·03 Ω, find :*

(*i*) *current in each section of distributor*

(*ii*) *voltage at points B and C*

Solution.

Resistance per 100 m of distributor

$$= 2 \times 0{\cdot}03 = 0{\cdot}06\ \Omega$$

Resistance of section *AB*, $R_{AB} = 0{\cdot}06 \times 150/100 = 0{\cdot}09\ \Omega$

Resistance of section *BC*, $R_{BC} = 0{\cdot}06 \times 50/100 = 0{\cdot}03\ \Omega$

Resistance of section *CA*, $R_{CA} = 0{\cdot}06 \times 100/100 = 0{\cdot}06\ \Omega$

(*i*) Let us suppose that a current I_A flows in section *AB* of the distributor. Then currents in sections *BC* and *CA* will be $(I_A - 120)$ and $(I_A - 200)$ respectively as shown in Fig. 13.36 (*i*).

According to Kirchhoff's voltage law, the voltage drop in the closed loop *ABCA* is zero *i.e.*

$$I_{AB} R_{AB} + I_{BC} R_{BC} + I_{CA} R_{CA} = 0$$

or $$0{\cdot}09\, I_A + 0{\cdot}03\,(I_A - 120) + 0{\cdot}06\,(I_A - 200) = 0$$

or $$0{\cdot}18\, I_A = 15{\cdot}6$$

∴ $$I_A = 15{\cdot}6/0{\cdot}18 = 86{\cdot}67\ \text{A}$$

The actual distribution of currents is as shown in Fig. 13.36 (*ii*) from where it is seen that *B* is the point of minimum potential.

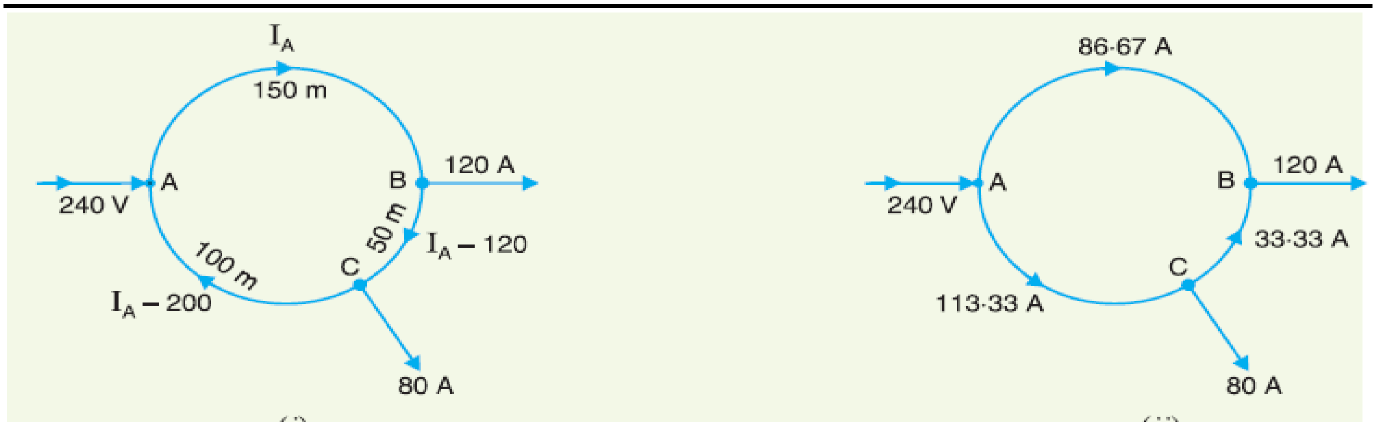


Fig. 13.36

Current in section *AB*, $I_{AB} = I_A =$ **86·67 A** *from A to B*

Current in section *BC*, $I_{BC} = I_A - 120 = 86{\cdot}67 - 120 = -\,33{\cdot}33$ A

= **33.33 A** *from C to B*

Current in section *CA*, $I_{CA} = I_A - 200 = 86{\cdot}67 - 200 = -\,113{\cdot}33$ A

= **113 ·33 A** *from A to C*

(*ii*) Voltage at point *B*, $V_B = V_A - I_{AB} R_{AB} = 240 - 86{\cdot}67 \times 0{\cdot}09 =$ **232·2 V**

$$\text{Voltage at point } C, V_C = V_B + I_{BC} R_{BC}$$
$$= 232{\cdot}2 + 33{\cdot}33 \times 0{\cdot}03 = \mathbf{233{\cdot}2\ V}$$

Example 13.23. *A 2-wire d.c. distributor ABCDEA in the form of a ring main is fed at point A at 220 V and is loaded as under :*

10A at B ; 20A at C ; 30A at D and 10 A at E.

The resistances of various sections (go and return) are : AB = 0·1 Ω ; BC = 0·05 Ω ; CD = 0·01 Ω ; DE = 0·025 Ω and EA = 0·075 Ω. Determine :

(i) the point of minimum potential

(ii) current in each section of distributor

Solution. Fig. 13.37 (*i*) shows the ring main distributor. Let us suppose that current I flows in section AB of the distributor. Then currents in the various sections of the distributor are as shown in Fig. 13.37 (*i*).

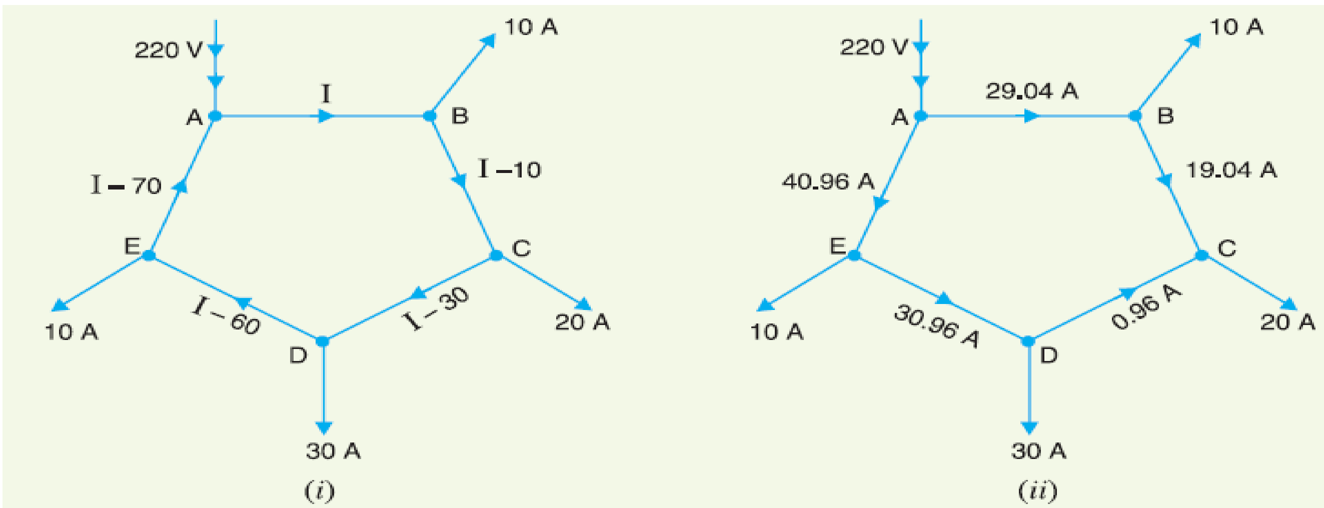


Fig. 13.37

(*i*) According to Kirchhoff's voltage law, the voltage drop in the closed loop *ABCDEA* is zero *i.e.*

$$I_{AB} R_{AB} + I_{BC} R_{BC} + I_{CD} R_{CD} + I_{DE} R_{DE} + I_{EA} R_{EA} = 0$$

or $$0{\cdot}1I + 0{\cdot}05\,(I - 10) + 0{\cdot}01\,(I - 30) + 0{\cdot}025\,(I - 60) + 0{\cdot}075\,(I - 70) = 0$$

or $$0{\cdot}26\,I = 7{\cdot}55$$

∴ $$I = 7{\cdot}55/0{\cdot}26 = 29{\cdot}04\text{ A}$$

The actual distribution of currents is as shown in Fig. 13.37 (*ii*) from where it is clear that *C* is the point of minimum potential.

∴ *C* is the point of minimum potential.

(*ii*) Current in section *AB* = I = **29·04 A** *from A to B*

Current in section *BC* = $I - 10 = 29{\cdot}04 - 10$ = **19·04 A** *from B to C*

Current in section *CD* = $I - 30 = 29{\cdot}04 - 30 = -\,0{\cdot}96$ A = **0·96 A** *from D to C*

Current in section *DE* = $I - 60 = 29{\cdot}04 - 60 = -\,30{\cdot}96$ A = **30·96 A** *from E to D*

Current in section *EA* = $I - 70 = 29{\cdot}04 - 70 = -\,40{\cdot}96$ A = **40·96 A** *from A to E*

Example 13.24. *A d.c. ring main ABCDA is fed from point A from a 250 V supply and the resistances (including both lead and return) of various sections are as follows : AB = 0·02 Ω ; BC = 0·018 Ω ; CD = 0·025 Ω and DA = 0·02 Ω. The main supplies loads of 150 A at B ; 300 A at C and 250 A at D. Determine the voltage at each load point.*

If the points A and C are linked through an interconnector of resistance 0·02 Ω, determine the new voltage at each load point.

Solution.

Without Interconnector. Fig. 13.40 (*i*) shows the ring distributor without interconnector. Let us suppose that a current *I* flows in section *AB* of the distributor. Then currents in various sections of the distributor will be as shown in Fig. 13.40 (*i*).

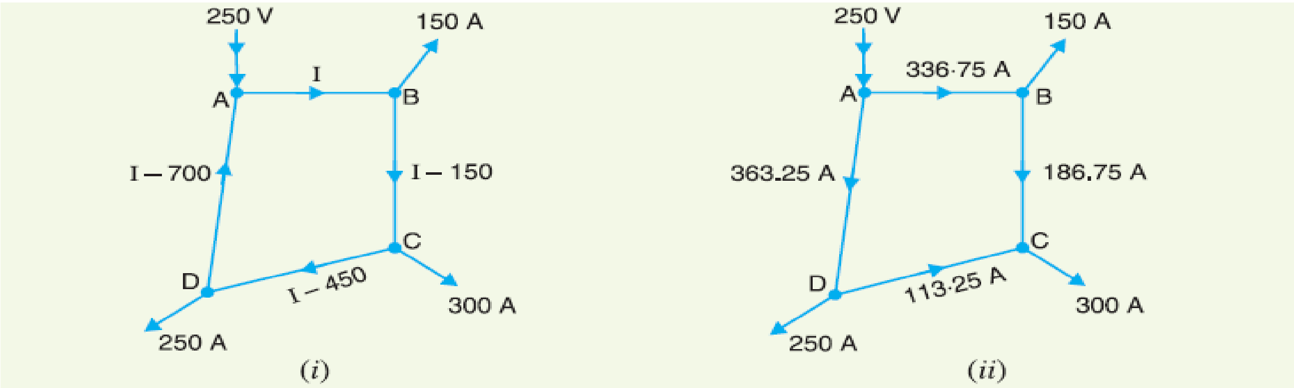


Fig. 13.40

According to Kirchhoff's voltage law, the voltage drop in the closed loop *ABCDA* is zero *i.e.*

$$I_{AB} R_{AB} + I_{BC} R_{BC} + I_{CD} R_{CD} + I_{DA} R_{DA} = 0$$

or $\quad 0{\cdot}02I + 0{\cdot}018\,(I - 150) + 0{\cdot}025\,(I - 450) + 0{\cdot}02\,(I - 700) = 0$

or $\quad 0{\cdot}083\,I = 27{\cdot}95$

$\therefore \quad I = 27{\cdot}95/0{\cdot}083 = 336{\cdot}75$ A

The actual distribution of currents is as shown in Fig. 13.40 (*ii*).

Voltage drop in *AB* = $336{\cdot}75 \times 0{\cdot}02 = 6{\cdot}735$ V

Voltage drop in *BC* = $186{\cdot}75 \times 0{\cdot}018 = 3{\cdot}361$ V

Voltage drop in *CD* = $113{\cdot}25 \times 0{\cdot}025 = 2{\cdot}831$ V

Voltage drop in *DA* = $363{\cdot}25 \times 0{\cdot}02 = 7{\cdot}265$ V

∴ Voltage at point *B* = $250 - 6{\cdot}735$ = **243·265 V**

Voltage at point *C* = $243{\cdot}265 - 3{\cdot}361$ = **239·904 V**

Voltage at point *D* = $239{\cdot}904 + 2{\cdot}831$ = **242·735 V**

With Interconnector. Fig. 13.41 (*i*) shows the ring distributor with interconnector *AC*. The current in the interconnector can be found by applying Thevenin's theorem.

E_0 = Voltage between points *A* and *C*

= $250 - 239{\cdot}904 = 10{\cdot}096$ V

R_0 = Resistance viewed from points *A* and *C*

$$= \frac{(0\cdot 02 + 0\cdot 018)\,(0\cdot 02 + 0\cdot 025)}{(0\cdot 02 + 0\cdot 018) + (0\cdot 02 + 0\cdot 025)} = 0\cdot 02\ \Omega$$

R_{AC} = Resistance of interconnector = 0·02 Ω

Thevenin's equivalent circuit is shown in Fig. 13.41 (*ii*). Current in interconnector *AC*

$$= \frac{E_0}{R_0 + R_{AC}} = \frac{10 \cdot 096}{0 \cdot 02 + 0 \cdot 02} = 252 \cdot 4 \ A \text{ from } A \text{ to } C$$

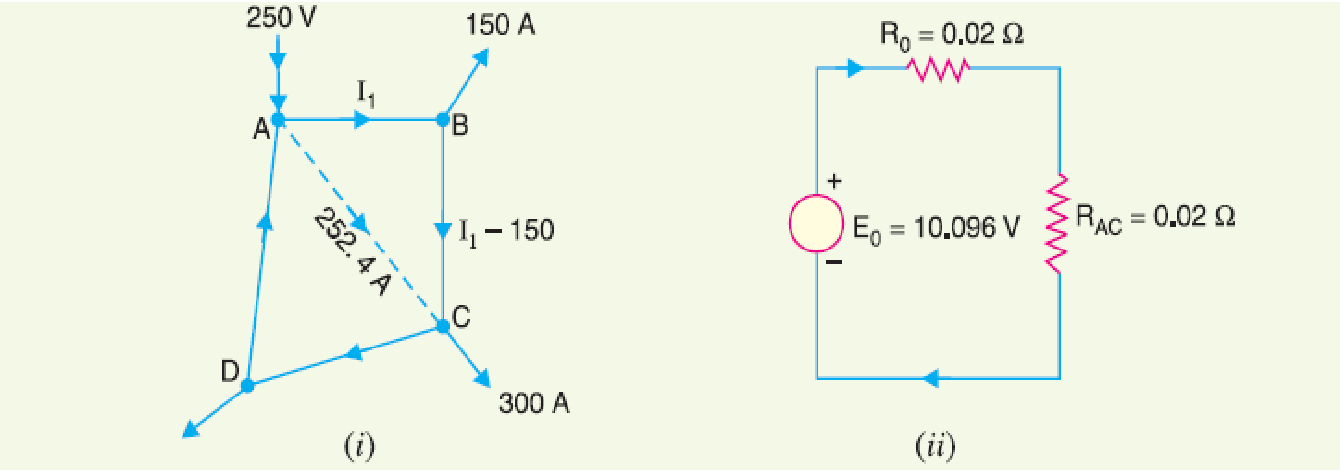


Fig. 13.41

Let us suppose that current in section *AB* is I_1. Then current in section *BC* will be $I_1 - 150$. As the voltage drop round the closed mesh *ABCA* is zero,

$\therefore \quad 0{\cdot}02\, I_1 + 0{\cdot}018\,(I_1 - 150) - 0{\cdot}02 \times 252{\cdot}4 = 0$

or $\quad 0{\cdot}038\, I_1 = 7{\cdot}748$

$\therefore \quad I_1 = 7{\cdot}748/0{\cdot}038 = 203{\cdot}15$ A

The actual distribution of currents in the ring distributor with interconnector will be as shown in Fig. 13.42.

Drop in *AB* = $203{\cdot}15 \times 0{\cdot}02 = 4{\cdot}063$ V

Drop in *BC* = $53{\cdot}15 \times 0{\cdot}018$

= $0{\cdot}960$ V

Drop in *AD* = $244{\cdot}45 \times 0{\cdot}02 = 4{\cdot}9$ V

$\therefore$ Potential of *B* = $250 - 4{\cdot}063$

= **245·93 V**

Potential of *C* = $245{\cdot}93 - 0{\cdot}96$

= **244·97 V**

Potential of *D* = $250 - 4{\cdot}9$ = **245·1 V**

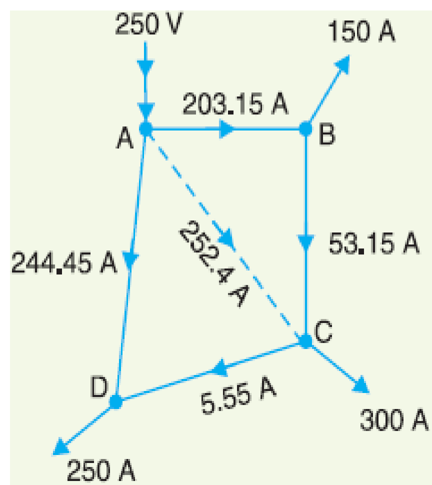


Fig. 13.42

It may be seen that with the use of interconnector, the voltage drops in the various sections of the distributor are reduced.

Example 13.25. *Fig. 13.43 shows a ring distributor with interconnector BD. The supply is given at point A. The resistances of go and return conductors of various sections are indicated in the figure. Calculate :*

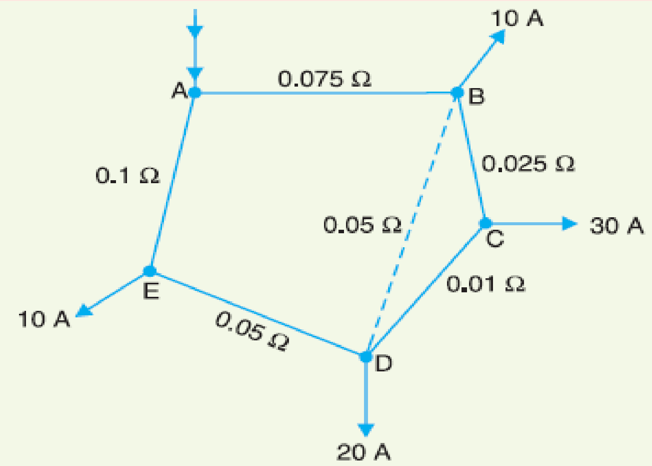


Fig. 13.43

(*i*) *current in the interconnector*

(*ii*) *voltage drop in the interconnector*

Solution. When interconnector *BD* is removed, let the current in branch *AB* be *I*. Then current distribution will be as shown in Fig. 13.44 (*i*). As the total drop round the ring *ABCDEA* is zero,

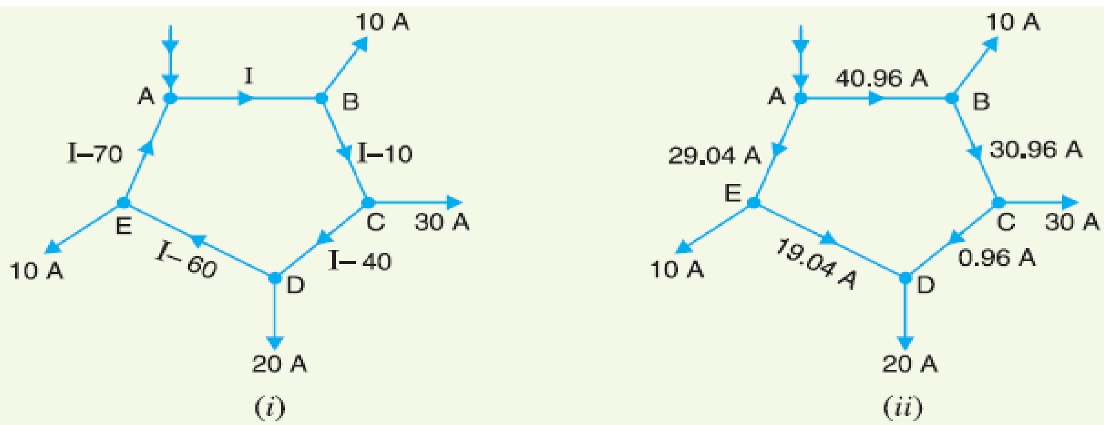


Fig. 13.44

$\therefore \quad 0{\cdot}075\, I + 0{\cdot}025\,(I - 10) + 0{\cdot}01\,(I - 40) + 0{\cdot}05\,(I - 60) + 0{\cdot}1\,(I - 70) = 0$

or $$0{\cdot}26\,I = 10{\cdot}65$$

$\therefore$ $$I = \frac{10\cdot 65}{0\cdot 26} = 40\cdot 96 \text{ A}$$

The actual distribution of currents will be as shown in Fig. 13.44 (*ii*).

$$\begin{aligned}\text{Voltage drop along } BCD &= 30{\cdot}96 \times 0{\cdot}025 + 0{\cdot}96 \times 0{\cdot}01 \\ &= 0{\cdot}774 + 0{\cdot}0096 = 0{\cdot}7836 \text{ V}\end{aligned}$$

This is equal to Thevenin's open circuited voltage E_0 *i.e.*

$$\begin{aligned}E_0 &= 0{\cdot}7836 \text{ V} \\ R_0 &= \text{Resistance viewed from } B \text{ and } D \\ &= \frac{(0\cdot 075 + 0\cdot 1 + 0\cdot 05)\,(0\cdot 025 + 0\cdot 01)}{(0\cdot 075 + 0\cdot 1 + 0\cdot 05) + (0\cdot 025 + 0\cdot 01)} \\ &= \frac{(0\cdot 225)\,(0\cdot 035)}{0\cdot 225 + 0.035} = 0\cdot 03\ \Omega\end{aligned}$$

(*i*) Current in interconnector BD is

$$I_{BD} = \frac{E_0}{R_0 + R_{BD}} = \frac{0\cdot 7836}{0\cdot 03 + 0.05} = \mathbf{9.8\ A}$$

(*ii*) Voltage drop along interconnector BD

$$= I_{BD}\, R_{BD} = 9{\cdot}8 \times 0{\cdot}05 = \mathbf{0{\cdot}49\ V}$$

A.C. DISTRIBUTIONS YSTEMS

14.1 A.C. Distribution Calculations

A.C. distribution calculations differ from those of d.c. distribution in the following respects :

(*i*) In case of d.c. system, the voltage drop is due to resistance alone. However, in a.c. system, the voltage drops are due to the combined effects of resistance, inductance and capacitance.

(*ii*) In a d.c. system, additions and subtractions of currents or voltages are done arithmetically but in case of a.c. system, these operations are done vectorially.

(*iii*) In an a.c. system, power factor (p.f.) has to be taken into account. Loads tapped off form the distributor are generally at different power factors. There are two ways of referring power factor *viz*

(*a*) It may be referred to supply or receiving end voltage which is regarded as the reference vector.

(*b*) It may be referred to the voltage at the load point itself.

There are several ways of solving a.c. distribution problems. However, symbolic notation method has been found to be most convenient for this purpose. In this method, voltages, currents and impedances are expressed in complex notation and the calculations are made exactly as in d.c. distribution.

14.2 Methods of Solving A.C. 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.* receiving or sending end voltage or (*ii*) *w.r.t.* to load voltage itself. Each case shall be discussed separately.

(*i*) Power factors referred to receiving end voltage. Consider an a.c. distributor AB with concentrated loads of I_1 and I_2 tapped off at points C and B as shown in Fig. 14.1. Taking the receiving end voltage V_B as the reference vector, let lagging power factors at C and B be $\cos\phi_1$ 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 sections AC and CB of the distributor.

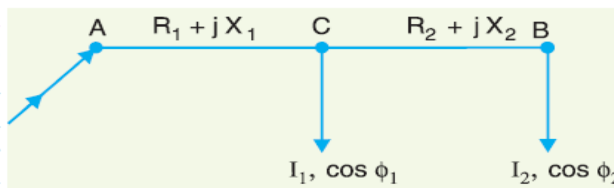


Fig. 14.1

Impedance of section AC, $\overrightarrow{Z_{AC}} = R_1 + j\,X_1$

Impedance of section CB, $\overrightarrow{Z_{CB}} = R_2 + j\,X_2$

Load current at point C, $\overrightarrow{I_1} = I_1(\cos\phi_1 - j\sin\phi_1)$

Load current at point B, $\overrightarrow{I_2} = I_2(\cos\phi_2 - j\sin\phi_2)$

Current in section CB, $\overrightarrow{I_{CB}} = \overrightarrow{I_2} = I_2(\cos\phi_2 - j\sin\phi_2)$

Current in section AC, $\overrightarrow{I_{AC}} = \overrightarrow{I_1} + \overrightarrow{I_2}$

$$= I_1 (\cos \phi_1 - j \sin \phi_1) + I_2 (\cos \phi_2 - j \sin \phi_2)$$

Voltage drop in section CB, $\overrightarrow{V_{CB}} = \overrightarrow{I_{CB}}\,\overrightarrow{Z_{CB}} = I_2 (\cos \phi_2 - j \sin \phi_2)(R_2 + j X_2)$

Voltage drop in section AC, $\overrightarrow{V_{AC}} = \overrightarrow{I_{AC}}\,\overrightarrow{Z_{AC}} = \left(\overrightarrow{I_1} + \overrightarrow{I_2}\right) Z_{AC}$

$$= [I_1(\cos\phi_1 - j\sin\phi_1) + I_2(\cos\phi_2 - j\sin\phi_2)]\,[R_1 + jX_1]$$

Sending end voltage, $\overrightarrow{V_A} = \overrightarrow{V_B} + \overrightarrow{V_{CB}} + \overrightarrow{V_{AC}}$

Sending end current, $\overrightarrow{I_A} = \overrightarrow{I_1} + \overrightarrow{I_2}$

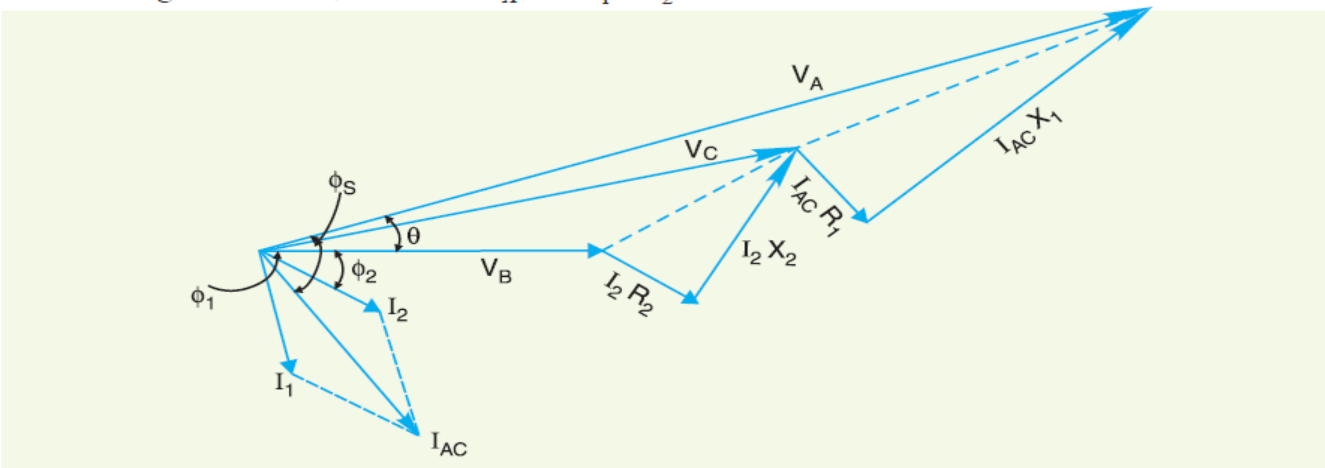


Fig. 14.2

The vector diagram of the a.c. distributor under these conditions is shown in Fig. 14.2. 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. Suppose the power factors of loads in the previous Fig. 14.1 are referred to their respective load voltages. Then ϕ_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 in Fig. 14.3.

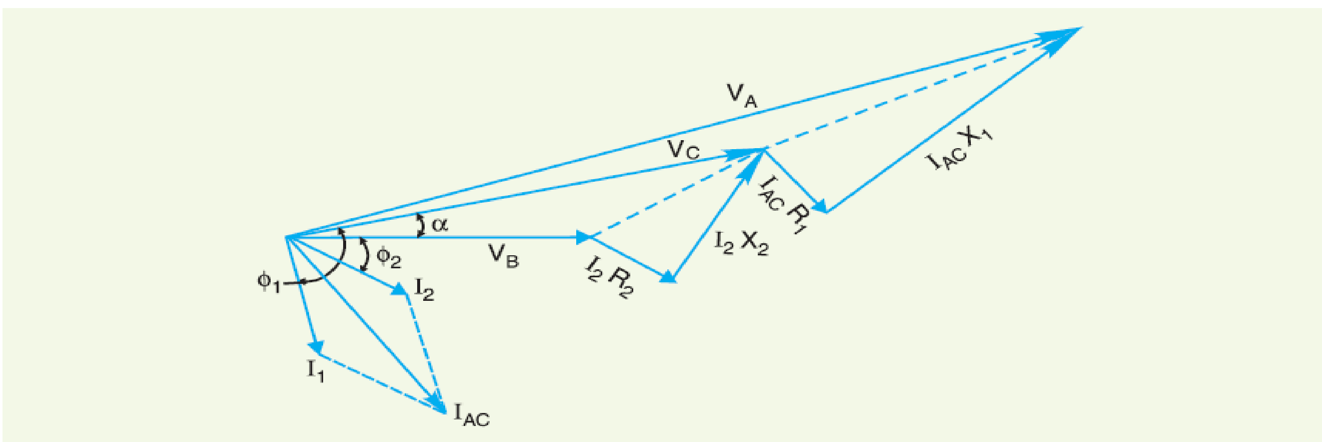


Fig. 14.3

Voltage drop in section $CB = \overrightarrow{I_2}\,\overrightarrow{Z_{CB}} = I_2(\cos\phi_2 - j\sin\phi_2)(R_2 + jX_2)$

Voltage at point $C = \overrightarrow{V_B}$ + Drop in section $CB = V_C \angle \alpha$ (say)

Now	$\vec{I_1}$	$= I_1 \angle -\phi_1$ *w.r.t.* voltage V_C
∴	$\vec{I_1}$	$= I_1 \angle -(\phi_1 - \alpha)$ *w.r.t.* voltage V_B
i.e.	$\vec{I_1}$	$= I_1 [\cos(\phi_1 - \alpha) - j \sin(\phi_1 - \alpha)]$
Now	$\vec{I_{AC}}$	$= \vec{I_1} + \vec{I_2}$

$$= I_1 [\cos(\phi_1 - \alpha) - j \sin(\phi_1 - \alpha)] + I_2 (\cos\phi_2 - j \sin\phi_2)$$

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

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

Example 14.1. *A single phase a.c. distributor AB 300 metres long is fed from end A and is loaded as under :*

(i) 100 A at 0·707 p.f. lagging 200 m from point A

(ii) 200 A at 0·8 p.f. lagging 300 m from point A

The load resistance and reactance of the distributor is 0·2 Ω and 0·1 Ω per kilometre. Calculate the total voltage drop in the distributor. The load power factors refer to the voltage at the far end.

Solution. Fig. 14.4 shows the single line diagram of the distributor.

Impedance of distributor/km $= (0{\cdot}2 + j\,0{\cdot}1)\ \Omega$

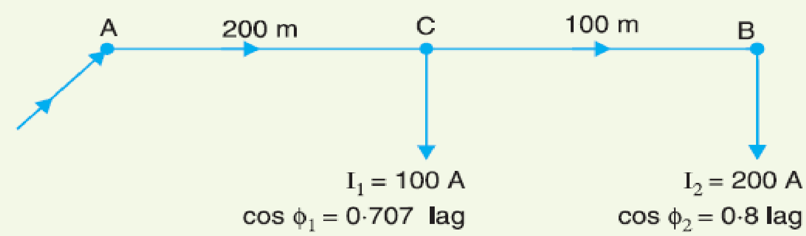


Fig. 14.4

Impedance of section AC, $\vec{Z_{AC}} = (0{\cdot}2 + j\,0{\cdot}1) \times 200/1000 = (0{\cdot}04 + j\,0{\cdot}02)\ \Omega$

Impedance of section CB, $\vec{Z_{CB}} = (0{\cdot}2 + j\,0{\cdot}1) \times 100/1000 = (0{\cdot}02 + j\,0{\cdot}01)\ \Omega$

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

Load current at point B, $\vec{I_2} = I_2 (\cos\phi_2 - j \sin\phi_2) = 200\,(0{\cdot}8 - j\,0{\cdot}6)$

$= (160 - j\,120)$ A

Load current at point *C*,	$\vec{I_1}$	$= I_1 (\cos \phi_1 - j \sin \phi_1) = 100\ (0{\cdot}707 - j\ 0{\cdot}707)$
		$= (70{\cdot}7 - j\ 70{\cdot}7)$ A
Current in section *CB*,	$\overrightarrow{I_{CB}}$	$= \vec{I_2} = (160 - j\ 120)$ A
Current in section *AC*,	$\overrightarrow{I_{AC}}$	$= \vec{I_1} + \vec{I_2} = (70{\cdot}7 - j\ 70{\cdot}7) + (160 - j\ 120)$
		$= (230{\cdot}7 - j\ 190{\cdot}7)$ A
Voltage drop in section *CB*,	$\overrightarrow{V_{CB}}$	$= \overrightarrow{I_{CB}}\ \overrightarrow{Z_{CB}} = (160 - j\ 120)\ (0{\cdot}02 + j\ 0{\cdot}01)$
		$= (4{\cdot}4 - j\ 0{\cdot}8)$ volts
Voltage drop in section *AC*,	$\overrightarrow{V_{AC}}$	$= \overrightarrow{I_{AC}}\ \overrightarrow{Z_{AC}} = (230{\cdot}7 - j\ 190{\cdot}7)\ (0{\cdot}04 + j\ 0{\cdot}02)$
		$= (13{\cdot}04 - j\ 3{\cdot}01)$ volts
Voltage drop in the distributor		$= \overrightarrow{V_{AC}} + \overrightarrow{V_{CB}} = (13{\cdot}04 - j\ 3{\cdot}01) + (4{\cdot}4 - j\ 0{\cdot}8)$
		$= (17{\cdot}44 - j\ 3{\cdot}81)$ volts
Magnitude of drop		$= \sqrt{(17 \cdot 44)^2 + (3 \cdot 81)^2}$ = **17·85 V**

Example 14.2. *A single phase distributor 2 kilometres long supplies a load of 120 A at 0·8 p.f. lagging at its far end and a load of 80 A at 0·9 p.f. 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 0·05 Ω and 0·1 Ω respectively. If the voltage at the far end is maintained at 230 V, calculate :*

(*i*) *voltage at the sending end*

(*ii*) *phase angle between voltages at the two ends.*

Solution. Fig. 14.5 shows the distributor AB with C as the mid-point

Impedance of distributor/km $= (0{\cdot}05 + j\,0{\cdot}1)\ \Omega$

Impedance of section AC, $\vec{Z}_{AC} = (0{\cdot}05 + j\,0{\cdot}1) \times 1000/1000 = (0{\cdot}05 + j\,0{\cdot}1)\ \Omega$

Impedance of section CB, $\vec{Z}_{CB} = (0{\cdot}05 + j\,0{\cdot}1) \times 1000/1000 = (0{\cdot}05 + j\,0{\cdot}1)\ \Omega$

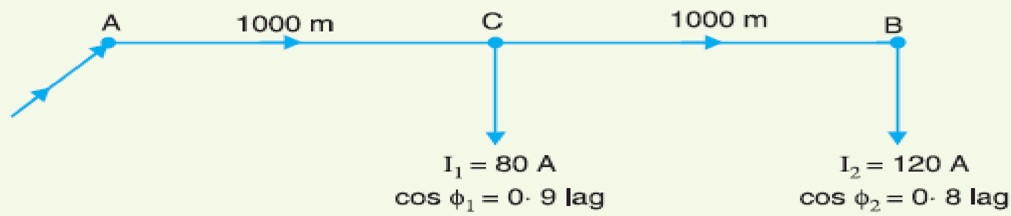


Fig. 14.5

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

Then, $\vec{V_B} = 230 + j\,0$

(i) Load current at point B, $\vec{I_2} = 120\,(0{\cdot}8 - j\,0{\cdot}6) = 96 - j\,72$

Load current at point C, $\vec{I_1} = 80\,(0{\cdot}9 - j\,0{\cdot}436) = 72 - j\,34{\cdot}88$

Current in section CB, $\vec{I_{CB}} = \vec{I_2} = 96 - j\,72$

Current in section AC, $\vec{I_{AC}} = \vec{I_1} + \vec{I_2} = (72 - j\,34{\cdot}88) + (96 - j\,72)$

$= 168 - j\,106{\cdot}88$

Drop in section CB, $\vec{V_{CB}} = \vec{I_{CB}}\,\vec{Z_{CB}} = (96 - j\,72)\,(0{\cdot}05 + j\,0{\cdot}1)$

$= 12 + j\,6$

Drop in section AC, $\vec{V_{AC}} = \vec{I_{AC}}\,\vec{Z_{AC}} = (168 - j\,106{\cdot}88)\,(0{\cdot}05 + j\,0{\cdot}1)$

$= 19{\cdot}08 + j\,11{\cdot}45$

$\therefore$ Sending end voltage, $\vec{V_A} = \vec{V_B} + \vec{V_{CB}} + \vec{V_{AC}}$

$= (230 + j\,0) + (12 + j\,6) + (19.08 + j\,11.45)$

$= 261.08 + j\,17.45$

Its magnitude is $= \sqrt{(261{\cdot}08)^2 + (17{\cdot}45)^2} =$ **261·67 V**

(ii) The phase difference θ between V_A and V_B is given by :

$$\tan\theta = \frac{17{\cdot}45}{261{\cdot}08} = 0{\cdot}0668$$

$$\therefore \quad \theta = \tan^{-1} 0{\cdot}0668 = \mathbf{3{\cdot}82^\circ}$$

Example 14.3. *A single phase distributor one km long has resistance and reactance per conductor of 0·1 Ω and 0·15 Ω respectively. At the far end, the voltage V_B = 200 V and the current is 100 A at a p.f. of 0·8 lagging. At the mid-point M of the distributor, a current of 100 A is tapped at a p.f. of 0·6 lagging with reference to the voltage V_M at the mid-point. Calculate :*

(i) voltage at mid-point

(ii) sending end voltage V_A

(iii) phase angle between V_A and V_B

Solution. Fig. 14.6 shows the single line diagram of the distributor *AB* with *M* as the mid-point.

Total impedance of distributor $= 2(0{\cdot}1 + j\,0{\cdot}15) = (0{\cdot}2 + j\,0{\cdot}3)\ \Omega$

Impedance of section *AM*, $\overrightarrow{Z_{AM}} = (0{\cdot}1 + j\,0{\cdot}15)\ \Omega$

Impedance of section *MB*, $\overrightarrow{Z_{MB}} = (0{\cdot}1 + j\,0{\cdot}15)\ \Omega$

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

Then, $\overrightarrow{V_B} = 200 + j\,0$

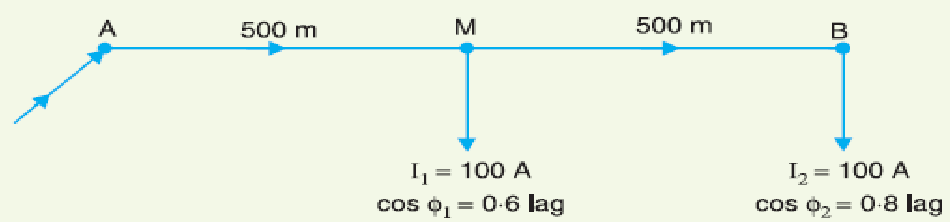


Fig. 14.6

(i) Load current at point *B*, $\overrightarrow{I_2} = 100\,(0{\cdot}8 - j\,0{\cdot}6) = 80 - j\,60$

Current in section *MB*, $\overrightarrow{I_{MB}} = \overrightarrow{I_2} = 80 - j\,60$

Drop in section *MB*, $\overrightarrow{V_{MB}} = \overrightarrow{I_{MB}}\ \overrightarrow{Z_{MB}}$

$= (80 - j\,60)\,(0{\cdot}1 + j\,0{\cdot}15) = 17 + j\,6$

∴ Voltage at point *M*, $\overrightarrow{V_M} = \overrightarrow{V_B} + \overrightarrow{V_{MB}} = (200 + j\,0) + (17 + j\,6)$

$= 217 + j\,6$

Its magnitude is $= \sqrt{(217)^2 + (6)^2} = $ **217·1 V**

Phase angle between V_M and V_B, α = $\tan^{-1} 6/217 = \tan^{-1} 0{\cdot}0276 = 1{\cdot}58°$

(ii) The load current I_1 has a lagging p.f. of 0·6 *w.r.t.* V_M. It lags behind V_M by an angle $\phi_1 = \cos^{-1} 0{\cdot}6 = 53{\cdot}13°$

$\therefore$ Phase angle between I_1 and V_B, $\phi'_1 = \phi_1 - \alpha = 53{\cdot}13° - 1{\cdot}58 = 51{\cdot}55°$

Load current at M, $\vec{I_1} = I_1 (\cos \phi_1' - j \sin \phi_1') = 100 (\cos 51{\cdot}55° - j \sin 51{\cdot}55°)$

$= 62{\cdot}2 - j\, 78{\cdot}3$

Current in section AM, $\overrightarrow{I_{AM}} = \vec{I_1} + \vec{I_2} = (62{\cdot}2 - j\, 78{\cdot}3) + (80 - j\, 60)$

$= 142{\cdot}2 - j\, 138{\cdot}3$

Drop in section AM, $\overrightarrow{V_{AM}} = \overrightarrow{I_{AM}}\, \overrightarrow{Z_{AM}} = (142{\cdot}2 - j\, 138{\cdot}3)\,(0{\cdot}1 + j\, 0{\cdot}15)$

$= 34{\cdot}96 + j\, 7{\cdot}5$

Sending end voltage, $\vec{V_A} = \vec{V_M} + \overrightarrow{V_{AM}} = (217 + j\, 6) + (34{\cdot}96 + j\, 7{\cdot}5)$

$= 251{\cdot}96 + j\, 13{\cdot}5$

Its magnitude is $= \sqrt{(251{\cdot}96)^2 + (13{\cdot}5)^2}$ = **252·32 V**

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

$\tan \theta = 13{\cdot}5/251{\cdot}96 = 0{\cdot}05358$

$\therefore \quad \theta = \tan^{-1} 0{\cdot}05358 =$ **3·07°**

Hence supply voltage is 252·32 V and leads V_B by 3·07°.

Example 14.4. *A single phase ring distributor ABC is fed at A. The loads at B and C are 20 A at 0.8 p.f. lagging and 15 A 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 + j 1), (1+ j2) and (1 + j3) ohms respectively. Find the total current fed at A and the current in each section. Use Thevenin's theorem to obtain the results.*

Solution. Fig. 14.7 (*i*) shows the ring distributor *ABC*. Thevenin's theorem will be used to solve this problem. First, let us find the current in *BC*. For this purpose, imagine that section *BC* is removed as shown in Fig. 14.7 (*ii*).

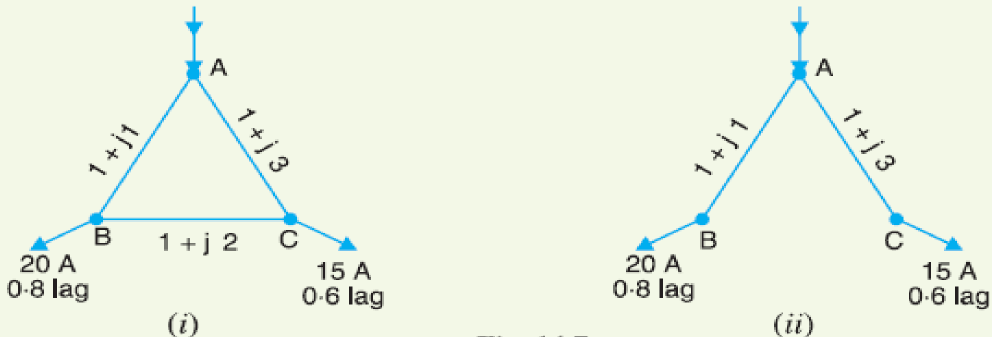


Fig. 14.7

Referring to Fig.14.7 (*ii*), we have,

Current in section *AB* $= 20\,(0{\cdot}8 - j\,0.6) = 16 - j\,12$

Current in section *AC* $= 15\,(0{\cdot}6 - j\,0{\cdot}8) = 9 - j\,12$

Voltage drop in section *AB* $= (16 - j\,12)\,(1 + j1) = 28 + j\,4$

Voltage drop in section *AC* $= (9 - j\,12)\,(1 + j\,3) = 45 + j\,15$

Obviously, point *B* is at higher potential than point *C*. The p.d. between *B* and *C* is Thevenin's equivalent circuit e.m.f. E_0 *i.e.*

Thevenin's equivalent circuit e.m.f., E_0 = p.d. between *B* and *C*

$$= (45 + j\,15) - (28 + j\,4) = 17 + j\,11$$

Thevenin's equivalent impedance Z_o can be found by looking into the network from points *B* and *C*.

Obviously, $Z_0 = (1 + j1) + (1 + j\,3) = 2 + j4$

$$\therefore \quad \text{Current in } BC = \frac{E_0}{Z_0 + \text{Impedance of } BC}$$

$$= \frac{17 + j11}{(2 + j4) + (1 + j2)} = \frac{17 + j11}{3 + j6}$$

$$= 2{\cdot}6 - j\,1{\cdot}53 = \mathbf{3\angle{-30{\cdot}48°}\ A}$$

$$\text{Current in } AB = (16 - j\,12) + (2{\cdot}6 - j\,1{\cdot}53)$$

$$= 18{\cdot}6 - j\,13{\cdot}53 = \mathbf{23\angle{-36{\cdot}03^\circ}\ A}$$

$$\text{Current in } AC = (9 - j\,12) - (2{\cdot}6 - j\,1{\cdot}53)$$

$$= 6{\cdot}4 - j\,10{\cdot}47 = \mathbf{12{\cdot}27\angle{-58{\cdot}56^\circ}\ A}$$

$$\text{Current fed at } A = (16 - j\,12) + (9 - j\,12)$$

$$= 25 - j\,24 = \mathbf{34{\cdot}65\angle{-43{\cdot}83^\circ}\ A}$$

Example 14.5. *A 3-phase, 400V distributor AB is loaded as shown in Fig.14.8. The 3-phase load at point C takes 5A per phase at a p.f. of 0·8 lagging. At point B, a 3-phase, 400 V induction motor is connected which has an output of 10 H.P. with an efficiency of 90% and p.f. 0·85 lagging.*

If voltage at point B is to be maintained at 400 V, what should be the voltage at point A ? The resistance and reactance of the line are 1Ω and 0·5Ω per phase per kilometre respectively.

Solution. It is convenient to consider one phase only. Fig.14.8 shows the single line diagram of the distributor. Impedance of the distributor per phase per kilometre = $(1 + j\,0{\cdot}5)\ \Omega$.

Impedance of section AC, $\quad \vec{Z}_{AC} = (1 + j\,0{\cdot}5) \times 600/1000 = (0{\cdot}6 + j\,0{\cdot}3)\ \Omega$

Impedance of section CB, $\quad \vec{Z}_{CB} = (1 + j\,0{\cdot}5) \times 400/1000 = (0{\cdot}4 + j\,0{\cdot}2)\ \Omega$

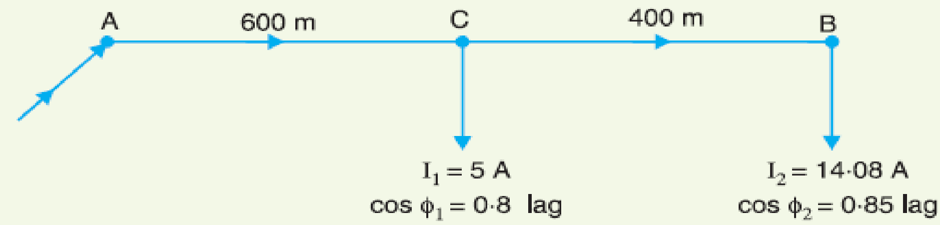


Fig. 14.8

Phase voltage at point B, $\quad V_B = 400/\sqrt{3} = 231\ \text{V}$

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

Then, $\quad \vec{V}_B = 231 + j\,0$

Line current at B

$$= \frac{\text{H.P.} \times 746}{\sqrt{3} \times \text{line voltage} \times \text{p.f.} \times \text{efficiency}}$$

$$= \frac{10 \times 746}{\sqrt{3} \times 400 \times 0 \cdot 85 \times 0 \cdot 9} = 14{\cdot}08\ \text{A}$$

$\therefore$ *Current/phase at B, $\quad I_2 = 14{\cdot}08\ \text{A}$

Load current at B, $\quad \vec{I}_2 = 14{\cdot}08\,(0{\cdot}85 - j\,0{\cdot}527) = 12 - j\,7{\cdot}4$

Load current at C, $\quad \vec{I}_1 = 5\,(0{\cdot}8 - j\,0{\cdot}6) = 4 - j\,3$

Current in section AC, $\quad \vec{I}_{AC} = \vec{I}_1 + \vec{I}_2 = (4 - j\,3) + (12 - j\,7{\cdot}4)$
$= 16 - j\,10{\cdot}4$

Current in section CB, $\quad \vec{I}_{CB} = \vec{I}_2 = 12 - j\,7{\cdot}4$

Voltage drop in CB, $\quad \vec{V}_{CB} = \vec{I}_{CB}\vec{Z}_{CB} = (12 - j\,7{\cdot}4)\,(0{\cdot}4 + j\,0{\cdot}2)$
$= 6{\cdot}28 - j\,0{\cdot}56$

Voltage drop in AC, $\quad \vec{V}_{AC} = \vec{I}_{AC}\vec{Z}_{AC} = (16 - j\,10{\cdot}4)\,(0{\cdot}6 + j\,0{\cdot}3)$
$= 12{\cdot}72 - j\,1{\cdot}44$

* In a 3-phase system, if the type of connection is not mentioned, then star connection is understood.

$$
\begin{aligned}
\text{Voltage at } A \text{ per phase,} \quad \vec{V}_A &= \vec{V}_B + \vec{V}_{CB} + \vec{V}_{AC} \\
&= (231 + j\,0) + (6 \cdot 28 - j\,0 \cdot 56) + (12 \cdot 72 - j\,1 \cdot 44) \\
&= 250 - j\,2 \\
\text{Magnitude of } V_A/\text{phase} &= \sqrt{(250)^2 + (2)^2} = 250 \text{ V} \\
\therefore \quad \text{Line voltage at } A &= \sqrt{3} \times 250 = \mathbf{433\ V}
\end{aligned}
$$

Example 14.6. *A 3-phase ring main ABCD fed at A at 11 kV supplies balanced loads of 50 A at 0.8 p.f. lagging at B, 120 A at unity p.f. at C and 70 A at 0·866 lagging at D, the load currents being referred to the supply voltage at A. The impedances of the various sections are :*

Section AB = (1 + j 0·6) Ω ; Section BC = (1·2 + j 0·9) Ω

Section CD = (0·8 + j 0·5) Ω ; Section DA = (3 + j 2) Ω

Calculate the currents in various sections and station bus-bar voltages at B, C and D.

Solution. Fig.14.9 shows one phase of the ring main. The problem will be solved by Kirchhoff's laws. Let current in section *AB* be $(x + j\,y)$.

∴ Current in section *BC*, $\overrightarrow{I_{BC}} = (x + j\,y) - 50\,(0{\cdot}8 - j\,0{\cdot}6) = (x - 40) + j\,(y + 30)$

Current in section *CD*, $\overrightarrow{I_{CD}} = [(x - 40) + j\,(y + 30)] - [120 + j\,0]$

$= (x - 160) + j\,(y + 30)$

Current in section *DA*, $\overrightarrow{I_{DA}} = [(x - 160) + j\,(y + 30)] - [70\,(0{\cdot}866 - j\,0{\cdot}5)]$

$= (x - 220{\cdot}6) + j\,(y + 65)$

Drop in section *AB* $= \overrightarrow{I_{AB}}\,\overrightarrow{Z_{AB}} = (x + jy)\,(1 + j0{\cdot}6)$

$= (x - 0{\cdot}6y) + j\,(0{\cdot}6x + y)$

Drop in section *BC* $= \overrightarrow{I_{BC}}\,\overrightarrow{Z_{BC}}$

$= [(x - 40) + j\,(y + 30)]\,[(1{\cdot}2 + j\,0{\cdot}9)]$

$= (1{\cdot}2x - 0{\cdot}9\,y - 75) + j\,(0{\cdot}9x + 1{\cdot}2\,y)$

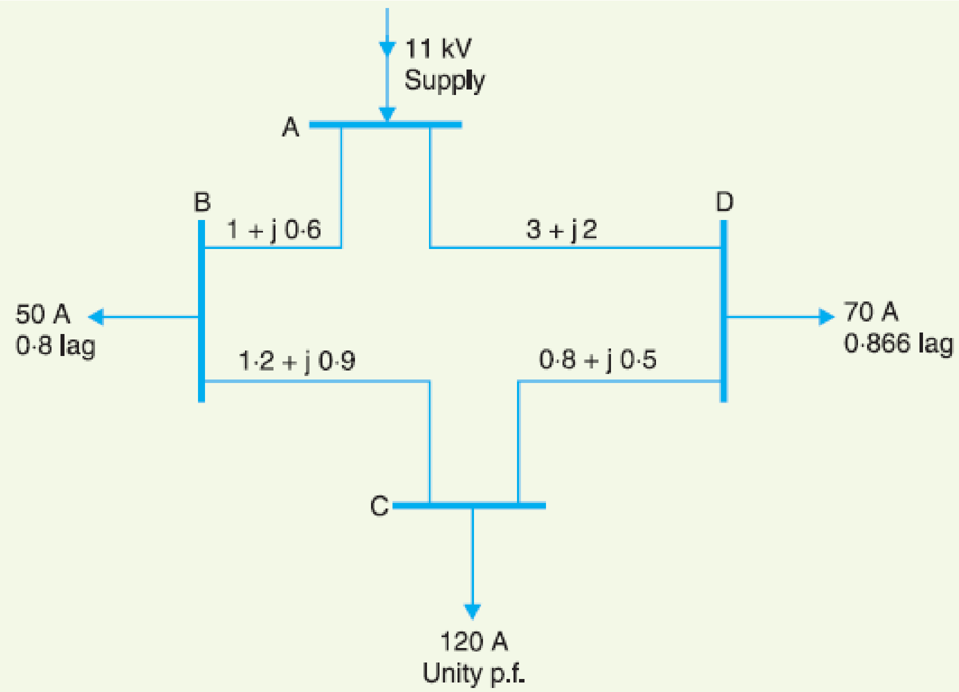

11 kV
Supply
A
B
D
1 + j 0·6
3 + j 2
50 A
0·8 lag
70 A
0·866 lag
1·2 + j 0·9
0·8 + j 0·5
C
120 A
Unity p.f.

Fig. 14.9

$$\text{Drop in section } CD = \overrightarrow{I_{CD}}\ \overrightarrow{Z_{CD}}$$
$$= [(x - 160) + j\,(y + 30)]\ [(0{\cdot}8 + j\,0{\cdot}5)]$$
$$= (0{\cdot}8x - 0{\cdot}5y - 143) + j\,(0{\cdot}5x + 0{\cdot}8y - 56)$$
$$\text{Drop in section } DA = \overrightarrow{I_{DA}}\ \overrightarrow{Z_{DA}}$$
$$= [(x - 220{\cdot}6) + j\,(y + 65)]\ [(3 + j\,2)]$$
$$= (3x - 2y - 791{\cdot}8) + j\,(2x + 3y - 246{\cdot}2)$$

Applying Kirchhoff's voltage law to mesh *ABCDA*, we have,

Drop in *AB* + Drop in *BC* + Drop in *CD* + Drop in *DA* = 0

or
$$[(x - 0{\cdot}6y) + j\,(0{\cdot}6x + y)] + [(1{\cdot}2x - 0{\cdot}9y - 75) + j\,(0{\cdot}9x + 1{\cdot}2y)] + [(0{\cdot}8x - 0{\cdot}5y - 143) + j\,(0{\cdot}5x + 0{\cdot}8y - 56)] + [(3x - 2y - 791{\cdot}8) + j\,(2x + 3y - 246{\cdot}2)] = 0$$

or
$$(6x - 4y - 1009{\cdot}8) + j\,(4x + 6y - 302{\cdot}2) = 0$$

As the real (or active) and imaginary (or reactive) parts have to be separately zero,

$\therefore$ $$6x - 4y - 1009{\cdot}8 = 0$$

and $$4x + 6y - 302{\cdot}2 = 0$$

Solving for x and y, we have,

$$x = 139{\cdot}7 \text{ A} \quad ; \quad y = -\,42{\cdot}8 \text{ A}$$

Current in section *AB* = **(139·7 – j 42·8) A**

Current in section *BC* $= (x - 40) + j\,(y + 30)$

$= (139{\cdot}7 - 40) + j\,(-\,42{\cdot}8 + 30) =$ **(99·7 – j 12·8) A**

Current in section *CD* $= (x - 160) + j\,(y + 30)$

$= (139{\cdot}7 - 160) + j\,(-\,42{\cdot}8 + 30)$

		$= (-20{\cdot}3 - j\,12{\cdot}8)$ **A**
Current in section DA		$= (x - 220{\cdot}6) + j\,(y + 65)$
		$= (139{\cdot}7 - 220{\cdot}6) + j\,(-42{\cdot}8 + 65)$
		$= (-80{\cdot}9 + j\,22{\cdot}2)$ **A**
Voltage at supply end A,	V_A	$= 11000/\sqrt{3} = 6351$ V/phase
∴ Voltage at station B,	$\vec{V_B}$	$= \vec{V_A} - \vec{I_{AB}}\,\vec{Z_{AB}}$
		$= (6351 + j\,0) - (139{\cdot}7 - j\,42{\cdot}8)\,(1 + j\,0{\cdot}6)$
		$= (6185{\cdot}62 - j\,41{\cdot}02)$ **volts/phase**
Voltage at station C,	$\vec{V_C}$	$= \vec{V_B} - \vec{I_{BC}}\,\vec{Z_{BC}}$
		$= (6185{\cdot}62 - j\,41{\cdot}02) - (99{\cdot}7 - j\,12{\cdot}8)\,(1{\cdot}2 + j\,0{\cdot}9)$
		$= (6054{\cdot}46 - j\,115{\cdot}39)$ **volts/phase**
Voltage at station D,	$\vec{V_D}$	$= \vec{V_C} - \vec{I_{CD}}\,\vec{Z_{CD}}$
		$= (6054{\cdot}46 - j\,115{\cdot}39) - (-20{\cdot}3 - j\,12{\cdot}8) \times (0{\cdot}8 + j\,0{\cdot}5)$
		$= (6064{\cdot}3 - j\,95)$ **volts/phase**

Unit: - 3 Distribution Systems:

1. Classify the distribution systems.
2. Explain different types of distribution systems with the help of neat sketches.
3. Distinguish between primary and secondary distribution systems with suitable examples.
4. On what factors does the primary distribution voltage depend?
5. Describe briefly different types of DC distribution.
6. What are the advantages of a doubly fed distributor over a singly fed distributor?
7. Explain the concept of ring mains with suitable diagrams.
8. What is meant by radial and loop systems of distribution?
9. Draw single line diagram of radial primary feeder and mention the factors that influence the selection of primary feeder.
10. List out the advantages and disadvantages of ring mains.
11. Give the significance of interconnectors in ring main distribution system.
12. What is ring distributor? How many types of ring distributors are there? What are the advantages of providing interconnector in the ring distributor?
13. Explain the difference between radial distribution system and ring main distribution system.
14. What is the purpose of interconnection in a DC ring main distributor?
15. Explain briefly the various systems of AC distribution.
16. Explain about 3-wire and 2-wire distributors.
17. Compare AC and DC distribution systems.
18. Discuss the relative merits and demerits of underground and overhead systems.
19. Discuss briefly the requirements of a distribution system.
20. What are the important requirements for a good distribution system?
21. Explain the following:

i. Feeder

ii. Distributor
iii. Service mains
22. Give the design features of distribution systems.
23. A 2-wire DC distributor AB, 600m long is fed from point A and is loaded as under:

Distance from A (mts) :	100	300	500	600
Loads (Amps) :	20	40	50	60

If the specific resistance of copper is $1.7*10^{-8}$ W-m.what must be cross section of each wire in order that the voltage drop in the distributor should not exceed 10V.

24. A 2-wire DC distributor AB, 600m long as loaded as under:

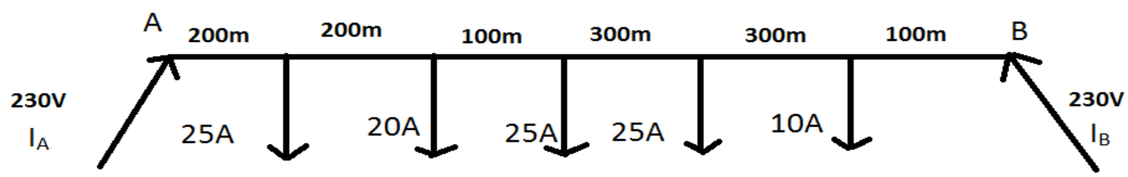
Distance from A (mts) :	150	300	350	450
Loads (Amps) :	100	200	250	300

The feeding point A is maintained at 440V and that of B at 430V. If each conductor has a resistance of 0.01W per 100m, calculate
i. the currents supplied from A to B
ii. The power dispatched in the distributor.
25. A 2-wire DC distributor 200m long is uniformly loaded with 2 A/m. resistance of single wire is 0.3 W/Km. If the distributor is fed at one end. Calculate,
    i. The voltage drop up to a distance of 150 m from the feeding point.
    ii. The maximum voltage drop

26. A uniformly distributed load on a distributor of length 500m is rated at 2A/m. The distributor is fed from one end at 230V.determine the voltage drop at a distance of 300m from the feeding point. Assume a loop resistance of $2*10^{-5}$ Ω/m.

27. An 800m distributor fed from both ends A and B is loaded uniformly at the rate of 1.2A/m run, the resistance of each conductor being 0.05 ohm per/km. Determine the minimum voltage and the point where it occurs if feeding points A and B are maintained at 255 V and 250 V respectively. Find also the current supplied from feeding point A and B.

28. A two wire distributor is loaded as shown in figure. The voltage at the two ends is 230V and 230V respectively. The distances between selections are given in meters. Determine the cross section of the conductor for a minimum consumer's voltage of 220V.

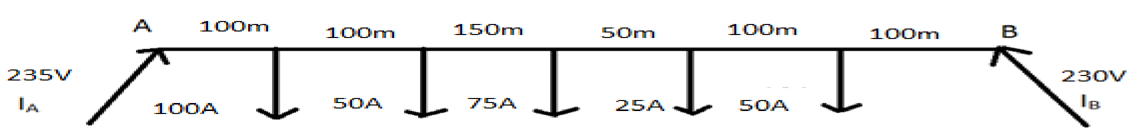


29. A two wire distributors are fed at F1 and F2 at 230 V and 220 V respectively. Loads of 150 A and 100 A are taken at points P and Q. Resistance of both the conductors between F1P is 0.03, between PQ is 0.05 and between QF2 is 0.02. Determine the current in each section of the distributor and voltage at each load point.
30. A DC 2-wire distributors are fed at F_1 and F_2 at 220V and 225V respectively. The total length of the distributor is 250m.the loads tapped off from long is fed from F_1 are:

Distance from A (mts) :	20	40	25	35
Loads (Amps) :	50	75	100	200

If resistance per Km of one conductor is 0.3Ω. Determine the current in various sections of the distributor and the voltage at the point of minimum potential.

31. A two wire distributor is loaded as shown in figure. Determine the cross section of the conductor for a minimum consumer's voltage of 220V.



32. A distributor is fed at both ends at same voltage of 250V. The total length of the feeder is 250m and the loads are tapped off as follows,

60A at 50m from X,50A at 80m from X,40A at 120m from X and 30A of 160m from X. find out

i. The point of minimum potential.
ii. The current in each section
iii. The voltage at minimum potential. The resistances per Km of the conductor for go and return is 0.9Ω.

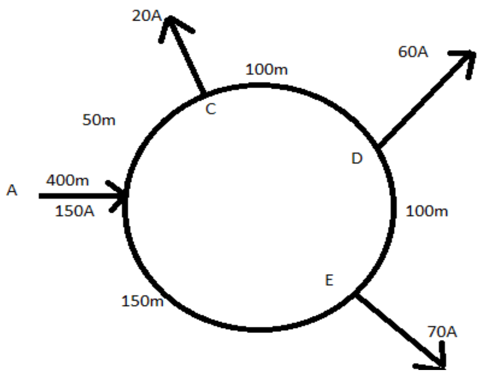
33. A 1000m distributor fed from both ends A and B is loaded uniformly at the rate of 1.5A per meter run, the resistance of each wire being 0.08Ω per Km. determine the minimum voltage and the point where it occurs if feeding point A and B are maintained at 255V and 250V respectively. Find also the current supplied from feeding points A and B.

34. A DC two wire distributor 600m fed from both ends A and B at 220V shown in figure. The loads consists of 50A at 100m from A,75A at 150m from A, and uniform loading 0f 0.5A per

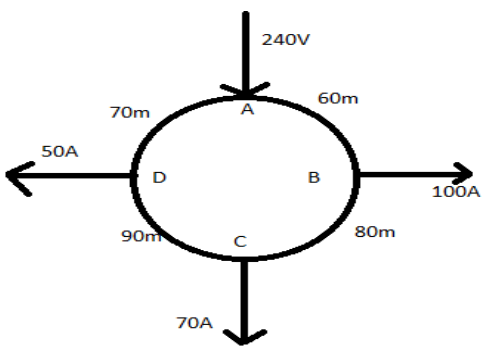
meter for the last 400m.the resistance of each conductor is 0.05Ω/Km. determine the location and magnitude of minimum voltage.

35. A ring main distributor is supplied through a feeder AB and is loaded as shown in figure. determine the,
    i. Cross-section of AB
    ii. Cross-section of the ring main for minimum volume of copper.

Assume that the maximum voltage drop from A to the point of minimum potential is 15V.Take ρ= 1.73μΩ/m^3.



36. A 300m ring distributor has loads as shown in figure, where distances are in meters. The resistance of each conductor is 0.2Ω per Km and the loads are tapped off at points B, C and D as shown. If the distributor is fed at A at 240V, find voltages at B, C and D.

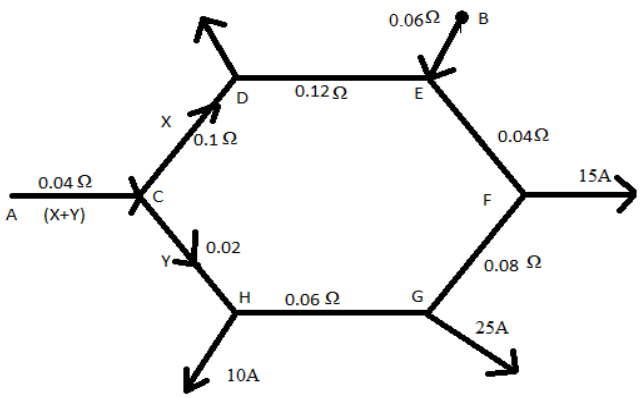


37. A 2-wire DC ring distributor is 300m long and is fed at 240V at point A. At point B, 150m from A, a load of 120A is taken and at C, 100m in the opposite direction, a load of 80a is taken if the resistance per 100m of single conductor is 0.03Ω, find

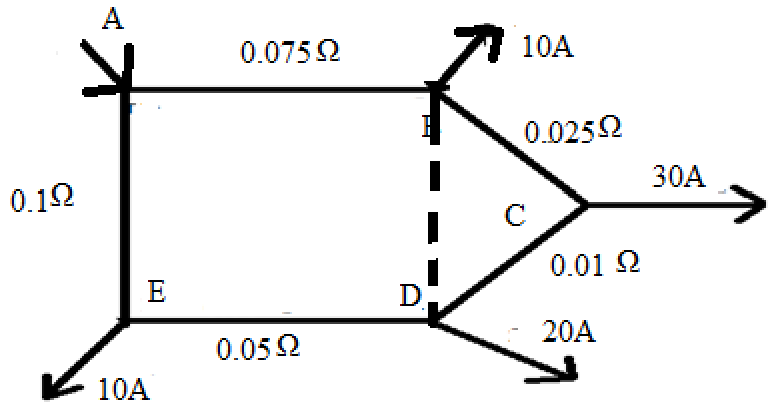
i. current in each section of distributor

ii. Voltage at points B and C.

38. Determine the currents supplied to the ring main as shown in figure from A and B when,
    i. $V_A = V_B$ and
    ii. $V_B = (V_A + 5)$ Volts



39. Figure shown in a ring distributor with interconnector BD. The supply is given at a point A. the resistance of go and return of various sections are indicated in the figure. calculate
    i. current in the inter connector
    ii. voltage drop in inter connector



40. Draw the phasor diagrams of AC distributor with concentrated loads for power factors with respect to respective load points.
41. A single phase line distributor has resistance of 0.3Ω at the midpoint (A),a current of 100A at 0.6 p.f. lag at the far end (B) a current of 100A at 0.8 p.f. lag is tapped .if the voltage at far end is 200V.
    a. find the voltage at supply end
    b. its phase angle w.r.t voltage at far end when,
    i) Power factors w.r.t respective voltages at the load points
    ii) Power factors w.r.t voltages at far end voltage
42. A single phase AC distributor 1 km long has resistance and reactance per conductor of 0.1 ohm and 0.15 ohm respectively. At the far end, the voltage VB = 200 volts and the current is 100 A at the power factor of 0.8 (lagging). At the midpoint M of the distributor, a current of 100 A is tapped at a power factor 0.6 lagging with reference to the voltage VM at the midpoint. Calculate

(a) Voltage at midpoint
(b) Sending end voltage VA
(c) Phase angle between VA and VB.

43. A single phase line (PQR) of length 2 km has resistance and reactance (go and return) as 0.06 and 0.1 ohms / km. P is the feeding point, Q is the midpoint of the line taking a load of 100A at 0.8 p.f. lead and R is the far end taking a load of 100 A at UPF. The voltage at the far end R is 220V. Determine the voltage at the sending end and the phase angle difference between the voltages of two ends. If

i) Power factors of the loads are with reference to far end voltage

ii) Power factors of the loads are with reference to the voltages at the load points.

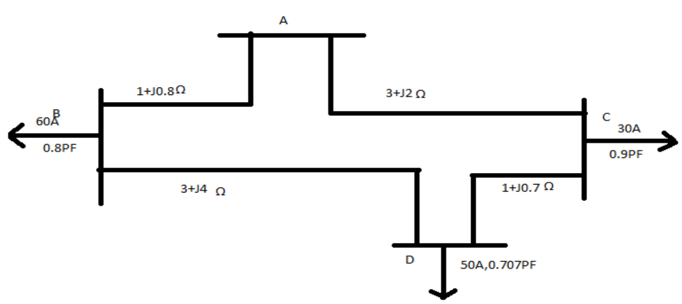
44.) Explain the method of voltage drop calculations in A,C distributor.

45.) A single phase Ac distributor AB 300m long is fed from end A and is loaded as follows:

i. 100 A at 0.707 power factor lagging 200 metres from point A.

ii. 200 A at 0.8 power factor lagging 300 metres from point A. The total resistance and reactance of the distributor is 0.2 ohms and 0.1 ohms per kilometer. Calculate the total voltage drop in the distributor. The load power factors are referred to the voltage at the far end.

46. The figure shows a three phase system supplied at 11kv at A. The load currents are balanced and p.f's (all lagging) are with respect to supply voltage at A.
   i) Calculate the current at section AC.
   ii) Calculate the current at section BD.
   iii) Calculate the current at section DC and voltage at load point C.



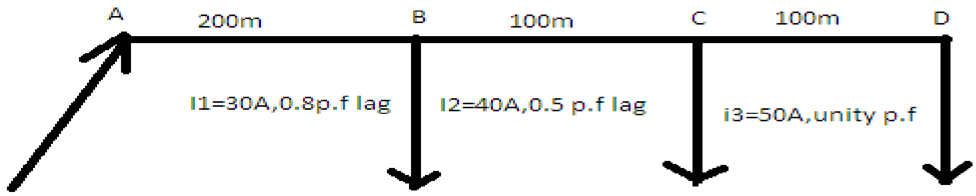
47. How do you solve the single phase A.C distribution system in which the power factors of the load currents are referred with respect to receiving end voltage?

48. What are the factors to be considered during the voltage drop calculation of an AC distribution?

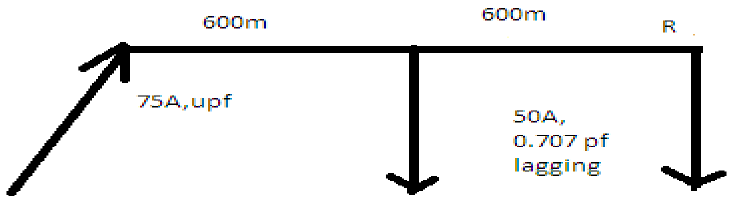
49. Contrast between AC and DC distribution problems.

50. Describe briefly how you will solve AC distribution problems.

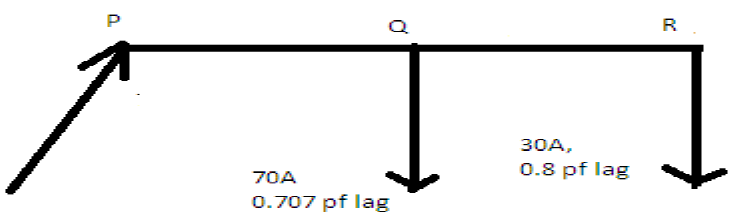
51. The loading on a distributor is shown in the figure. The distributor is a two-core cable for which the resistance and reactance are 0.5Ω and 0.25Ω per 1000meters of cable run respectively. What should be the voltage at point A to maintain 440v at point D.?



52. A single phase two-wire feeder,200 m long, supplies a load of 30A at 0.8 p.f, 50A at 0.85,70A at 0.88 p.f lagging at distances of 800m,1500m,200m respectively from the feeding point. The resistance and reactance of the feeder per kilometre length are 0.05Ω and 0.2Ω respectively. If the voltage at the far end is to be maintained at 230V, calculate the voltage at the sending end and its phase angle with respect to the receiving end voltage.
53. A two wire distributor 1200m long is loaded as shown in figure. The power factors at the two load points refer to the voltage at R. The impedance of each line is (0.15+j0.2) Ω. calculates the sending end voltage, current and power factor. The voltage at point R is 230V.



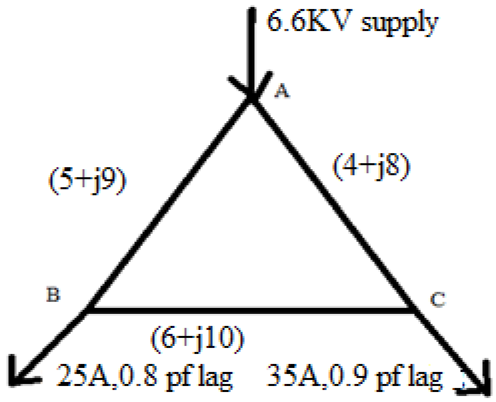
54. A single phase distributor PQR fed at P is as shown in figure. The power factors are lagging and expressed relative to the voltage at the far end is 230V.calculate the voltage at the supply end and its phase angle with respect to the far end.



55. A two-wire feeder ABC has a load of 120A at C and 60A at B both at pf 0.8 lagging. The impedance AB is (0.04+j0.08)Ω and that of BC is (0.08+j0.012)Ω. if the voltage at the far end C is to be maintain at 400V,determine the voltage.
    i. At A and
    ii. At B.
56. A single phase distributor has a loop resistance of 0.3Ω and reactance of 0.4Ω. The far end of the distributor has a load current of 100A and the power factor 0.8 lagging at 220V.the midpoint q of the distributor has a load current of 50A at power factor 0.9 lagging with reference to voltage Q. Determine the sending end voltage and power factor.
57. A three-phase distribution system power is supplied at 11 kV (line voltage) and balanced load of 50 A/phase at 0.8 lagging p.f and 70 A at 0.9 lagging p.f are taken at Q and R

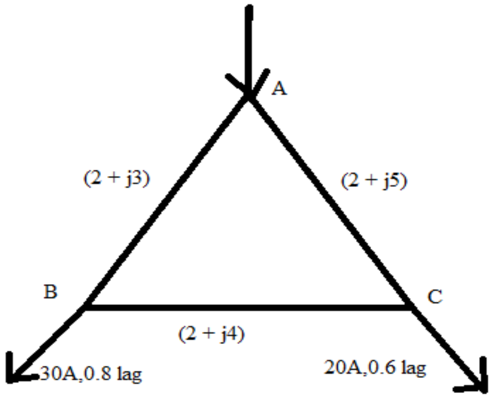
respectively. The impedance of the feeders are PQ = (5+j9), QR = (6+j10) and RP = (4+j8). Calculate the voltage at Q and R and the current in each branch. Power factors are assumed with respect to voltage at P.

58. A 3-phase distribution system is shown in figure. Power is supplied at A at line voltage of 6.6 kV and balanced loads of 25A per phase at 0.8 lagging p.f and 35A per phase at 0.9 lagging p.f are taken at B and C respectively. The impedances of the feeders are AB = (5 + j9) , BC = (6 + j10) and CA = (4 + j8) . Calculate the voltage at B and C and the current in each branch p.f.'s are assumed w.r. to voltage at A.

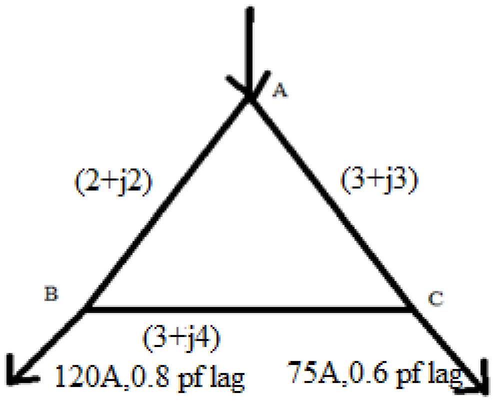


59. Explain the following with neat diagrams,
    i. AC 3-phase, 3-wire distribution system.
    ii. AC 3-phase, 4-wire system.

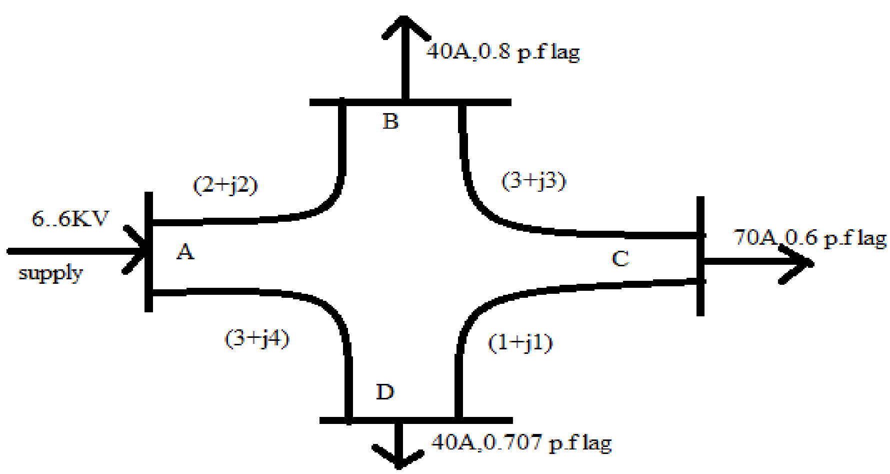
60. A single phase ring distributor ABC is fed at A. the loads at B and C are 30A at 0.8 p.f lagging and 20A at 0.6 p.f lagging respectively, both expressed with reference to the voltage at A. the total impedance of the three sections AB ,BC and CA are (2 + j3), (2 + j4) and (2 + j5)Ω respectively. Find the total current fed at A and the currents in each section. Use Thevenin's theorem to obtain the results.



61. A 3-phase, 6.6 KV sub-station supplies a load of 120A at 0.8 p.f lagging at B and 75A 0.6 p.f lagging at C. the impedance of each branch is shown in figure. Find out the current in each branch, the p.f of load are referred to the section A.



62. A three phase ring main PQRS fed at P of 11 kV, supplies balanced loads of 50 A at 0.8 p.f lagging at Q, 120 A at unity p.f at R and 70A at 0.866 lagging at S, the resistance being referred to the various sections are: Section PQ = (1+j0.6) ohm; section QR = (1.2+j0.9) ohm; Section RS = (0.8+j0.5) ohm; Section SP = (3+j2) ohms. Determine the currents in various sections and station bus-bar voltages at Q, R and S.
63. In a 3-phase, 4-wire distribution system with 240 volts between lines and neutral there is a balanced motor load of 250 kW at 0.8 power factor. Lamp loads connected between respective lines and neutral absorb 25, 75 and 100 kW. Calculate the current in each line and in the neutral wire of the feeder cable.
64. A 3-phase system is supplied at 6.6 KV at terminal 'A' as shown in figure. The load is balanced and the p.f lagging, calculate load current at each branch.



UNIT-V

Economics of Power Generation

Introduction to Economics of Power Generation:

The function of a power station is to deliver power at the lowest possible cost per kilo watt hour. This total cost is made up of fixed charges consisting of interest on the capital, taxes, insurance, depreciation and salary of managerial staff, the operating expenses such as cost of fuels, water, oil, labor, repairs and maintenance etc.

The cost of power generation can be minimized by:

1. Choosing equipment that is available for operation during the largest possible % of time in a year.

2. Reducing the amount of investment in the plant.

3. Operation through fewer men.

4. Having uniform design

5. Selecting the station as to reduce cost of fuel, labor, etc.

All the electrical energy generated in a power station must be consumed immediately as it cannot be stored. So the electrical energy generated in a power station must be regulated according to the demand. The demand of electrical energy or load will also vary with the time and a power station must be capable of meeting the maximum load at any time. Certain definitions related to power station practice are given below:

Load curve:

Load curve is plot of load in kilowatts versus time usually for a day or a year.

Load duration curve:

Load duration curve is the plot of load in kilowatts versus time duration for which it occurs.

Maximum demand:

Maximum demand is the greatest of all demands which have occurred during a given period of time.

Average load:

Average load is the average load on the power station in a given period (day/month or year)

$$L_{av} = \frac{\text{Energy (energy consumed)}}{\text{total time (h)}} = \frac{E}{h}$$

Base load:

Base load is the minimum load over a given period of time.

Connected load:

Connected load of a system is the sum of the continuous ratings of the load consuming apparatus connected to the system.

Peak load:

Peak load is the maximum load consumed or produced by a unit or group of units in a stated period of time. It may be the maximum instantaneous load or the maximum average load over a designated interval of time.

Demand factor:

Demand factor is the ratio of maximum demand to the connected load of a consumer.

Diversity factor:

Diversity factor is the ratio of sum of individual maximum demands to the combined maximum demand on power stations

$$DF = \frac{\text{Sum of individual max load within the group}}{\text{Maximum load of the system}}$$

$$= \frac{L_{\max 1} + L_{\max 2} + L_{\max 3} + 0000}{L_{\max (system)}} \geq 1$$

Load factor:

Load factor is the ratio of average load during a specified period to the maximum load occurring during the period.

$$LF = \frac{L_{av}}{L_{max}}$$

Station load factor:

Station load factor is the ratio of net power generated to the net maximum demand on a power station.

Plant factor:

Plant factor is the ratio of the average load on the plant for the period of time considered, to the aggregate rating of the generating equipment installed in the plant.

Capacity factor:

Capacity factor is the ratio of the average load on the machine for a period of time considered, to the rating of the machine.

$$CF = \frac{\text{average load on power plant}}{\text{rated capacity of the power plant}} = \frac{L_{av}}{C} < 1$$

Demand factor:

Demand factor is the ratio of maximum demand of system or part of system, to the total connected load of the system, or part of system, under consideration.

$$DF = \frac{\text{Consumer actual max load}}{\text{Connected load}} \leq 1$$

For example, hotels DF = 0.25 – 0.95
Cold stores DF = 0.80 – 0.90

Utilization factor:

Utilization factor is the ratio of maximum demand of a system or part of the system, to the rated capacity of the system, or part of the system, under consideration.

$$UF = \frac{\text{maximum load}}{\text{rated capacity of the PP}} = \frac{L_{max}}{C} \leq 1$$

Firm power:

Firm power is the power intended always to be available even under emergency conditions.

Prime power:

Prime power is the maximum potential power constantly available for transformation into electrical power.

Cold reserve**:**

Cold reserve is the reserve generating capacity that is available for service but not in operation.

Hot reserve:

Hot reverse is the reserve generating capacity that is in operation but not in service.

Spinning reserve:

Spinning reserve is the reserve generating capacity that is connected to the bus and ready to take load.

Run of river station:

Run of river station is a hydro-electric station that utilizes the stream flow without water storage.

Base Load supply:

In inter connected systems with many generating stations of various types, the choice of station to supply the varying load is of considerable economic significance. Entire load of the system may be divided into two parts e.g., base load and peak load. Base load is the load which is supplied for most of the time which remains more or less constant. Peak load is the intermittent requirement at particular hours of the day and so on.

The main considerations for base load provision are:

(i) High efficiency

(ii) High availability of the system.

Even a higher capital cost is sometime favored if it can ensure resultant gain in efficiency, as the cost is spread over a large total energy value.

Nuclear power plants are invariably used as base load plants. Thermal power plants and hydroelectric power plants can also be used as base load plants.

As far as peak load plants are concerned, these plants should have:

(i) Ability to start and take full load with a short time

(ii) Low capacity cost in view of the small annual output with the efficiency only a secondary condition.

Obsolete steam plant, through less efficient can't be used to met with peak load demand. Gas turbines, diesel engine plant and pumped storage stations are also suitable for peak load operation.

Peak Load:

Load on a power plant seldom remain constant. The load varies from season to season and also in a day from hour to hour. In summer, due to fans and air conditioners the plants have generally high load as compared to winter months. During day time also lights are switched on in the evening, the load on the plant will increase. During the days of festivals like national festivals, national days etc., there is excessive demand of electrical power. A power generating plant has to meet with all such variable demand sand at the same time maintain overall economy of operation. The period during which the demand on a power station is highest is known as peak load. Peak load on a plant may exist for small duration but still the plant has to devise ways and means for meeting with such demands.

Some of the methods are given below to meet with peak load demand:

1. Peak Load Plants:

Such plants arc operated only during peak load periods. These plants must be capable of quickly starting from cold conditions. Diesel engine plants, gas turbine plants, pumped storage plants and sometimes steam power plants and hydroelectric plants are used as peak load plants. Efficiency of such plants is of secondary importance as these plants operate for limited period only.

2. Use of accumulators:

Although electrical energy cannot be stored, however steam can be stored in steam accumulators, which can be used to generate additional power during peak load period.

3. Purchasing power:

When a power plant cannot generate sufficient power to meet with the demand, it may purchase power from neighboring plants if facilities exist.

4. Load Shedding:

When there is no alternative available the supply to some consumers is cut off temporarily, which is known as load shedding. Sometimes load shedding is done by switching off feeders by rotation or by reducing system voltage or by reducing frequency.

SELECTION OF TYPE OF GENERATION

It is done on the basis of

1. Capacity of power plant

2. Probable load factor

3. Space

4. Cost of fuel and transpiration facilities

5. Availability of water

6. Interest and depreciation

7. Reliability

Cost of Electrical Energy:

Capital cost of a power plant is due to

1. Cost of land and buildings

2. Cost of generating equipment and accessories

3. Cost of transmission and distribution network

4. Cost of designing and planning the power station

In general following plants are preferred for base load operations:

1. Nuclear power plant

2. Hydroelectric plant

3. Steam power plant

Following points are preferred for peak load operations:

1. Diesel engine power plant.

2. Gas turbine power plant

3. Pumped storage plant.

Cost of generation:

The cost of generating electricity in a power plant can be conveniently split into two parts: fixed costs and variable costs.

(A) Fixed Cost:

Fixed costs are to be borne by the plants irrespective of the load. These costs consist

(i) Interest on capital:

Capital cost of a plant includes the cost of land, buildings, of equipment including installation, designing, engineering etc. Since the capital cost of a plant is fixed therefore interest on the amount is considered as fixed cost.

(ii) Taxes:

A power generating and distributing company has to pay taxes to the Government. This amount is more or less fixed.

(iii) Cost of Transmission and Distribution:

Power transmission and. distribution network involves huge capital expenditure. This involves cost of transmission lines, transformers, substations and associated equipment. Interest on the capital involved is considered as a fixed cost.

(iv) Depreciation:

It is decrease in value caused by the wear due to constant use of an equipment Under the income tax laws there is provision for setting aside a fixed proportion of the capital employed, towards the depreciation fund.

(v) Insurance:

The plant and also life of some of workers working in dangerous areas, has to be insured against various risks involved. For this purpose a fixed sum is payable as premium for the insurance cover.

(vi) Salary for Managerial Staff:

Irrespective of whether the plant works or not certain managerial staff has to be retained by the organization. The salary liability of such staff is a part of the fixed cost.

(B) Variable Cost:

These costs vary in some proportion of the power generated in a plant. These costs consist of

(i) Cost of fuel:

Cost of fuel is directly related with the amount of power generated. For generating more power, more fuel is required. Cost of fuel may be 10% to 25% of the total cost of production. In case of hydroelectric plants the cost of fuel is zero.

(ii) Maintenance and Repair Charges:

In order to keep the plant in running condition, certain repairs are always needed. Stock of some consumable and non- consumable items has got to be maintained. All chargers for such staff are considered as operating costs.

(iii) Wages:

Salaries including allowances bonus, benefits etc. for the workers are considered as operating costs.

Total cost of production is thus sum of the fixed charges and the operating charges. As the plant load factor improves, the cost per kWh decreases. The sum of the charges for various factors will give an optimum load factor where such charges will be least.

9.10. FACTORS AFFECTING ECONOMICS OF GENERATION AND DISTRIBUTION OF POWER

The economics of power plant operation is greatly influenced by :

(*i*) Load factor (*ii*) Demand factor

(*iii*) Utilisation factor.

Load factor. In a *hydro-electric power station* with water available and a fixed staff for maximum output, the cost per unit generated at 100% *load factor* would be *half* the cost per unit at 50% load factor. In a *steam power station* the difference would not be so pronounced since fuel cost constitutes the major item in operating costs and does not vary in the same proportion as load factor. The cost at 100% load factor in case of this station may, therefore, be about 2/3rd of the cost at 50% load factor. For a *diesel station* the cost per unit generated at 100% load factor may be about at 3/4th of the same cost at 50% load factor. From the above discussion it follows that :

(*i*) *Hydro-electric power station should be run at its maximum load continuously on all units.*

(*ii*) *Steam power station* should be run in such a way that *all its running units are economically loaded.*

(*iii*) *Diesel power station* should be worked for *fluctuating loads* or *as a stand by.*

Demand factor and utilisation factor. *A highly efficient station, if worked at low utilisation factor, may produce power at high unit cost.*

The time of maximum demand occurring in a system is also important. In an interconnected system, *a study of the curves of all stations is necessary to plan most economical operations.*

The endeavour should be to load the most efficient and cheapest power producing stations to the greatest extent possible. Such stations, called *"base load stations"* carry full load over 24 hours *i.e.*, for three shifts of 8 hours.

- The stations in the *medium range of efficiency* are operated only during the two shifts of 8 hours during 16 hours of average load.
- The older or *less efficient stations* are used *as peak or standby stations* only, and are operated *rarely* or for *short periods of time.*

Presently there is a tendency to use units of large capacities to reduce space costs and to handle larger loads. However, the *maximum economical benefit of large sets occurs only when these are run continuously at near full load. Running of large sets for long periods at lower than maximum continuous rating increases cost of unit generated.*

9.11. HOW TO REDUCE POWER GENERATION COST ?

The cost of power generation can be *reduced by* :

1. Using a plant of simple design that *does not need highly skilled personnel.*
2. Selecting equipment of *longer life and proper capacities.*
3. Carrying out *proper maintenance* of power plant equipment to avoid plant breakdowns.
4. Running the power stations at *high load factors.*
5. Increasing the efficiency of the power plant.
6. Keeping proper supervision, which ensures *less breakdowns* and extended plant life.

9.12. POWER PLANT—USEFUL LIFE

The useful life of a power plant is that *after which repairs become so frequent and extensive that it is found economical to replace the power plant by a new one*. Useful life of some of the power plants is given below :

Plant	*Useful life*
1. Conventional thermal power plant	20–25 years
2. Nuclear power plant	15–20 years
3. Diesel power plant	About 15 years.

The useful life of some of the equipment of a *steam power plant* is given below :

Equipment	*Useful life (years)*
1. Boilers	
(*i*) Fire tube	10–20
(*ii*) Water tube	20
2. Steam turbine	5–20
3. Steam turbo-generators	10–20
4. Condensers	20
5. Pumps	15–20
6. Coal and ash machinery	10–20
7. Feed water heaters	20–30
8. Stacks	10–30
9. Stokers	10–20
10. Transformers	15–20
11. Motors	20
12. Electric meters and instruments	10–15
13. Transmission lines	10–20

Tariff Method

A tariff is the rate of charge per kilowatt hour of energy supplied to a consumer. The cost of generation of electrical energy may be conveniently split into two parts e.g. fixed charges plus the operating charges. So a tariff should be adjusted in such a way that the total receipts balance the total expenditure involved in generating the energy. There are several solutions to this problem, some of which are given below:

1. Flat Rate Tariff:

In this case there is a fixed rate per unit amount of energy consumed. The consumption of energy is measured by the energy meter installed at the premises of the consumer. This type of tariff accounts for all the costs involved in the generation of power. This is the simplest tariff easily understood by consumers. However, this type of tariff does not distinguish between small power domestic consumer and bulk power industrial consumers.

2. **Two Part Tariff**:

In this the total charges are split into two parts - fixed charges based on maximum demand (in kW) plus the charges based on energy consumption (in kWh). This method suffers from the drawback that an additional provision is to be incorporated for the measurement of maximum demand. Under such tariff, the consumers having 'peaked' demand for short duration are discouraged.

3. **Block Rate Tariff**:

In this the fixed charges are merged into the unit charges for one or two blocks of consumption, all units in excess being charged at low or high unit rate. Lower rates for higher blocks are fixed in order to encourage the consumers for more and more consumptions. This is done in case the plant has got larger spare capacity. Wherever the plant capacity is inadequate, higher blocks are charged at higher rate in order to discourage the consumers for higher than minimum consumption.

4. Three Part Tariff:

It is an extension of the two part tariff in that it adds to the consumer some fixed charges irrespective of the energy consumption or maximum demand. In this ever if the consumer has got zero power consumption, he has to pay some charges merely because a connection has been provided to him.

5. Power Factor Tariff:

In ac power supply size of the plant is determined by the kVA rating. In case the power factor of a consumer installation is low, the energy consumption in terms of kW will be low. In order to discharge such consumers, power factor tariff is introduced, which may be of the following types.

(a) Maximum kVA demand Tariff:

In this instead of kW the kVA consumption is measured and the charge are Based partly or fully on this demand.

(b) Sliding Scale:

In this case the average power factor is fixed say at 0.8 lagging. Now if the power factor of a consumer falls below by 0.01 or multiples thereof, some additional charges are imposed. A discount may be allowed in case the power factor is above 0.8.

The depreciation on the plant is charged by any of the following methods

1. Straight Line method

2. Sinking fund method

3. Diminishing value method.

9.17. TARIFF FOR ELECTRICAL ENERGY

9.17.1. Introduction

The cost of generation of electrical energy consists of *fixed cost and running cost*. Since the electricity generated is to be supplied to the consumers, the total cost of generation has to be recovered from the consumers. *Tariffs or energy rates are the different methods of charging the consumers for the consumption of electricity*. It is desirable to charge the consumer according to the maximum demand (kW) and the energy consumed (kWh). *The tariff chosen should recover the fixed cost, operating cost and profit etc. incurred in generating the electrical energy*.

9.17.2. Objectives and Requirements of Tariff

Objectives of tariff :

1. Recovery of cost of capital investment in generating equipment, transmission and distribution system.
2. Recovery of the cost of operation, supplies and maintenance of the equipment.
3. Recovery of the cost of material, equipment, billing and collection cost as well as for miscellaneous services.
4. A net return on the total capital investment must be ensured.

Requirements of tariff :

1. It should be easier to understand.
2. It should provide low rates for high consumption.
3. It should be uniform over large population.
4. It should encourage the consumers having high load factors.
5. It should take into account maximum demand charges and energy charges.
6. It should provide incentive for using power during off-peak hours.
7. It should provide less charges for power connection than lighting.
8. It should have a provision of penalty for low power factors.
9. It should have a provision for higher demand charges for high loads demanded at system peaks.
10. It should apportion equitably the cost of service to the different categories of consumers.

4.7 Tariffs

For the proper management of any electricity utility, it is important to have a source of income to meet its expenses. It is also important that electricity industry should have some income for future expansion work. There are two different types of charges: *Fix* charges and *running* charges. Fixed charges include (a) capacity related: interests and depreciation, cost of plant, buildings, transmission and distribution network, part of salaries of staff and (b) consumer related: cost of meter, billing, collection, service, etc. Running charges, also called *variable cost*, include fuel cost, operation and maintenance cost and some wages.

The total cost of supply is to be shared by consumers and should pay a sum according to use. The main objectives in framing a tariff are:

(a) The consumers must readily understand the tariffs.
(b) The tariff must be equitable as amongst different consumers.
(c) The tariff should also be such as to encourage consumers to improve the power factor.
(d) The tariff should also be such as to encourage consumers to improve load factor or to transfer their demand from peak to off-peak hours.
(e) Tariffs can be modified from time to time.
(f) Use of electricity is encouraged so that the economy of utilities is improved.

There are different types of consumers who consume electricity for different purposes. They can be classified into four subgroups:

1. *Domestic* consumers use electricity for domestic purposes.
2. *Agricultural* consumers use electricity of agricultural purposes such as irrigation, thrashing, etc.

3. *Industrial* consumers use electricity for industrial production such as heavy industries, manufacturing companies, etc.
4. *Commercial* consumers use electricity for commercial purposes such as municipalities, hospitals, etc.

The general form of tariff is

$$a \text{ kWh (or hp)} + b \text{ kW} + c$$

where a, b, c are the constants. Different types of tariffs are discussed below:

Flat rate tariff. In this rate, b and c are zero. The electricity charge is directly multiplication of energy consumption and the factor a. It is simple to understand and is independent on the contracted maximum demand.

Two-part tariff. The total charge under this kind of tariff is split into two components: a fixed charge based on the maximum demand (irrespective of energy consumption) and variable charge on the basis of actual energy consumption. The main objection of this tariff scheme is that consumer has to pay even if his consumption is nil.

Block rate tariff. Under this tariff scheme, different blocks of energy consumption are charged at different rates. The problem of two-part tariff is eliminated by this tariff. For example,

First 50 units	Rs 4.00/unit
Next 50 units	Rs 3.00/unit

And for additional unit @ Rs 2.00 per unit. This is for a particular month.

Maximum demand tariff. In this scheme of tariff, the charges are calculated based on the maximum demand only. The coefficient a and c are zero.

Power factor tariff. In ac system, the size of plant not only depends on the kW but also on power factor. Power factor tariffs are devised to differentiate between good power factor users and poor power factor users. The three main classes are:

1. *kVA maximum demand tariff:* Instead of charging the maximum real power (kW) demand, maximum kVA demand is charged in addition to the charge corresponding to the energy.
2. *kWh and kVArh tariff:* Under this scheme, both kWh (real power energy) and kVArh (reactive power consumption) are charged separately.
3. *Sliding scale or average power factor tariff:* There is some extra charge if the power factor is worsening from the set value. In this scheme, if consumers improve the power factor, an incentive will be given to those consumers. Let power factor is set to 0.8 lagging. If the power factor is 0.9, some discount will be offered and if power factor is 0.7, some extra charges are taken.

Example 4.5 Load factor of a consumer is 35% and the monthly consumption is 504 kWh. If the rate of electricity is Rs 180 per kW of maximum demand plus Rs 2.00 per kWh, find

(a) the monthly bill and the average cost per kWh
(b) the overall cost per kWh if the consumption is increased by 20% with the same load factor
(c) the overall cost per kWh if the consumption remains same but load factor is increased to 40%.

Solution

$$\text{Maximum demand} = \frac{\text{Average monthly consumption}}{\text{Load factor} \times 24 \times 30} = \frac{504}{0.35 \times 720} = 2.0 \text{ kW}$$

(a) Monthly bill (Rs) = (2 × 180) + (2 × 504) = 1368

$$\text{Overall cost per kWh} = \frac{1368}{504} = \text{Rs } 2.71$$

(b) New consumption = 504 × 1.20 = 604.8 kWh

$$\text{Since the load factor is same, the maximum demand} = \frac{604.8}{0.35 \times 720} = 2.4 \text{ kW}$$

Monthly bill (Rs) = (2.4 × 180) + (2 × 604.8) = 1641.6

$$\text{Overall cost per kWh} = \frac{1641.6}{604.8} = \text{Rs } 2.71$$

(c) Since the load factor is 40%, the maximum demand $= \dfrac{504}{0.40 \times 720} = 1.75$ kW

Monthly bill (Rs) = (1.75 × 180) + (2 × 504) = 1323

$$\text{Overall cost per kWh} = \frac{1323}{504} = \text{Rs } 2.63$$

Example 4.6 The load variation at a power supply station is given as:

$$P = 30 - 8 * \sin(kt) + 0.325t \text{ MW}.$$

where t is time in hours of a day and $k = 0.6$ red/sec. There are three generators of 15 MW each. It is advantageous to fully load a machine before connecting the others.

Determine:

(a) Maximum demand on the system.
(b) Load factor of the system.
(c) The total installed load, if density factor is 3.
(d) The minimum no. hours of each generator is in operation.

Solution Maximum demand can be obtained by $\delta P/\delta t = 0$

Thus $-4.8 \times \cos(0.6t) + 0.325 = 0$.

$\cos(0.6t) = 0.325/4.8 = 0.0677083 = \cos(1.0503032 + 2n\pi) \quad n = 0, 1, 2...$

$0.6t = 2n\pi + 1.503032$ or $2n\pi - 1.503032, n = 0, 1, 2...$

$t = 2.5051, 7.9669, 12.977, 18.4389, 23.449.$

During $t = 0$ to 24 hrs, the load curve has 5 maxima and minimas.

The corresponding load at these times will be

$P = 22.8325, 40.5709, 26.2359, 43.974, 29.639$ MW.

Thus

(a) Maximum demand = 43.974 MW.

(b) Average load $= (1/24) \times \int_0^{24} (30 - 8 \times \sin(0.6t) + 0.325t)\,dt$

$$= (1/24) \times [30 \times 24 + (8/0.6) \times \cos(0.6t)|_0^{24} + 0.325 \times 24^2/2] = 33.20 \text{ MW}.$$

Load factor = 33.20/43.974 = 0.755

(c) Total installed load = peak demand × Diversity factor = 43.974 × 3 = 131.922 MW.

(d) Since min. load is 22.8325 MW, two units will run for whole day, 3rd unit will run when $P > 30$MW. Hence finding the t when $P > 30$

$30 - 8 \times \sin(kt) + 0.3250 = 30$

$\sin(kt) = 0.040625t$

Using hit and trial methods (or using graph),

$t = 4.904, 11.265, 14.65, 22.94$

Unit-3 will be in operation for = (11.265 – 4.904) + (22.94 – 14.65) hrs.

= 14.651 hrs.

Example 9.29. *Two electrical units used for same purpose are compared for their economical working :*

(i) Cost of Unit-1 is Rs. 6000 and it takes 120 kW.

(ii) Cost of Unit-2 is Rs. 16800 and it takes 72 kW.

Each of them has a useful life of 40000 hours.

Which unit will prove economical if the energy is charged at Rs. 96 per kW of maximum demand per year and 6 p. per kWh ?

Assume both units run at full load.

Solution. (*i*) **Unit-1 :**

Capital cost per hour $= \frac{6000}{40000} =$ Re. 0.15

Maximum demand = 120 kW

Charge for maximum demand per hour

$$= \frac{120 \times 96}{(365 \times 24)} = \text{Rs. } 1.315$$

Energy charge per hour = Maximum demand × one hour × charge per kWh

$$= 120 \times 1 \times \frac{6}{100} = \text{Rs. } 7.2$$

∴ Total charges per hour for operation of Unit-1

$$= 0.15 + 1.135 + 7.2 = \text{Rs. } 8.485$$

(*ii*) **Unit-2 :**

Capital cost per hour $= \frac{16800}{40000} =$ Re. 0.42.

Charge for maximum demand per hour

$$= \frac{72 \times 96}{365 \times 24} = \text{Re. } 0.789$$

Energy charge per hour $= 72 \times 1 \times \frac{6}{100} =$ Rs. 4.32

Total charges per hour for the operation of Unit-2

$$= 0.42 + 0.789 + 4.32 = \text{Rs. } 5.529$$

The charges of operation for the Unit-2 per hour are less than the charges of operation for the Unit-1, therefore *Unit-2 is more economical* in this case. **(Ans.)**

Example 9.30. *The monthly electricity consumption of a residence can be approximated as under :*

Light load	*: 6 tube lights 40 watts each working for 4 hours daily*
Fan load	*: 6 fans 100 watts each working for 6 hours daily*
Refrigerator load	*: 2 kWh daily*
Miscellaneous load	*: 2 kW for 2 hours daily*

Find the monthly bill at the following tariff :

First 20 units	*Rs. 0.50/kWh*
Next 30 units	*Rs. 0.40/kWh*
Remaining units	*Rs. 0.30/kWh*
Constant charge	*Rs. 2.50 per month*

Discount for prompt payment = 5 per cent.

Solution. Total energy consumption in 30 days

$$= (6 \times 40 \times 4 \times 30 + 6 \times 100 \times 6 \times 30) \times \frac{1}{1000} + 2 \times 30 + 2 \times 2 \times 30$$

$$= (28800 + 108000) \times \frac{1}{1000} + 60 + 120 = 316.8 \text{ kWh per month}$$

The monthly bill $= \text{Rs. } [(20 \times 0.5 + 30 \times 0.4 + 266.8 \times 0.3) + 2.5]$

$$= \text{Rs. } [(10 + 12 + 80.04) + 2.5] = \text{Rs. } 104.54$$

$$\left[\because \text{ Remaining units per month } = 316.8 - 20 - 30 = 266.8\right]$$

Net monthly bill if the payment is made promptly

$$= 104.54 \times 0.9 = \textbf{Rs. 94.08.} \quad \textbf{(Ans.)}$$

Example 9.31. *An industrial undertaking has a connected load of 220 kW. The maximum demand is 180 kW. On an average each machine works for 60% time. Find the yearly expenditure on electricity if the tariff is :*

Rs. 1200 + Rs. 120 per kW of maximum demand per year + Re. 0.15 per kWh.

Solution. Energy consumption in one year

$$= 180 \times 0.6 \times (365 \times 24) = 946080 \text{ kWh}$$

Total electricity bill $= \text{Rs. } (1200 + 120 \times 180 + 0.15 \times 946080) =$ **Rs. 164712. (Ans.)**

☞**Example 9.32.** *A Hopkinson demand rate is quoted as follows :*

Demand rates :

First 1 kW of maximum demand	*= Rs. 6/kW/month*
Next 4 kW of maximum demand	*= Rs. 5/kW/month*
Excess 5 kW of maximum demand	*= Rs. 4/kW/month*

Energy rates :

First 50 kWh	*= 7 paise/kWh*
Next 50 kWh	*= 5 paise/kWh*
Next 200 kWh	*= 4 paise/kWh*
Next 400 kWh	*= 3 paise/kWh*
Excess over 700 kWh	*= 2 paise/kWh.*

Determine : (i) The monthly bill for a total consumption of 2000 kWh and a maximum demand of 15 kW. Also find out the unit energy cost.

(ii) Lowest possible bill for a month and a corresponding unit energy cost.

Solution. (*i*) Monthly bill and energy cost :

Demand charges per month $= \text{Rs. } (1 \times 6 + 4 \times 5 + 10 \times 4) = \text{Rs. } 66$

Energy charge $= \text{Rs. } [50 \times 7 + 50 \times 5 + 200 \times 4 + 400 \times 3 + 1300 \times 2] \times \frac{1}{100}$

$$= \text{Rs. } (350 + 250 + 800 + 1200 + 2600) \times \frac{1}{100} = \text{Rs. } 52$$

∴ *Monthly bill* $= 66 + 52 =$ **Rs. 118. (Ans.)**

Average unit energy cost $= \frac{118}{2000} \times 100 =$ **5.9 paise/kWh. (Ans.)**

(*ii*) Lowest possible bill :

The lowest possible bill will occur when average load

= Maximum load or at 100% load factor

∴ Maximum load $= \text{Average load} = \frac{2000}{30 \times 24} = 2.77 \text{ kW}$

∴ Demand charges $= \text{Rs. } (6 + 1.77 \times 5) = \text{Rs. } 14.85$

Energy charges will be same = Rs. 52

∴ *Minimum monthly bill* $= 14.85 + 52 =$ **Rs. 66.85. (Ans.)**

Unity energy cost for this condition

$$= \frac{66.85}{2000} \times 100 = \textbf{3.34 paise/kWh.} \quad \textbf{(Ans.)}$$

Example 9.33. *A new factory requires a maximum demand of 700 kW and load factor of 25%. The following two suppliers are available :*

(i) Public supply tariff is Rs. 48 per kW of maximum demand plus 2.4 p. per kWh.

Capital cost	*= Rs. 84000*
Interest and depreciation	*= 10 per cent*

(ii) Private oil engine generating station :

Capital cost	*= Rs. 300000*
Fuel consumption	*= 3 N/kWh*
Cost of fuel	*= Rs. 8.4 per kN*
Wages	*= 0.48 p/kWh*
Maintenance cost	*= 0.36 p/kWh*
Interest and depreciation	*= 15 per cent.*

Find which supply will be more economical ?

Solution. Load factor $= \dfrac{\text{Average load}}{\text{Maximum demand}}$

$\therefore$ Average load = Load factor × maximum demand = 0.25 × 700 = 175 kW

Energy consumed per year $= 175 \times (365 \times 24) = 1.533 \times 10^6$ kWh.

(i) Public supply :

Maximum demand charges per year

$= 48 \times 700 =$ Rs. 33600

Energy charge per year $= \dfrac{2.4}{100} \times 1.533 \times 10^6 =$ Rs. 36792

Interest and depreciation $= \dfrac{10}{100} \times 84000 =$ Rs. 8400

Total cost = Rs. (33600 + 36792 + 8400) = Rs. 78792

$\therefore$ *Energy cost per kWh* $= \dfrac{78792}{1.533 \times 10^6} \times 100 =$ **5.14 p.**

(ii) Private oil engine generating station :

Fuel consumption $= \dfrac{3 \times 1.533 \times 10^6}{1000} = 4599$ kN

Cost of fuel $= 4599 \times 8.4 =$ Rs. 38631

Cost of wages and maintenance $= \left(\dfrac{0.48 + 0.36}{100}\right) \times 1.533 \times 10^6 =$ Rs. 12877

Interest and depreciation $= \dfrac{15}{100} \times 300000 =$ Rs. 45000

Total cost = Rs. (38631 + 12877 + 45000) = Rs. 96508

Energy cost per kWh $= \dfrac{96508}{1.533 \times 10^6} \times 100 =$ **6.29 p.**

As the energy cost per kWh for oil engine is less than the public supply, the oil engine generation is more preferable. **(Ans.)**

☞**Example 9.34.** *A load having a maximum demand of 100 MW and a load factor of 0.4 may be supplied by one of the following schemes :*

(i) A steam station capable of supplying the whole load.

(ii) A steam station in conjunction with pump storage plant which is capable of supplying 130×10^6 kWh energy per year with a maximum output of 40 MW.

Find out the cost of energy per unit in each of the two cases mentioned above.

Use the following data :

Capital cost of steam station	*= Rs. 2000 / kW of installed capacity*
Capital cost of pump storage plant	*= Rs. 1300 / kW of installed capacity*
Operating cost of steam plant	*= 6 p. / kWh*
Operating cost of pump storage plant	*= 0.5 p. / kWh*

Interest and depreciation together on the capital invested should be taken as 12 per cent. Assume that no spare capacity is required.

Solution. (*i*) **Steam station :**

Capital cost $= 100 \times 10^3 \times 2000 = \text{Rs. } 200 \times 10^6$

Interest and depreciation $= \dfrac{12}{100} \times 200 \times 10^6 = \text{Rs. } 24 \times 10^6$

Average load = Load factor × maximum demand

$= 0.4 \times 100 \times 10^3 = 40000$ kW

Energy supplied per year = Average load × (365 × 24)

$= 40000 \times 365 \times 24 = 350.4 \times 10^6$ kWh

∴ Interest and depreciation charges *per unit of energy*

$$= \frac{24 \times 10^6}{350.4 \times 10^6} \times 100 = 6.85 \text{ p/kWh}$$

∴ *Total cost per unit* $= 6 + 6.85 =$ **12.85 p/kWh. (Ans.)**

(*ii*) **Steam station in conjunction with pump-storage plant :**

The load supplied by the steam plant $= 100 - 40 = 60$ MW

∴ Capital cost of steam plant $= 60 \times 1000 \times 2000 = \text{Rs. } 120 \times 10^6$

Capital cost of pump storage plant $= 40 \times 1000 \times 1300 = \text{Rs. } 52 \times 10^6$

∴ Total capital cost of combined station $= 120 \times 10^6 + 52 \times 10^6 = \text{Rs. } 172 \times 10^6$

Interest and depreciation charges on capital investment

$$= \frac{12}{100} \times 172 \times 10^6 = \text{Rs. } 20.64 \times 10^6$$

∴ Operating cost of pump storage plant $= \dfrac{0.5}{100} \times 130 \times 10^6 = \text{Rs. } 0.65 \times 10^6$

The energy units supplied by steam station

= Total units required – energy units supplied by pump storage plant

$= 350.4 \times 10^6 - 130 \times 10^6 = 220.4 \times 10^6$ kWh

Operating cost of the steam station

$$= \frac{6}{100} \times 220.4 \times 10^6 = \text{Rs. } 13.22 \times 10^6$$

Total cost per year $= \text{Rs. } (20.64 \times 10^6 + 0.65 \times 10^6 + 13.22 \times 10^6) = \text{Rs. } 34.51 \times 10^6$

$$\textit{Total cost per unit} = \frac{34.51 \times 10^6}{350.4 \times 10^6} \times 100 = \mathbf{9.85\ p/kWh.} \quad \textbf{(Ans.)}$$

Note : If the above example is repeated with a load factor of 0.7 it will be observed from the results that the *cost of generation becomes less with higher load factor irrespective of the type of the plant.*

Example 9.35. *The following data relate to a 2000 kW diesel power station :*

The peak load on the plant	= *1500 kW*
Load factor	= *0.4*
Capital cost per kW installed	= *Rs. 1200*
Annual costs	= *15 per cent of capital*
Annual operating costs	= *Rs. 50000*
Annual maintenance costs :	
(*i*) *Fixed*	= *Rs. 9000*
(*ii*) *Variable*	= *Rs. 18000*
Cost of fuel	= *Rs. 0.45 per kg*
Cost of lubricating oil	= *Rs. 1.3 per kg*
C.V. of fuel	= *41800 kJ/kg*
Consumption of fuel	= *0.45 kg/kWh*
Consumption of lubricating oil	= *0.002 kg/kWh*

Determine the following :

(*i*) *The annual energy generated.*

(*ii*) *The cost of generation per kWh.*

Solution. Capital cost of the plant $= 2000 \times 1200 = \text{Rs. } 2.4 \times 10^6$ per year

Interest on capital $= \frac{15}{100} \times 2.4 \times 10^6 = \text{Re. } 0.36 \times 10^6$ per year.

(*i*) **Annual energy generated** = Load factor × maximum demand × (365 × 24)

$= 0.4 \times 1500 \times 365 \times 24 = \mathbf{5.256 \times 10^6\ kWh.}$ **(Ans.)**

(*ii*) **Cost of generation :**

Fuel consumption $= 0.45 \times 5.256 \times 10^6 = 2.365 \times 10^6$ kg per year

Cost of fuel $= \text{Rs. } 0.45 \times 2.365 \times 10^6 = \text{Rs. } 1.064 \times 10^6$ per year

Lubricant consumption $= 0.002 \times 5.256 \times 10^6 = 10512$ kg per year

Cost of lubricating oil $= 1.3 \times 10512 = \text{Rs. } 13665$ per year

Total fixed cost = Interest + maintenance (fixed)

$= 0.36 \times 10^6 + 9000 = \text{Rs. } 369000$ per year

Total running or variable costs

= Fuel cost + lubricant cost + maintenance (running) + annual operating costs

$= 1.064 \times 10^6 + 13665 + 18000 + 50000 = \text{Rs. } 1145665$ per year

Total cost = Fixed cost + running cost = 369000 + 1145665 = Rs. 1514665

$$\textit{Cost of generation} = \frac{1514665}{5.256 \times 10^6} \times 100 = \mathbf{28.8\ paise/kWh.} \quad \textbf{(Ans.)}$$

☞**Example 9.36.** *The annual costs of operating a 15 MW thermal plant are given below :*

Capital cost of plant	= *Rs. 1500/kW*
Interest, insurance and depreciation	= *10 per cent of plant cost*

Capital cost of primary and secondary distribution = *Rs.* 20×10^6
Interest, insurance and depreciation on the capital cost of primary and secondary distribution = *5% the capital cost*
Plant maintenance cost = *Rs.* 100×10^3 *per year*
Maintenance cost of primary and secondary equipment = *Rs.* 2.2×10^5 *per year*
Salaries and wages = *Rs.* 6.5×10^5 *per year*
Consumption of coal = 40×10^4 *kN per year*
Cost of coal = *Rs. 9 per kN*
Dividend to stockholders = *Rs.* 1.5×10^6 *per year*
Energy loss in transmission = *10 per cent*
Diversity factor = *1.5*
Load factor = *0.75*
Maximum demand = *12 MW*

(i) Devise a two-part tariff.
(ii) Find the average cost per kWh.

Solution. (*i*) Two-part tariff :

$$\text{Load factor} = \frac{\text{Average load}}{\text{Maximum demand}}$$

$\therefore$ Average load = Load factor × maximum demand
$= 0.75 \times 12 \times 10^3 = 9000$ kW

Energy generated per year $= 9000 \times (365 \times 24) = 78.84 \times 10^6$ kWh

Cost of the plant $= 15 \times 10^3 \times 1500 = \text{Rs. } 22.5 \times 10^6$

Interest, insurance and depreciation charges of the plant

$$= \frac{10}{100} \times 22.5 \times 10^6 = \text{Rs. } 2.25 \times 10^6$$

Interest, insurance and depreciation charges of primary and secondary equipments

$$= \frac{5}{100} \times 20 \times 10^6 = \text{Rs. } 1.0 \times 10^6$$

Total fixed cost = Insurance, interest and depreciation costs + dividend to stock-holders
$= \text{Rs. } (2.25 \times 10^6 + 1.5 \times 10^6) = \text{Rs. } 3.75 \times 10^6$

Sum of individual maximum demand
= Maximum demand × diversity factor
$= 12 \times 10^3 \times 1.5 = 18000$ kW

$\therefore$ *Fixed charges per kW* $= \dfrac{3.75 \times 10^6}{18000} =$ **Rs. 208.3.**

Total variable charges = All maintenance costs + salaries and wages + fuel cost
$= (100 \times 10^3 + 2.2 \times 10^5) + 6.5 \times 10^5 + 40 \times 10^4 \times 9$
$= (1 \times 10^5 + 2.2 \times 10^5) + 6.5 \times 10^5 + 36 \times 10^5$
$= \text{Rs. } 45.7 \times 10^5$ or $\text{Rs. } 4.57 \times 10^6$

Energy transmitted = Energy generated × transmission efficiency

$$= 78.84 \times 10^6 \times \left(\frac{100 - \text{energy loss in transmission}}{100}\right)$$

$$= 78.84 \times 10^6 \times \frac{90}{100} = 70.956 \times 10^6 \text{ kWh}$$

∴ *Charges for energy consumption*

$$= \frac{4.57 \times 10^6}{70.956 \times 10^6} \times 100 = \mathbf{6.44\ paise/kWh.}$$

∴ *Two-part tariff* = **Rs. 208.3/kW + 6.44 paise/kWh. (Ans.)**

(*ii*) Average cost per kWh :

Total charges = Fixed charges + variable charges

$$= 3.75 \times 10^6 + 4.57 \times 10^6 = \text{Rs. } 8.32 \times 10^6$$

Average cost of supply $= \frac{8.32 \times 10^6}{70.956 \times 10^6} \times 100 =$ **11.72 paise/kWh. (Ans.)**

Example 9.37. *A 10 MW thermal power plant has the following data :*

Peak load	*= 8 MW*
Plant annual load factor	*= 0.72*
Cost of the plant	*= Rs. 800 / kW installed capacity*
Interest, insurance and depreciation	*= 10 per cent of the capital cost*
Cost of transmission and distribution system	*= Rs. 350 × 10³*
Interest, depreciation on distribution system	*= 5 per cent*
Operating cost	*= Rs. 350 × 10³ per year*
Cost of coal	*= Rs. 6 per kN*
Plant maintenance cost	*= Rs. 30000 / year (fixed)*
	= Rs. 40000 / year (running)
Coal used	*= 250000 kN / year*

Assume transmission and distribution costs are to be charged to generation

(i) Devise a two-part tariff.

(ii) Average cost of generation in paise / kWh.

Solution. (*i*) Two-part tariff :

S. No.	*Items*	*Fixed cost per year (in Rs.)*	*Running cost per year (in Rs.)*
1.	Interest, depreciation etc. of the plant	$\frac{10}{100} \times 10000 \times 800$ $= \text{Rs. } 800 \times 10^3$	—
2.	Interest, depreciation etc. of the transmission and distribution	$\frac{5}{100} \times 350 \times 10^3$ $= 17.5 \times 10^3$	—
3.	Annual cost of coal	—	250000×6 $= 1500 \times 10^3$
4.	Operating cost	—	$= 350 \times 10^3$
5.	Plant maintenance cost	$= 30 \times 10^3$	$= 40 \times 10^3$
	Total cost	847.5×10^3	1890×10^3

∴ Grand total cost = Fixed cost + running cost

$$= 847.5 \times 10^3 + 1890 \times 10^3 = \text{Rs. } 2737.5 \times 10^3$$

Energy generated/year = Average load × (365 × 24)

$= (\text{Peak load} \times \text{load factor}) \times (365 \times 24)$

$= (8 \times 10^3 \times 0.72) \times (365 \times 24) = 50.46 \times 10^6$ kWh

∴ *Two-part tariff* $= \dfrac{\text{Fixed cost}}{\text{Maximum load}} + \dfrac{\text{Running cost}}{\text{Energy generated}}$

$$= \frac{847.5 \times 10^3}{8 \times 10^3} + \frac{1890 \times 10^3}{50.46 \times 10^6} \times 100$$

= **Rs. 105.9/kW + paise 3.74/kWh. (Ans.)**

(*ii*) Average cost generation in paise/kWh :

Average generation cost $= \dfrac{\text{Grand total cost}}{\text{Energy generated}}$

$= \dfrac{2737.5 \times 10^3}{50.46 \times 10^6} \times 100 =$ **5.42 paise/kWh. (Ans.)**

Example 9.38. *Determine the load factor at which the cost of supplying a unit of electricity is same in Diesel station as in a steam station if the respective annual fixed and running charges are given below :*

Diesel : *Rs. (40/kW + 0.06/kWh)*

Steam : *Rs. (160/kW + 0.015/kWh).*

Solution. Let, P = Maximum load in kW, and

x = Load factor (same for both the stations).

Then, Average load = $P \times x$

Cost of diesel station,

$$C_{diesel} = 40\,P + 0.06 \times P \times x \times (365 \times 24)$$

Cost of steam station,

$$C_{steam} = 160\,P + 0.015 \times P \times x \times (365 \times 24)$$

As given in the problem,

Unit energy cost (diesel station) = Unit energy cost (steam station)

$$\therefore \quad \frac{40\,P + 0.06\,Px \times (365 \times 24)}{Px \times (365 \times 24)} = \frac{160\,P + 0.015\,Px \times (365 \times 24)}{Px \times (365 \times 24)}$$

$$\therefore \quad 40\,P + 0.06\,Px \times 8760 = 160\,P + 0.015\,Px \times 8760$$

or $$40\,P + 525.6\,Px = 160\,P + 131.4\,Px$$

or $$120\,P = 394.2\,Px \quad \text{or} \quad x = \frac{120}{394.2} = 0.3$$

i.e., *Load factor* = **0.3. (Ans.)**

Example 9.2 Find out the minimum two part tariff to be charged in the following case.

(a) Generating cost per kWh = \$ 0.004
(b) Generating cost power kW of maximum demand = \$ 1
(c) Total energy generated per year = 4500×10^4 kWh
(d) Load factor of the generating station = 60%
(e) Annual charge for distribution = \$ 2500
(f) Diversity factor = 1.3
(g) Total loss between station and consumer = 12%

Solution

$$\text{Load factor} = \frac{\text{Number of units generated}}{\text{Station maximum demand} \times 8760}$$

or

$$\frac{60}{100} = \frac{4500 \times 10^4}{\text{Station maximum demand} \times 8760}$$

or

$$\text{Station maximum demand} = \frac{4500 \times 10^4}{0.6 \times 8760}\ \text{kW}$$

$$= \frac{4500 \times 10^4}{5256}\ \text{kW}$$

$$= 8561.6\ \text{kW}$$

Annual cost of generation per kW of maximum demand = \$ 1.

Total annual cost of generation 8561.6 kW = \$ 8561.6

Annual charges for distribution = \$ 2500

∴ Annual fixed charge = (8561.6 + 2500) = \$ 11061.6

$$\text{Diversity factor} = \frac{\text{Sum of consumer's maximum demand}}{\text{Station maximum demand}}$$

$$1.3 = \frac{\text{Sum of consumer's maximum demand}}{8561.6}$$

or Sum of consumer's maximum demand = $8561.6 \times 1.3 = 11130.08$ kW

There is a 12% loss between the generating station and consumer. Therefore, the maximum demand practically

$$= 11130.08 \times (0.88)\ \text{kW}$$

$$= 9794.47\ \text{kW}$$

$$\text{Fixed charges per kW of maximum demand} = \frac{11061.6}{9794.47} = 1.129$$

Therefore, the two part tariff can be described as follows:

(a) \$ 1.129 per kW of maximum demand.
(b) \$ 0.004 per kWh.

Unit 5:-

Economic Aspects of Power Generation and Tariff Methods

1. What do you understand by the load curve? What information is conveyed by a load curve?
2. What information can be obtained from the load duration curve?
3. Explain the integrated load duration curve.
4. What are the uses of integrated load duration curve?
5. Define the following forms in connection with power supply systems,
    i. Connected load
    ii. Maximum/peak demand
6. Discuss the important points to be taken into consideration while selecting the size and number of units of a power station.
7. Define the following terms in connection with power supply systems:
   (i) Connected load (ii) maximum demand
   (iii) Demand factor .
8. Discuss how load factor and diversity factor influence the installed capacity of a generating station.
9. Define the following terms in connection with power supply systems:
   (i) Load factor (ii) diversity factor
   (iii) Demand factor
10. Define and explain the significance of plant capacity factor.
11. Define the following terms in connection with power supply system,
    i. Plant use factor
    ii. Utilization factor
12. Define the diversity factor. What is its importance?
13. Define the terms, plant capacity factor and plant use factor and explain their importance in an electric supply system.
14. Define the terms 'annual plant use factor' and 'annual plant capacity factor' of a power station and discuss the effect of these factors on choice of the size and number of generator units, the reserve capacity of plant and operation schedule of station.
15. Write short notes on the advantages of load factor.
16. Define the load factor. What is its importance?
17. Discuss the role of load factor on the cost of electrical energy.
18. State the effects of load factor and diversity factor on the cost of generation.
19. From a load duration curve, the following data are available: the maximum demand on the system is 25 MW. The load supplied by two units is 15 MW and 12.5 MW. Unit no.1 acts as a base load unit and No.2 as a peak load unit. The base load unit works for 100% of the time and peak load unit for only 40% of time the energy generated by unit

No.1 is 1 ×108 units and that by No.2 is 1×107 units. Determine the load factor, plant capacity factor and plant use factor of each unit and load factor of the total plant.

20. A generating station supplies the following loads; 150MW; 120MW; 85MW; 60MW and 5MW. The station has maximum demand of 220MW. The annual load factor of the station is 48%. Calculate
    i. The number of units supplied annually,
    ii. Diversity factor and
    iii. Demand factor.
21. A central station supplied energy to two substations A and B, four feeders take off from each of the sub stations, the maximum demand are as given below,

Central station: 10MW

Feeders on substation A: 1.5,2, 5, 3MW

Substation A: 6MW

Feeders on substation B: 2, 4, 5, 1MW

Substation B: 8MW

Calculate the diversity factors between,

i) Substations

ii) Feeders on substation A and

iii) Feeders on substation B

22. A power supply is having the following loads.

Type of load	Max.demand(KW)	Diversity of group	Demand factor
Domestic	15,000	1.25	0.7
Commercial	25,000	1.2	0.9
Industrial	50,000	1.3	0.98

If the overall system diversity factor is 1.5, determine

i. the maximum demand

ii. Connected load of each type.

23. The peak load on a 50MW power station is 39 MW. It supplies power through for transformers whose connected loads are 17, 12, 9 and 10 MW. The maximum demands on these transformers are 15, 10 8 and 9 MW respectively. If the annual load factor is 50% and the plant is operating for 65% of the period in the year, find out

    i. average load on the station

    ii. Energy supplied per year

    iii. Demand factor

    iv. Diversity factor and

    v. use factor for the power station.

24. A generating station supplies the following connected loads, 15 lamps of 40W each of two heaters of 1000W each. His maximum demand is 15000W. on the average he uses

10 lamps for 5 hours a day and each heater for three hours a day. Find his average load, monthly energy consumption and load factor.

25. A generating station has maximum demand of 500MW.the annual load factor is 40%. Find the reserve capacity of the plant.
26. A generating station has maximum demand of 50MW, a load factor of 62%, a plant use factor of 82% and a plant capacity factor of 50%. Find
    a. The daily energy produced
    b. The reserve capacity of the plant
    c. The maximum energy that could be produced daily if the plant were running all the time
    d. The maximum energy that could be produced daily if the plant, when running fully loaded
27. A base load station having a capacity of 500MW and a standby station having a capacity of 50MW share a common load. Find the annual load factors and capacity factors of two power stations, from the following data.

    Annual standby station output= 77.35x 10^6 KWh

    Annual base load station output= 103 x 10^6 KWh

    Peak load an standby station = 40MW

    Hours of use by standby station per year = 3000 hours
28. A generating station supplies the four loads; 15MW; 12MW; 8.5MW; 6MW. The maximum demand on the station of 20MW. The annual load factor is 45%. Calculate the number of units supplied annually, the diversity factor and demand factor.
29. A generating station has the following daily load cycle

Load(MW)	Time(hrs)
40	0-6
50	6-10
60	10-12
50	12-16
70	16-20
40	20-24

Draw the load curve and find

i. maximum demand

ii. Units generated per day

iii. Average load and load factor.

30. The annual load duration curve of a certain power station can be considered as a straight line from 20MW to 4MW. To meet this load, three turbine generator units, two rated at 10MW each and one rated at 5MW are installed. Determine,
    i. Installed capacity

ii. Plant capacity factor
iii. Units generated per annum and
iv. Utilization factor

31. A base load station having a capacity of 400MW and a standby station having a capacity of 50MW share a common load. Find the annual load factors and capacity factors of two power stations, from the following data.

Annual standby station output= 87.35x 10^6 KWh
Annual base load station output= 101.0 x 10^6 KWh
Peak load an standby station = 120MW
Hours of use by standby station per year = 3000 hours

32. A generating station has maximum demand of 15MW and the daily load on the station as follows.

10 P.M to 5 A.M = 2500KW
5 A.M to 7 A.M = 3000KW
7 A.M to 11 A.M = 9000KW
11 A.M to 1 P.M = 6000KW
1 P.M to 4 P.M = 10,000KW
4 P.M to 6 P.M = 12,000KW
6 P.M to 8 P.M = 15,000KW
8 P.M to 10 P.M = 5,000KW

Determine the size and number of generator units, plant load factor, plant capacity factor and use factor of the plant.

33. A residential consumer has a connected load of 15 lamps of 100 W at his premises. His demand is as follows.

From midnight to 6 AM -- 300 W
From 6 AM to 6 PM -- No load
From 6 PM to 7 PM -- 600 W
From 7 PM to 10 PM -- 1300 W
From 10 PM to Midnight -- 500 W

From above data

a) Plot the load curve
b) Find the energy consumption during 24 hours
c) Calculate the demand factor, average load, maximum load and load factor.

34. A generating station has a connected load of 43MW and a maximum demand of 20MW; the units generated being 61.5 x 10^6 per annum. Calculate,

a. The demand factor and
b. Load factor

35. A particular area can be supplied either by hydro station or steam station. The following data is available.

	hydro	steam

Capital cost/KW	Rs. 2100	Rs. 1200
Running cost/KWh	3.2 paisa	5 paisa
Interest and depreciation	7.5%	9 %
Reserve capacity	33%	25 %

a) At what load factor would the overall cost be the same in both cases?
b) What would be the cost of generating 40 x 10^6 units at this load factor?

36. It has been desired to install a diesel power station to supply power in a suburban area having the following particulars,
    a. 1000 houses with average connected load of 1.5 KW in each house. The demand factor and diversity factor being 0.4 and 2.5 respectively.
    b. 10 factories having overall maximum demand of 90KW
    c. 7 tube wells of 7 KW each and operating together in the morning.

    The diversity factor among above three types of consumers is 1.2. What should be the minimum capacity of power station?
37. What do you understand by "economics of power generation "? Discuss the different classifications of costs of electrical energy.
38. Discus the different classifications of costs of electrical energy.
39. Write a short note on cost of electrical energy.
40. What is the importance of interest on capital investment in calculating the cost of electrical energy?
41. Describe the desirable characteristics of a tariff.
42. What do you understand by tariff? Discuss the objectives of tariff.
43. What is tariff? Discuss and compare various tariffs used in practice. Also, explain the reasons why power factor tariff is imposed.
44. What are the factors influencing tariff design and explain the various types of tariffs in detail.
45. Write short notes on,
    i. Two-part tariff and
    ii. Three-part tariff
    iii. Briefly discuss for what type of consumers they are used.
46. Describe some of the important types of tariff commonly used.
47. Give the basis for expressing the service cost of an electric supply as (A+BKW+ C KWh) and explain the factors on which A,B and C depend.
48. Discuss the flat rate and block rate tariffs.
49. Write short notes on power factor tariff method.
50. Classify different types of tariff.
51. Distinguish between two-part and three-part tariff.
52. Explain with examples,
    i. flat rate tariffs
    ii. block rate tariffs

iii. Two-part tariff
iv. Power factor tariff

53. What are the special features of Two-part tariff? For which category of consumers is it used? Discuss the importance of encouraging customers to use electricity during off-peak hours.
54. What type of tariff is employed for domestic consumers? Why this tariff is not employed for bulk consumers.
55. A steam station with an installed capacity of 120 MW has the following data:

Maximum demand = 100 MW; Average Load factor = 0.75
Capital cost = Rs. 800/ kW installed
Interest and depreciation = 12%
Operational cost = Rs. 1 × 106 per annum.
Maintenance cost (2/5 fixed, 3/5 variable) = Rs. 6.5×10^5 p.a.
Cost of fuel = Rs. 35 per metric ton
Calorific value of fuel = 6,500 K. cal / kg
Generator efficiency = 96% Thermal efficiency of turbine = 28%
Boiler efficiency = 75% Overall thermal efficiency = 20%
Determine the total fixed costs, total variable costs and the cost / kW generated.

56. A factory has a maximum load of 240 kW at 0.8 p.f. lagging with an annual consumption of 50,000 units. The tariff in force is Rs 350 per kVA of maximum demand plus 2 paisa per unit. Calculate the flat rate of energy consumption. What will be the annual saving if p.f. is raised to unity?
57. The monthly readings of consumers meter are as follows:

Maximum demand = 50 kW
Energy consumed = 36 000 kWh
Reactive energy = 23 400 kvarh
If the tariff is Rs. 500 per kW of maximum demand plus Rs.2.5 per unit plus Rs. 0.5 per unit for each 1% of power factor below 86%, calculate the monthly bill of the consumer.

58. A power station has an installed capacity of 20,000KW. The cost of the station is Rs.1,200/kW. The fixed costs are 13% of the cost of investment on full load at 100% load factor, the variable costs of the station per year is 1.5 times the fixed costs. Assume that there is no reserve capacity of the plant and that are variable costs and proportional to energy production. Find the cost of generation per KWh at load factor of 100% and 20%. Comment on the results.
59. An industrial consumer has a maximum demand of 200 kW, maintain a load factor of 70%. The tariff in force is Rs 900 per kVA of maximum demand per annum plus Rs 2 paisa per KWh of energy consumed. If the average p.f. is 0.7 lagging. Calculate the total energy consumed per annum and the annual electricity bill. Also workout the overall cost per KWh consumed.

60. A consumer is charged electricity at the following tariff Rs 60/Ka of maximum demand plus 15 paisa per unit consumed. The consumer has an aggregate motor of load 300Kw at a p.f 0.8 lag. Find out the consumer's annual bill for a load factor of 75%.

61. The energy cost of a 100MW steam station working at 40% load factor comes out to be 12 paisa /KWh of energy generated. What will be the cost of energy generated if the load factor is improved to 60%. The fuel cost of power station due to increase the annual generation cost by 5%.

62. Calculate the annual bill of a consumer whose maximum demand is 100 KW. P.f=0.8 lagging and load factor=60%. The tariff used is Rs.475 per KVA of maximum demand plus Rs.2.5 per KWh consumed.

63. A consumer needs 1 million units per year and his annual load factor is 50%.the tariff in force is Rs.1200 per KW plus Rs.2.40 per unit. Estimate the saving in his energy cost, which would result if he improves his load factor to 100 percent.

64. Calculate the number of units to be consumed so that the annual bill on the basis of two-part tariff is same from the following data, maximum demand= 10 KW. Two-part tariff is Rs. 1200 per annum per KW of maximum demand plus Rs. 1.80 per unit consumed. Flat rate tariff Rs. 2.40 per unit.

65. An electric supply system has a maximum load of 50Mw. The annual expenses are:

Generation: Rs. 750×10^3

Fuel: Rs. $2,800\times10^3$

Transmission: Rs. 245×10^3

Distribution: Rs. 2150×10^3

Repairs and Maintenance: Rs. 300×10^3

The number of units generated annually is 400×10^6 kWh. The consumers have an aggregate maximum demand of 75MW. Assuming that the fixed charges for generation, fuel, transmission, distribution, repairs and maintenance are 85%, 15%, 90%, 95% and 40% respectively. Obtain a two tariff of the form [Rs A/kw + P.B/kwh]. Assume the losses in transmission and distribution to be 10%.

66. from the following data estimate the cost per KWh generation:

Plant capacity 50MW

Annual load factor 40%

Capital cost Rs 12×10^6

Annual cost of wages, taxes etcRs 4×10^6

Annual cost of fuel lubrication Rs 20×10^6

Annual Interest and Depreciation is 10%.

67.

An electrical supply company having a maximum load of 50 MW generates $18*10^7$ units per annum and the supply consumers have an aggregate demand of 75MW. The annual expenses including capital charges are:
For fuel= Rs. 90 lakhs;
Fixed charges concerning generation = Rs. 28 lakhs;
Fixed charges concerning transmission and distribution = Rs. 32 lakhs;
Assuming 90% of the fuel cost is essential to running charges and the loss in transmission and distribution as 15% of kWh generated, deduce a two part tariff to find the actual cost of supply to the consumers. [16]

68. A factory has a maximum demand of 500KW, the load factor being 60% during working hours. The following two tariffs are available:
    a. Rs. 8 per KW of maximum demand plus 3 paisa per KWh
    b. A flat rate of Rs. 0.1/KWh

    Determine the working hours per week above which tariff (a) will be cheaper.
69. A supply company offers the following tariffs,
    a. Standing charges of Rs. 75 per annum plus 3 paisa/KWh
    b. First 300KWh at 20 paisa/KWh, and additional energy at 5 paisa/KWh.

If the annual consumption is 1800KWh, which tariff is more economical and by how much?

70. What will be the annual bill of a consumer whose load factor is 70% and has maximum load of 500KW at 0.8 p.f lagging? The following data is available regarding the two part tariff of the supply systems to which he is connected:
    a. The fixed charges are Rs. 80 per KVA of the maximum demand of the consumer.
    b. Running charges are 5 paisa per KWh consumed.
71. Calculate the number of units to be consumed which will justify the two part tariff over flat rate tariff from the following data:
    Maximum demand 5KW,
    Two part tariff Rs. 100 per annum per KW of maximum demand plus Rs. 0.01 per unit consumed.
    Flat rate tariff Rs. 0.15 per unit
72. A bulk supply is taken at Rs. 100 per KW and 5 paisa 5 per unit. Calculate the KWh rate for load factors of 100% and 50%.
73. A hydroelectric plant costs Rs 3000 per KW, of installed capacity. The total annual charge consists of 5% as interest; depreciation at 2%, operation and maintenance at 2% and insurance, rent etc., 1.5%. Determine a suitable two part tariff if losses in transmission and distribution are 12.5% and diversity of load is 1.25. assume that maximum demand on station is 80% of capacity and annual load factor is 40%.What is the overall cost of generation per KWh?
74. A generating station has the following data: Installation capacity =300MW; capacity factor= 50%; Annual load factor=60%; annual cost of fuel, oil etc., = 9 x 10^7, capital cost = Rs. 10^9, annual interest and depriciation10%. Calculate
    i. The minimum reserve capacity of the station and.

ii. The cost per KWh generated.

75. An industrial consumer having a maximum demand of 100 kW, maintain a load factor of 60%. The tariff rates are Rs 900 per KVA of maximum demand plus 1.8 per KWh of energy consumed. If the average p.f. is 0.8 lagging, calculate the total energy consumed per annum and the annual electricity bill. Also workout the overall cost per KWh consumed.
76. . A supply company offers the following alternative tariffs for supply to a factory :
    (i) High voltage supply at Rs 70 per kva per annum plus 3 paisa per kWh.
    (ii) Low voltage supply at Rs 65 per kW per annum plus 4 paisa per kWh

    The cost of the transformers and switch gears for high voltage supply is Rs 50 per kva and full transformer losses are 2%. The annual fixed charges on the capital cost of H.V plant are 15%. If the factory runs for 6 hours a day, find the number of days for which the factory should be run, so that the H.V supply is cheaper.
77. A power station has an installed capacity of 50MW and it costs Rs. 1,000/kW. The annual fixed cost is 15% of the capital cost and at 100% load factor, the variable cost per year is 1.3 times the fixed cost. Assuming that there is no reserve capacity, the cost of generation per KWh at load factor of 25%, 50%, 75%, 90% and 100%. Comment on the results.
78. Obtain a two part tariff for the consumers of a supply undertaking which generates 390×10^6 KWh per annum and has a maximum demand of 130MW connected to it. The cost is distributed as follows: Fuel Rs. 5×10^6, generation Rs. 2.4×10^6, transmission Rs. 5×10^6 and distribution Rs. 3.4×10^6, of these items 90%, 10%, 5% and 7% respectively are allocated to running costs, the remainder being a fixed charge. The total loss between the station and the consumers is 10% of the generated energy. If the load factor of the station is raised to 40% for the same maximum demand, find the percentage saving in the overall cost per KWh.
79. Two systems of tariff are available for a factor working 8 hours a day for 360 days a year

    i. H.V. supply at 5 paisa per unit plus Rs. 4.5 per month per KVA of maximum demand.

    ii. LV supply at Rs. 5 per month per KVA of maximum demand plus 5.5 paisa per unit.

    The factor has an average load of 200 KW at 0.8 pf and a maximum demand of 250 kW at p.f of 0.8.

    The H.V. equipment costs Rs. 50 per KVA and losses can be taken as 4%, the interest and depreciation charges are 2%.Calculate the differences in cost between the two systems.