ELECTRICAL ENGINEERING

6TH SEMESTER

THEORY-5

1. ELECTIVE

POWER SYSTEM OPERATION (c)

PREPARED BY

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1. SOURCES OF ELECTRICAL ENGERY

1.1 Importance of electrical energy

- Energy may be needed as heat, light, as motive power etc. The present day advancement in science and technology has made it possible to convert electrical energy into any desired form
- Electrical energy is superior to all other forms of energy due to the following reasons:-

1 Convenient form:-

Electrical energy is a very convenient form of energy. It can be easily converted in to other forms of energy. For e.g., if we want to convert electrical energy into heat, the only thing to be done is to pass electrical current through a wire of high resistance (e.g. a heater).

2 Easy control:-

The electrically operated machines have simple and convenient starting, control and operation. For instance, an electric motor can be started or stopped by turning ON or OFF a switch.

3 Greater flexibility:-

One important reason for preferring electrical energy is the flexibility that it offers. It can be easily transported from one place to another with the help of conductors.

4 Cheapness:-

Electrical energy is much cheaper than other forms of energy. Thus it is overall economical to use this form of energy for domestic, commercial and industrial purposes.

5 High transmission efficiency:-

The consumers of electrical energy are generally situated quite away from centers of its productions. The electrical energy can be transmitted conveniently and efficiently from centers of generation to the consumers with the help of overhead conductors known as transmission lines.

1.2 Sources of electrical energy

- Since electrical energy is produced from energy available in various forms in nature, it is desirable to look into the various sources of energy.
- These sources of energy are (i) the Sun (ii) the Wind (iii) Water (iv) Fuels (v) Nuclear energy.

1. The Sun:-

The sun is the prime source of energy. The heat energy radiated by the sun focused over a small area by means of reflectors. This heat can be used to raise steam and electrical energy can be produced with the help of turbine alternator combination. However this method has limited applications because

(a) It requires a large area for the generation of even a small amount of electric power.
(b) It cannot be used in cloudy days or at night.
(c) It is an uneconomical method.

2. The wind:-

This method can be used where wind flows for a considerable length of times. The wind energy is used to run the wind mill which drives a small generator. In order to obtain the electrical energy from wind mill continuously, the generator is arranged to charge the batteries. The batteries supply the energy when wind stops. This method has the advantages that maintenance and generation costs are negligible. However the drawbacks of this method are (a) variable output (b) unreliable because of uncertainty about wind pressure (c) power generation is quite small.

3. Water:-

When water is stored at a suitable place, it possesses potential energy because of the heat created. This water energy can be converted into mechanical energy with the help of water turbines. The water turbine drives the alternator which converts mechanical energy into electrical energy. This method of generation of electrical energy has become very popular because it has low production and maintenance costs.

4. Fuel:-

The main sources of energy are solid fuel as coal, liquid fuel as oil and gas fuel as natural gas. The heat energy of these fuels is converted into mechanical energy by suitable drive movers such as steam engines, steam turbines, internal combustion engines etc. the prime mover drives the alternator which converts mechanical energy into electrical energy. Although fuels continue to enjoy the place of chief source for the generation of electrical energy, yet their reserves diminishing day by day.

5. **Nuclear Energy:-**

Towards the end of Second World War, it was discovered that large amount of heat energy is liberated by the fission of uranium and other fissionable materials. It is estimated that heat produced by 1kg of nuclear fuel is equal to that produced by 4500 tons of coal. The heat produced due to nuclear fission can be utilized to raise steam with suitable arrangements. The steam can run steam turbine which in turn can drive the alternator to produce electrical energy. However there are some difficulties in the use of nuclear energy. These are (a) high cost of nuclear plant (b) problem of disposal of radioactive waste.

1.3 Conventional Sources of Energy

I. The sources of energy which have been in use for a long time, e.g., coal, petroleum, natural gas and water power.

II. They are exhaust able except water.

III. They cause pollution when used, as they emit smoke and ash.

IV. They are very expensive to be maintained, stored and transmitted as they are carried over long distance through transmission grid and lines.

1.4 Non-Conventional Sources of Energy

I. The resources which are yet in the process of development over the past few years. It includes solar, wind, tidal, biogas, and biomass, geothermal.

II. They are inexhaustible.

III. They are generally pollution free.

IV. Less expensive due to local use and easy to maintain.

1.5 Hydro-electric power plant

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

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.

Advantages:-

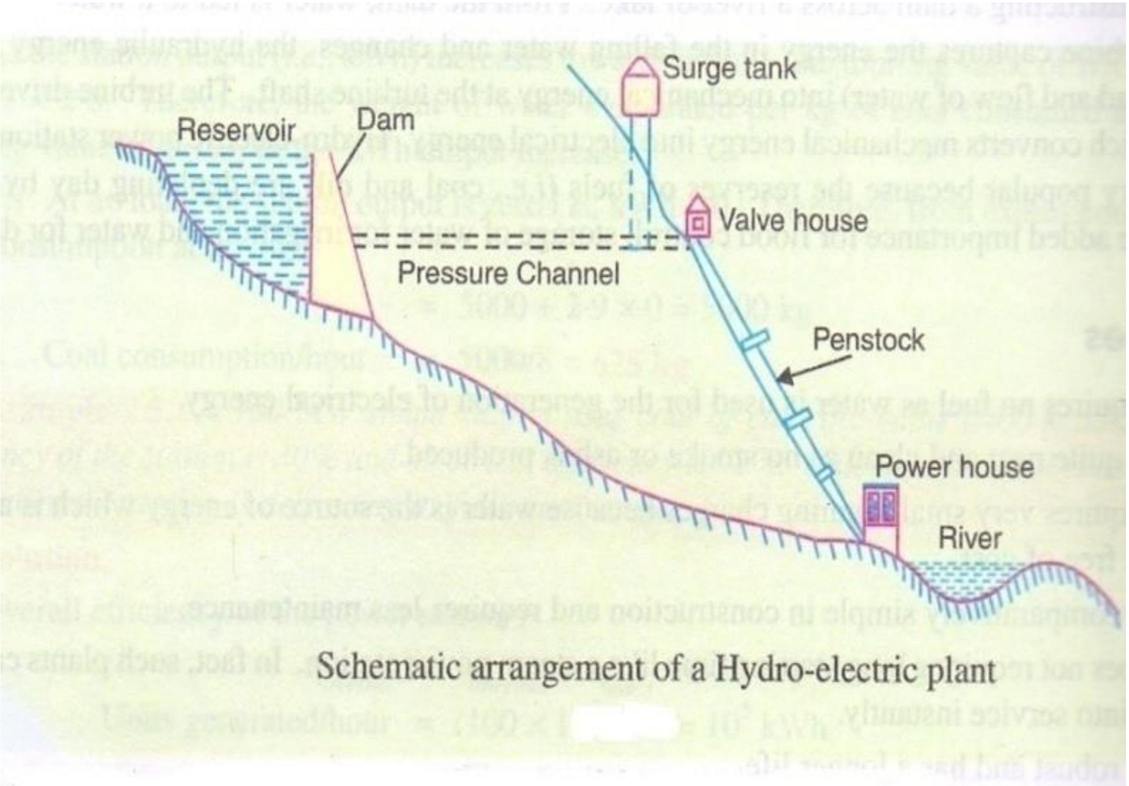
- It requires no fuel as water is used for the generation of electrical energy.
- It is quite neat and clean as no smoke or ash is produced.
- It is comparatively simple in construction and requires less maintenance.

Disadvantages:-

- It involves high capital cost due to construction of dam.
- There is a uncertainty about the availability of huge amount of water due to dependence on weather conditions.
- Skilled and experience hands are required to build the plant.

Schematic arrangement of hydro-electric power plant:-

The dam is constructed across the 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 automating isolating valves. The former controls the water flow to the power house and the latter cuts of supply of water when penstock bursts. From the valve house, water is taken to water turbine through huge steel pipe known as penstock. The water turbine converts hydraulic energy into mechanical energy.



Schematic arrangement of a Hydro-electric plant

FIG.1.1

Choice of site for hydro-electric power plant:-

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

(i) Availability of water: - The plant should be built at a place (e.g. river, canal) where adequate water is available at a good head.

(ii) Storage of water: - The site selected for a hydro-electric plant should provide adequate facilities for erecting a dam and storage water.

(iii) Cost and type of land: - The land for the construction of the plant should be available at reasonable price.

(iv) Transportation facilities:-The site selected for hydro-electric plant should be accessible by rail and road so that necessary equipment and machinery could be easily transported.

Constituents of hydro-electric plant

The constituent of hydro-electric plant are (1) hydraulic structures (2) water turbine and (3) electrical equipment

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 create water head. Dams are built of concrete or stone masonry, earth or rock fill.

   (ii) **Spillways: -** There are times when the river flow exceeds the storage capacity of reservoir. Such a situation arises during heavy rainfall in catchment area. In order to discharge the surplus water from the storage reservoir into the river on the down-stream side of the dam, spillways are used.

   (iii) **Head works: -** The head works consists of the diversion structures at the head of 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.

   (iv) **Surge tank: -** A surge tank is a small reservoir of tank (open at the top) in which water level rises or falls to reduce the pressure swings in the conduits. It is located near the beginning of the conduits. Surge tank overcomes the abnormal pressure in the conduit when load on the turbine falls and act as a reservoir during increase of load on turbine.

   (v) **Penstocks: -** Penstocks are open or closed conduits which carry water to the turbines. They are generally made of reinforced concrete or steel.

2. **Water turbines: -** Water turbines are used to convert the energy falling water into mechanical energy. These are two types

(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 e.g. of this type of turbine is pelton wheel. It consists of a wheel fitted with elliptical buckets along its periphery. The force of the water jet striking the buckets on the wheel drives the turbines.

(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

1.6 Thermal power plant

A generating station which converts heat energy of coal combustion into electrical energy is known as a steam power plant. Steam produced in the boiler by utilizing the heat of coal combustion. The steam is then expanded in the prime mover (i.e. steam turbine) and is condensed in a condenser to be fed into boiler again. The steam turbine drives the alternator which converts mechanical energy of the turbine into electrical energy.

Advantages:-

- The fuel(i.e. coal)used is quite cheap
- Less initial cost as compared to other generating station.

Disadvantages:-

- It pollutes the atmosphere due to production of large amount of smoke and fumes.
- It is costlier in running cost as compared to hydroelectric plant.

Schematic arrangement of steam power plant:-

The whole arrangement can be divided into following stages for sake of simplicity:

1. Coal and ash handling arrangement 2. Steam generating plant 3. Steam turbine 4. Alternator 5. Feed water 6. Cooling arrangement.

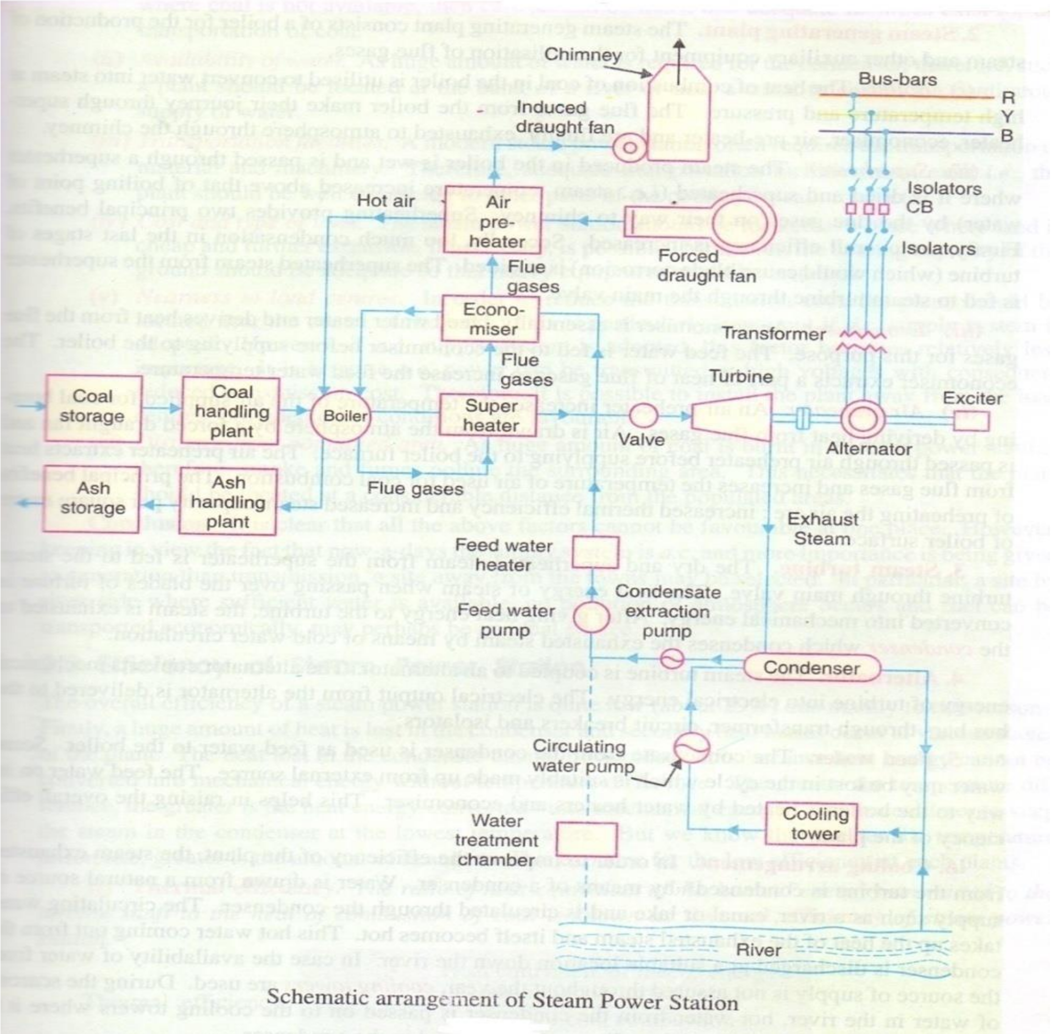


FIG.1.2

1. **Coal and ash handling plant: -** The coal is transported to the power station and is stored in the coal storage plant. From the coal storage plant, coal is delivered to the coal handling plant where it is pulverized (i.e., crushed into small pieces). The pulverised coal is fed to the boiler by belt conveyors.

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

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

(ii) ***Superheater: -*** The steam produced in the boiler is wet and is passed through a superheater where it is dried and superheated by the flue gases on their way to chimney. The superheated steam from the superheater is fed to steam turbine through main valve.

(iii) ***Economiser: -*** An economiser is essentially a feed water heater and derives heat from the flue gases for this purpose. The feed water is fed to the economiser before supplying to the boiler. The economiser 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 the flue gases. Air is drawn from the atmosphere by a forced draught fan and is passed through the air preheater before supplying to the boiler furnace.

3. **Steam turbine: -** The dry and superheated steam from the superheater 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.

4. **Alternator: -** The steam turbine is coupled to an alternator. The alternator converts mechanical energy of the turbine into electrical energy. The electrical output from the alternator is delivered to bus bars through transformer, circuit breaker 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 way to boiler is heated by water heaters and economiser.

6. **Cooling arrangement: -** In case the availability of water from the source of supply is not assured throughout the year, cooling tower are used. During the scarcity of water in the river, hot water from the condenser is passed on the cooling towers where it is cooled.

Choice of site for steam power plant:-

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 the transportation cost of fuel is minimum.

(ii) **Availability of water: -** A 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 plant often requires the transportation of material and machinery. Therefore adequate transportation facilities must exist.

1.7 Nuclear power plant

A generating power station in which nuclear energy is converted into electrical energy is known as nuclear power plant. In nuclear power plant heavy element such as Uranium (U^{235}) or Thorium (Th^{232}) are subjected to nuclear fission in a special apparatus known as a reactor. The heat energy thus released is utilised in raising steam at high temperature and pressure. The steam runs the steam turbine which converts mechanical energy into electrical energy. The most important feature of a nuclear power plant is that huge amount of electrical energy can be produced from a relatively small amount of nuclear fuel as compared to other conventional types of power station.

Advantages:-

- The amount of fuel required is quite small. Therefore, there is a considerable saving in the cost of fuel transportation.
- A nuclear power plant requires less space as compared to any other type of same size.
- This type of plant is very economical for producing bulk electrical power.

Disadvantages:-

- The fuel used is expensive and difficult to recover.
- The capital cost of a nuclear power plant is very high as compared to other types of plant.
- The fission by-product are generally radioactive and may cause a dangerous amount of radioactive pollution.

Schematic arrangement of nuclear power plant:-

The whole schematic arrangement of nuclear power plant can be divided into the following main stages:

(i) Nuclear reactor (ii) Heat exchanger (iii) Steam turbine (iv) Alternator.

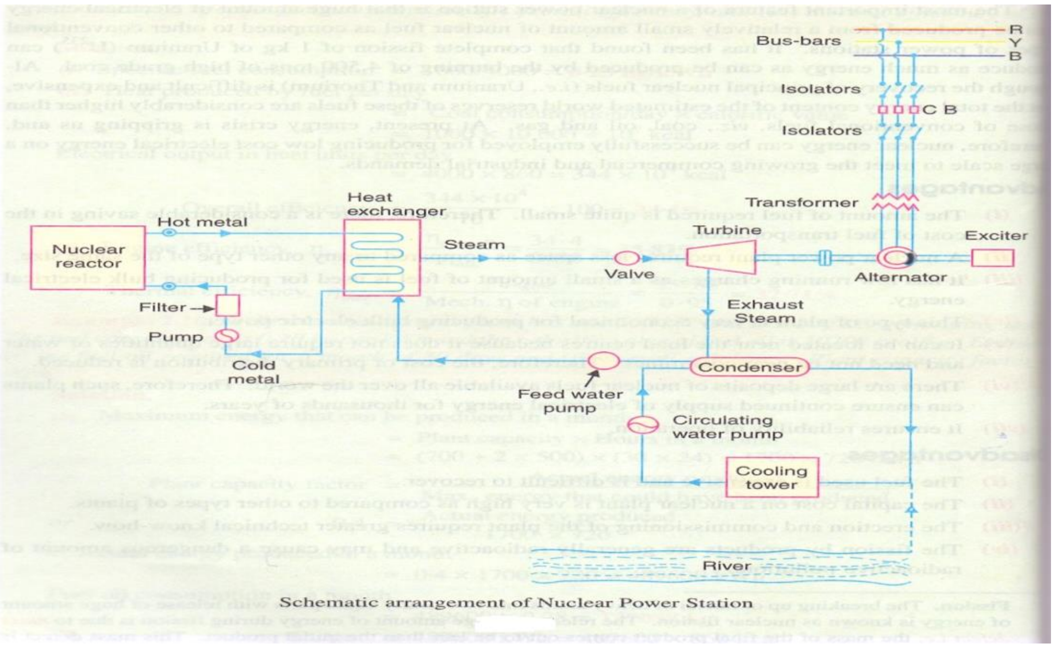


FIG.1.3

(i) Nuclear reactor: - It is an apparatus in which nuclear fuel (U^{235}) is subjected to nuclear fission. It controls the chain of reaction that starts once the fission is done. If chain reaction is not controlled, the result will be an explosion due to 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. 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 the supply of neutron 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, where as pushing them in it is reduced. In actual practice, the lowering or raising of control rods is accomplished automatically according to the requirements of load. The heat produced in a reactor is removed by coolant, generally a sodium metal. The coolant carries the heat to the heat exchanger.

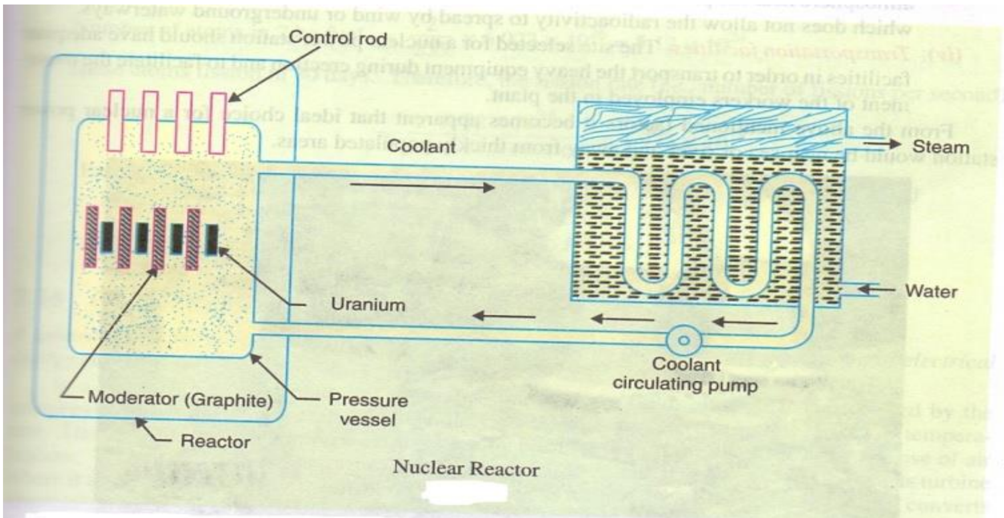


FIG.1.4

(ii) **Heat exchanger: -** The coolant give 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 a heat exchanger is led to 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-bar through transformer, circuit breakers and isolators.

Selection of site for nuclear power plant:-

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

(ii) Disposal of waste: - The waste produced by fission of nuclear power plant is generally radioactive which must be disposed of properly to avoid health hazard. The waste should either be buried in a deep trench or disposed off in a sea quite away from the sea shore.

(iii) Distance from populated area: - The site selected for nuclear power plant should be quite away from populated areas as there is a danger of presence of radioactive in the atmosphere near the plant.

2. RENEWABLE ENERGY

2.1 Wind power generation:-

The electrical energy can be generated by wind energy. The wind energy, which an indirect source of energy can be used to run a wind mill which in turn drives a generator to produce electricity.

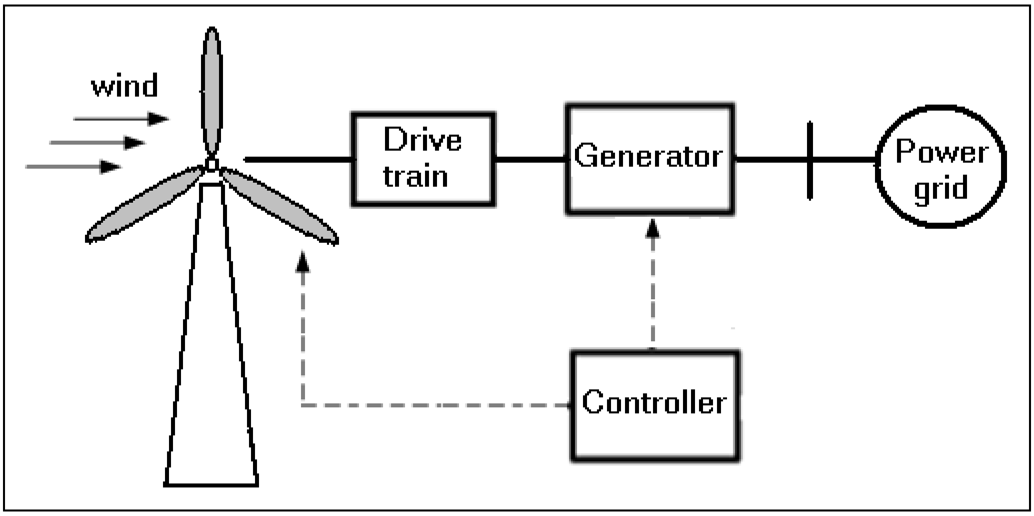


FIG.1.5

A typical electrical circuit for a wind turbine installation includes generator, storage batteries, and a charge controller. The ac output normally goes to a local transformer station (that collects all the turbines' outputs); it is then transformed to a higher voltage and transmitted via a cable or overhead line to an in feed point (another transformer station), where the connection to the normal power grid is made. This voltage must be synchronized with the utility grid.

WIND TURBINES

Wind flow, or motion energy, activates wind turbines that generate electricity. In operation, wind turbines blades spin a shaft that connects to a generator and produces electricity for the utility grid. Wind turbines come in a variety of sizes and power ratings. A large turbine can have rotors longer than a football field and can produce enough electricity to power 1,400 homes. Utility-scale offshore turbines range in size from 450 kW to 3.6 MW.A wind turbine blade works like an airplane's wing. Blowing air passes around both sides of the blade. The shape of the blade causes the air pressure to be uneven - higher on one side of the blade and lower on the other. The uneven pressure causes the blades to spin around the centre of the turbine.

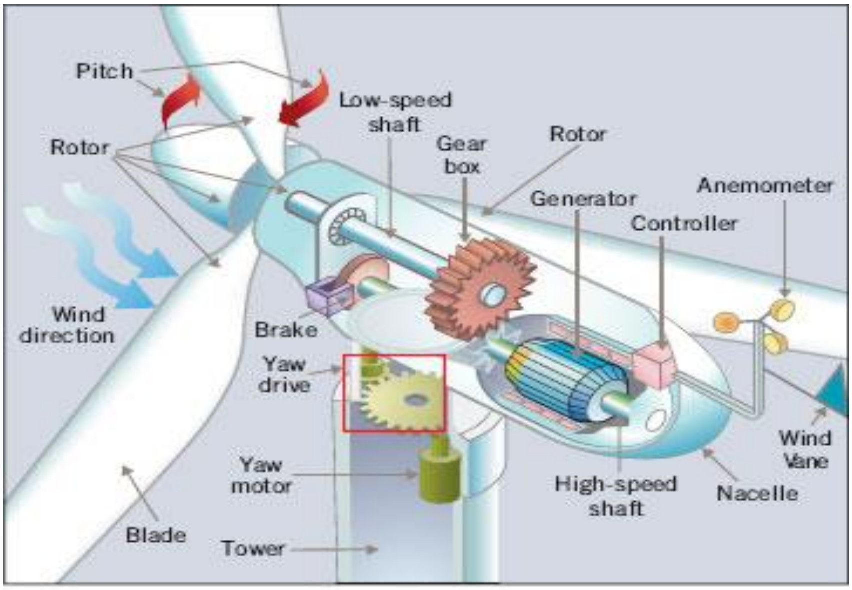


Fig. 3. Internal construction of a typical wind turbine assembly showing all the components.

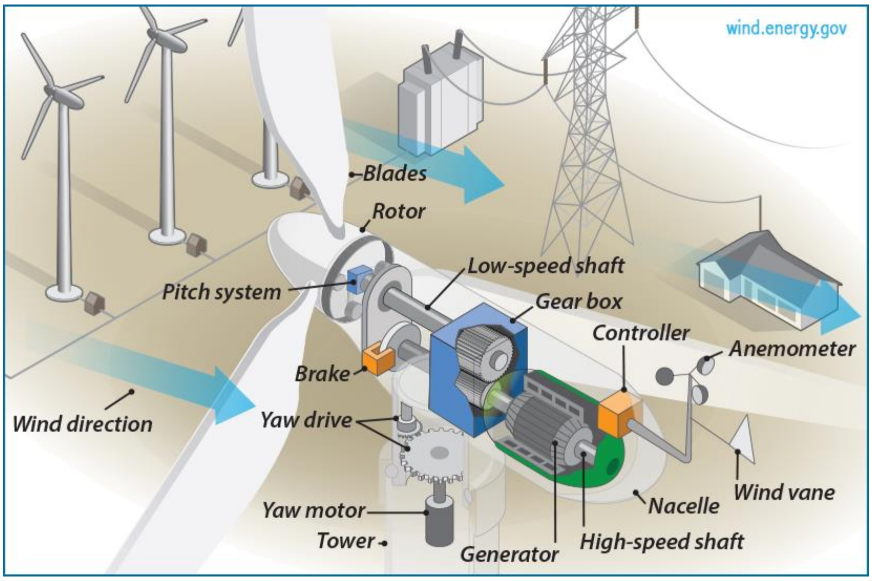


FIG.1.6

Anemometer that measures wind speed and, along with a weather vane and other devices for measuring meteorological conditions, and feeds that information into the turbine's controller. The controller then corrects the turbine's direction, pitch and yaw to best harvest the available wind energy.

Blades are usually made of fibreglass or balsa wood. Most turbines have either two or three blades. The spinning rotor is connected to a shaft, which turns with the breeze. That's not nearly fast enough to generate electricity with a regular generator (50-60 Hz), so in most wind turbines a gearbox secures the correct speed (rpm) for the generator to produce electricity.

Brake is a disc type that can be applied aerodynamically, electrically, or hydraulically to stop the rotor in emergencies. A brake shuts down the turbine if the winds become strong enough to impact the turbine's internal components.

Controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 55 mph. Turbines do not operate at wind speeds above about 55 mph because that might damage them.

Gear box connects the low-speed shaft to the high-speed shaft and increases the rotational speeds from about 15 to 30 rotations per minute (rpm) to about 1000 to 1800 rpm, the rotational speed required by most generators (alternators) to produce electricity. This is an expensive and heavy part of wind turbines, so some are being replaced with a direct-drive generator tailored specifically to producing electricity from wind. Such generators rely on the permanent magnetic fields created by rare earth magnets, like neodymium.

Generator is usually an off-the-shelf induction generator that produces 60-cycle AC electricity.

High-speed shaft: Drives the generator.

Low-speed shaft: The rotor turns the low-speed shaft at about 15 to 30 rotations per minute.

Nacelle sits atop the tower and contains the gear box, low- and high-speed shafts, generator, controller, and brake. It is essentially the cover for the machinery that translates wind power into electrical power.

Pitch turns blades out of the wind to control the rotor speed and keep the rotor from turning in winds that are too high or too low to produce electricity.

Rotor includes the blades and the hub together. The blades spin the rotor, which is attached to a shaft that transfers the torque it creates into the gearbox. The rotor provides pitch regulation for power output optimization and control. Its speed is variable to maximize the aerodynamic efficiency.

Tower is usually made from tubular steel, concrete, or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity. Wind turbines are mounted on tall towers because the higher up you go, the windier it is, which means more electricity.

Wind direction shown is an "upwind" turbine, because it operates facing into the wind. Other turbines are designed to run "downwind," facing away from the wind.

Wind vane measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

Yaw drive in upwind turbines face into the wind. The yaw drive keeps the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive; the wind blows the rotor downwind.

TURBINE TYPES

Modern wind turbines fall into two basic groups: the horizontal-axis and vertical-axis design, Horizontal-axis wind turbines typically either have two or three blades. These three-bladed wind turbines are operated “upwind,” with the blades facing into the wind. Horizontal-axis wind turbines (HAWTs) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Larger turbines capture wind energy more efficiently than smaller ones.

Since a tower produces turbulence behind it, the turbine is usually positioned upwind of its supporting tower. Turbine blades are made stiff to prevent them from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted forward into the wind a small amount. Most HAWTs are of upwind design. Vertical-axis wind turbines (VAWTs) have the main rotor shaft arranged vertically. Key advantages of this arrangement are that the turbine does not need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable, for example when integrated into buildings. The key disadvantages include the low rotational speed with the consequential higher torque and hence higher cost of the drive train.

2.2 Tidal generation:-

The periodic rise and fall of the water level of sea which are carried by the action of the sun and moon on water of the earth is called the ‘tide’. Tidal energy can furnish a significant portion of all such energies which are renewable in nature. The large scale up and down movement of sea water represents an unlimited source of energy. If some part of this vast energy can be converted into electrical energy, it would be an important source of hydro-power. The main feature of the tidal cycle is the difference in water surface elevations at the high tide and at the low tide. If this differential head could be utilized in operating a hydraulic turbine, the tidal energy could be converted into electrical energy by means of an attached generator.

Components of tidal power plants:-

The following are the components of a tidal power plant:

1. The dam or dyke (low wall) to form the pool or basin.
2. Sluice ways from the basin to the sea and vice versa.
3. The power house.

Dam or dyke:-

The function of dam or dyke is to form a barrier between the sea and the basin or between one basin and the other in case of multiple basins.

Sluice ways:-

These are used to fill the basin during the high tide or empty the basin during the low tide, as per operational requirement. These devices are controlled through gates.

Power house:-

A power house houses turbines, electric generators and other auxiliary equipments. As far as possible, the power house and sluice ways should be in alignment with the dam or dyke.

Classification and operation of tidal power plants:-

Tidal power plants are classified as follows:

1. Single basin arrangement:-
   - (i) Single ebb-cycle system
   - (ii) Single tide-cycle system
   - (iii) Double cycle system
2. Double basin arrangement:-

In a single basin arrangement, power can be generated only intermittently. In this arrangement, only one basin interacts with the sea. The two are separated by a dam and flow between them is through sluice ways located conveniently along the dam. The rise and fall of tidal water levels provide the potential head.

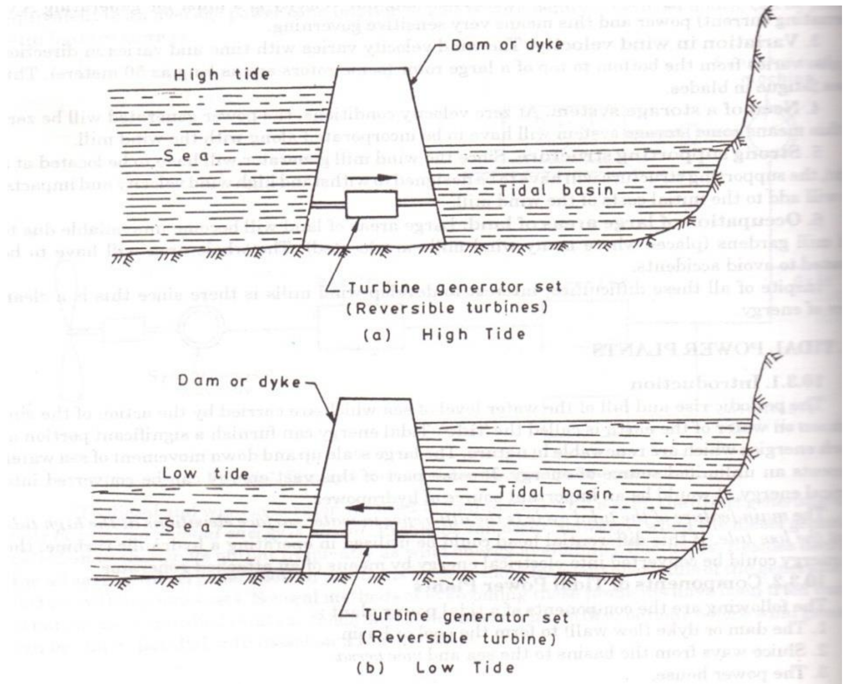


Fig. 10.8. General arrangement of tidal power plant.

FIG.1.7

Fig. shows a general arrangement of single basin tidal power plant (double-cycle system).Such plants are generally use reversible water turbines so that power is generated on low tide as well high tide.

The operation of the plant is as follows:

When the incoming tide sea level and tidal-basin level are equal, the turbine conduit is closed .When the sea level rises, and about half way to high tide the turbine valves are opened and the sea water flows into the basin through the turbine runner generating power. This also raises the level of water in the basin. The turbine continues to generate power until the tide passes through its high point and begins to drop. The water head then quickly diminishes till nit is not enough to supply the no load losses. By pass valve then quickly opens to let water into the basin to gain maximum water level. When sea and basin water level are again equal, the valves are closed as well as the turbine conduit. The basin level then stays constant while the tide continues to go out. After sufficient head has developed, the turbine valves are again opened and water now flows from basin to the sea, thereby generating power. The plant continues to generate power till the tide reaches its lowest level.

A single basin plant cannot generate power continuously, though it might do so by using a pumped storage plant if the load it supplies fluctuates considerably. A double basin scheme can provide power continuously or on demand, which is great advantage. The drawback is that the civil works becomes more extensive .In the simplest double-basin scheme; there must be a dam between each basin and the sea and also a dam between the basins, containing the power house. One basin is maintained always at a lower level than the other. The lower reservoir empties at low tide, the upper reservoir is replenished at high tide. If the generating capacity is to be large, the reservoirs must be large which means that long dams would be required.

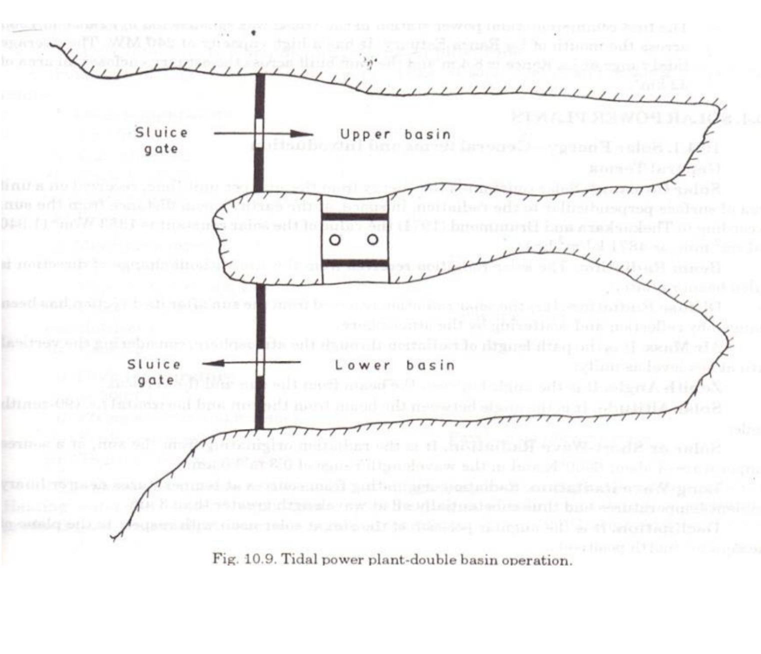


Fig. 10.9. Tidal power plant-double basin operation.

FIG.1.8

Advantages and limitations of tidal power generation:

Advantages:

1. Tidal power is completely independent of the precipitation (rain) and its uncertainty, besides being inexhaustible.
2. Large area of valuable land is not required.
3. When a tidal power plant works in combination with thermal or hydro-electric system peak power demand can be effectively met with.
4. Tidal power generation is free from pollution.

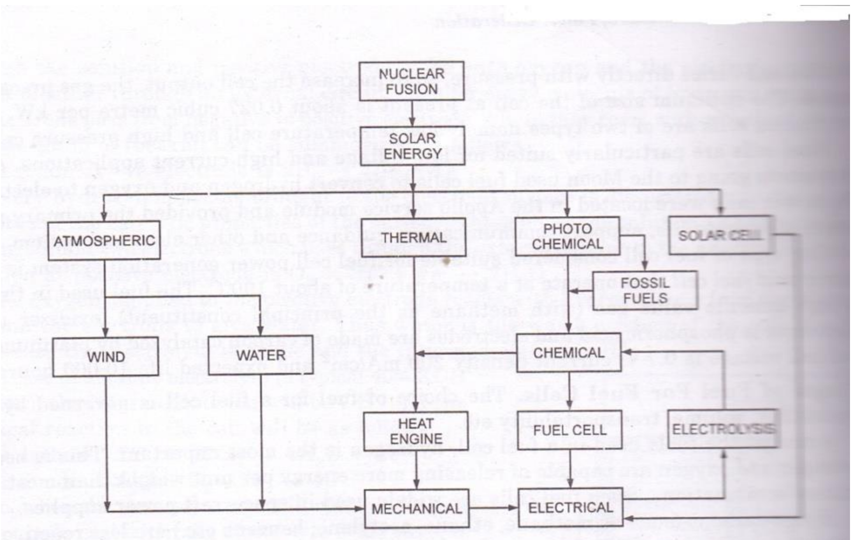
Limitations:

1. Due to variation in tidal range the output is not uniform.
2. Since the turbines have to work on a wide range of head variation (due to variable tidal range) the plant efficiency is affected.
3. There is a fear of machinery being corroded due to corrosive sea water.
4. It is difficult to carry out construction in the sea.
5. As compared to the other sources of energy, the tidal power plant is costly.

2.3 Solar Power Generation:-

Introduction:-

Sun is the greatest and prime source of energy. Solar energy appears to be the most promising among the non-conventional sources of energy. The sun's great energy released is the result of an elaborate chemical process in the sun's core-a process of thermo-nuclear fusion like the reaction in hydrogen bomb. Sun radiates energy of about 3.5×10^{23} kW into space and only 2×10^{14}kW reaches the earth. Converting even a part of the solar energy at a very very low efficiency can produce in far more energy than could conceivably be harnessed or utilized for power generation.



Methods of Converting Solar Energy into Electrical Energy

FIG.1.9

Since solar energy is widely dispersed, to use it gainfully it should be made available in concentrated form. For this two types of collectors are used:

1. Flat plate collectors
2. Focusing collectors

Flat plate collectors:- It is a low temperature collector with no concentration. The important parts of a typical flat plate collector are shown in figure. The absorber plate with several parallel tubes is fabricated from copper tube and sheet by soft soldering. The plate is blackened so as to absorb maximum amount of sun light. The plate is enclosed in a box to insulate it on the sides and bottom so as to prevent losses and there by attain high temperatures. Also one or more transparent glass or plastic sheets are placed on top of the blackened sheet so as to avoid heat losses by re-radiation. By this method, the absorbing capacity of the black paint is also preserved. The complete structure is placed at proper inclination to the sun to absorb solar radiation. The heat absorbed by plate is removed by circulating water or air in contact with it or through the tubes. The flat plate collector gives a temperature of only about 60^0C above ambient i.e. less than 100^0C with efficiency of 30 to 50 per cent.

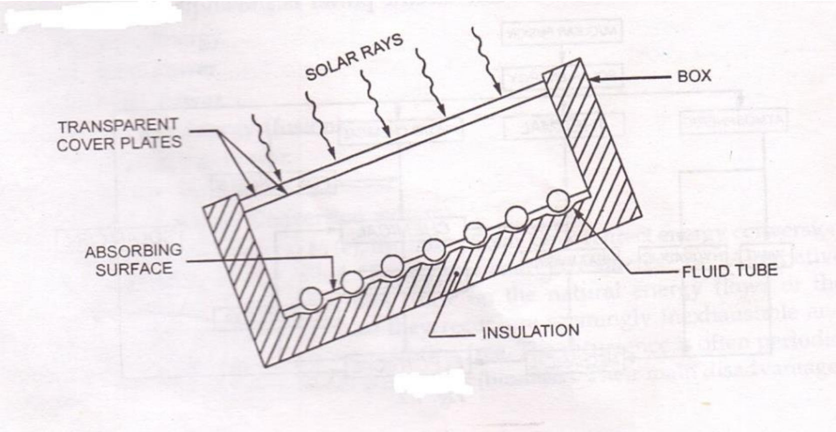


FIG.1.10

Focusing collectors:-

In focusing collectors, a parabolic or a Fresnel mirror is used. Sun rays are focused on the focal point of the mirror by reflection from its surface. A tube may be placed along the focal line of the mirror and a fluid circulated through it to absorb the heat, as shown in figure. With these collectors, temperatures of 200^0C to 300^0C or above may be obtained. Some mechanism should be provided to track the seasonally.

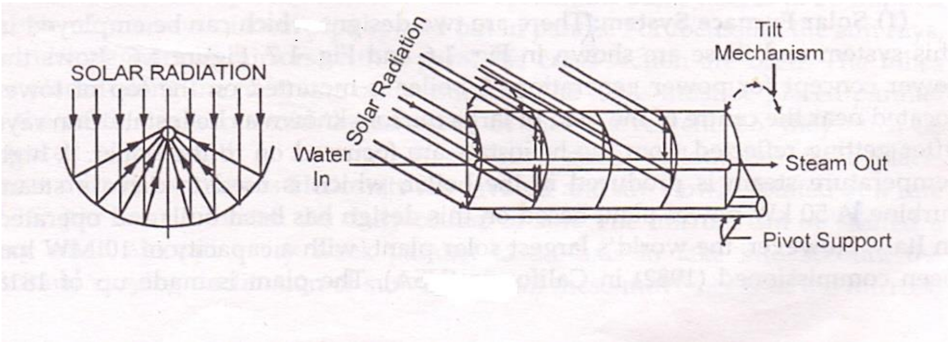


FIG.1.11

The focusing collector can have two arrangements:

- **A cylindrical parabolic concentrator:**
  This is a medium range temperature concentrator as shown in figure. It can give temperatures in the range of 100^0C to 200^0C. this type is usually used for vapour engines and turbines, process heating, refrigeration and cooking etc.
- **Parabolloids, mirror arrays:**
  This is a high temperature arrangement (above 200^0C). It can be used for: steam engines and turbines, Stirling engine and thermo electric generator.

Extensive research is being done in the various methods of converting solar energy into electric power. There are two methods which are being considered.

1. Conventional boiler method
2. Direct conversion method

1. Conventional boiler method:-

For this method, there are conflicting ideas about the best approach to the problem. Some engineers believe that small generating units located where the electricity is to be consumed are the ideal way. This group favours the use of power turbines that would operate at temperatures considerably lower than those common in nuclear or fossil fuel power plant, despite the low thermal efficiencies, that these units would have.

Small generating units: - such units are best suited for our country. For Indian condition, flat plate collectors with mirror booster and non-selective absorber which yield low pressure steam at 150^0C are best.

Large centralized units:-

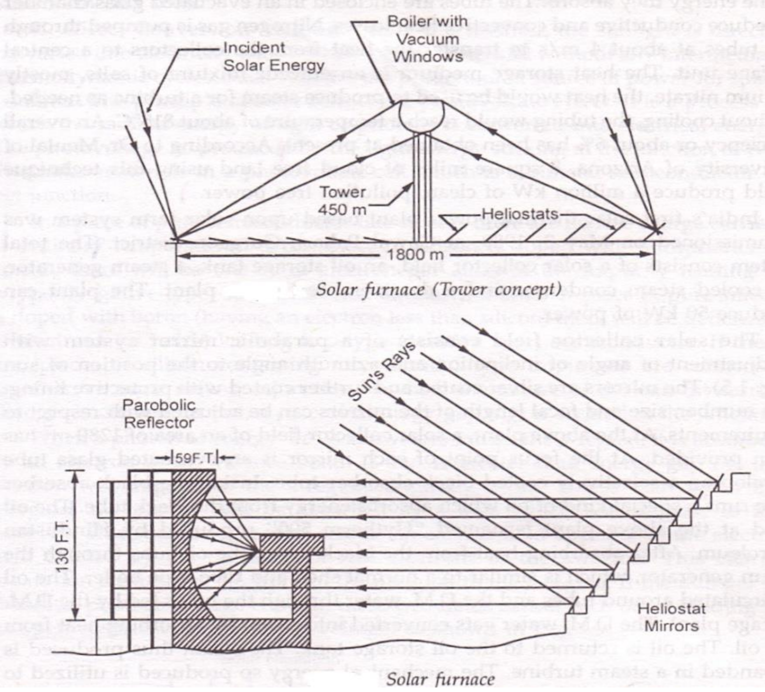
Under the large centralized units for power generation, there are two approaches:

1. The 'solar furnace' in which the sun rays reflected from many different heliostats are concentrated on a single heat exchanger ,and
2. The 'solar farm' in which a large number of linear reflectors focus sun rays on long pipes which collect heat.

(a) Solar furnace system:-

There are two designs which can be employed in this system and are shown in figures shows the tower concept for power generation .A boiler is mounted on the top of tower located near the centre of the field of large mirrors known as heliostats .Sun rays after getting reflected from the heliostats are focused on to the boiler. A high temperature steam is produced in the boiler, which is used to drive a steam turbine.

Another design of 'solar furnace' is shown in figure .It uses arrays of heliostats mirrors to focus sun rays into a cavity type boiler near the ground to produce steam for steam turbine power plant. Sun rays striking the heliostat mirrors are reflected on the parabolic reflector. Form the parabolic reflector, the sun rays get reflected and concentrate in the cavity of a heat exchanger.



Solar furnace (Tower concept)

Solar furnace

FIG.1.12

(b) Solar farm system:-

In solar farm system the sun's heat is to be trapped in extensive arrays of steel pipe spread out in panels. For focusing the sun rays, cylindrical concave mirror with a parabolic cross-section are used. The tubes are placed along the focal line of the mirrors. The tubes must be placed parallel to the earth's axis to avoid the necessity of their movement. So they must be oriented north-south at an angle of elevation equal to latitude of the place.

According to Dr. Menial of University of Arizona, 8 square miles of cloud free land using this technique could produce a million kW of clean, pollution free power. The total system consist of a solar collector field, an oil storage tank, a steam generator, air cooled steam condenser and a demineralised water plant.

The solar collector field consist of a parabolic mirror system with readjustment of angle of inclination and azimuth angle to the position of sun as shown in above fig.3. The mirrors are silver coated and further coated with protective lining. The number, size and focal length of the mirrors can be adjusted with respect to requirements. At the above plant, a solar collector field of an area of 1280 m^2 has been provided. At the focus point of each mirror is an evacuated glass tube enveloping a selectively coated black absorber tube. Inside the black absorber tube runs a special kind of oil which absorbs energy from the black tube. The oil used at the above plant is named 'hytherm 500' produced by Hindustan petroleum. After absorbing heat from the black tubes, the oil runs through the steam generator, which is similar to a normal shell and tube type boiler. The circulated around tubes and D.M. water through the tubes fed by the D.M. storage plant. The D.M. water gets converted into steam by absorbing heat from the oil. The oil is returned to the oil storage tank. The steam thus produced is expanded in a steam turbine. The mechanical energy so produced is utilised to run a generator which is coupled to the turbine shaft. The electricity produced is passed to transformer which increases its voltage to further transit it to the power lines into the grid system. The steam which has exhausted its energy in rotating the turbine is condensed back into water in an air cooled steam condenser requiring no cooling water. The condensed steam is reused in the steam generator. The simple layout of the plant is shown in the figure below.

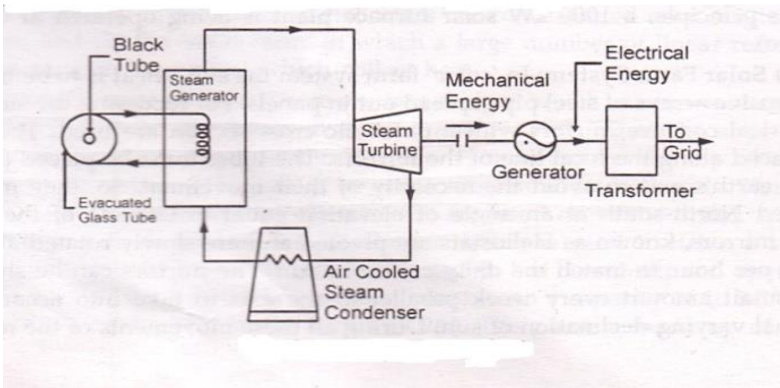


FIG.1.13

2. Direct conversion method:-

Under this method, the sun light is directly converted into electricity with the help of solar cells and without any intermediate thermodynamic cycles. Such cells are the predominant source of power for space satellites. The principle of solar cells is the photovoltaic effect. It is a process in which the radiant energy of light or photons is converted into electrical energy. The photo voltages so produce by the light energy striking at the junction of two dissimilar materials in a photovoltaic cell which is a bimetal semiconductor or p-n junction.

In a piece of pure semiconductor like silicon, there are no free charge carriers at ordinary temperatures. If this piece of silicon is doped with phosphorus or arsenic there will be one extra electron per atom of the impurity leading to n-type (negative type) semiconductor. Similarly if another piece of pure silicon is doped with boron (having an electron less than silicon) there will be deficiency of electrons (or holes) leaving to p-type (positive type) semiconductor. If these two pieces of silicon containing n-type and p-type impurities are connected together by some means, a junction at which the nature of the current carrier changes is created. In fact, a potential energy gap (Eg) is created at the junction.

When a photon of energy 'hv' is allowed to fall on the p-region, it is absorbed by an electron in the valance bond. If 'hv' is greater than energy gap Eg in the n-region, the photon will be absorbed by a hole which will migrate to the p-region. This charge separation creates an electric field opposite to the electric field created by the diffusion of free electrons of the n-region. This charge separation creates free electrons of the n-region to the p-region. If the number of absorbed photons is large enough, these two fields cancel each other, leading to an open electrical circuit with a voltage as shown in figure.

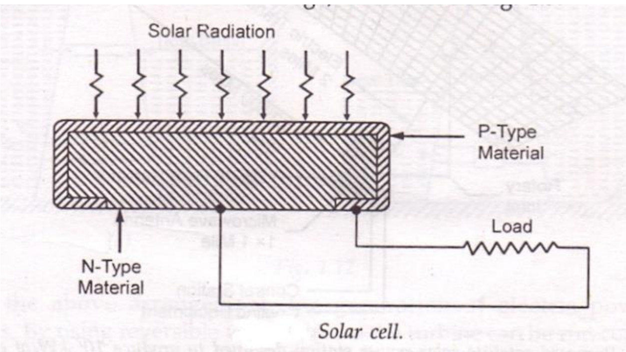


FIG.1.14

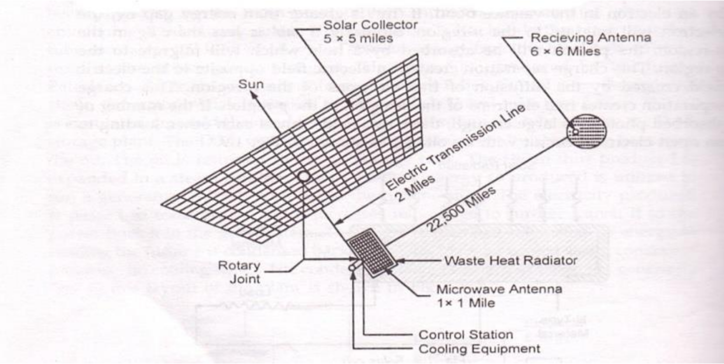
(a)Roof top array system:-

The roof top array system is an earth –based solar cell system mounted on roofs. The main difficulty is the problem of energy storage since this system will work when there is sunshine. The various alternatives are:

1. Electro-chemical storage, but batteries of adequate capacity that can also withstand frequent charging and discharging for many years are yet to be developed.
2. Hydro-storage in which water is pumped uphill when power is abundant and allowed to flow through hydro-generators at a time of peak demand.
3. Mechanical storage in high speed flywheels.
4. To storage energy in the form of hydrogen, which could be reconverted into electricity in fuel cells. Hydrogen is obtained by the electrolysis of water by the output of the solar cells.

(b) Satellite system:-

A more long range system that would also avoid the need for major storage of power is a space power station in synchronous orbit around the earth. According to the proposal put forward by Dr. Glaser of Massachusetts, (U.S.A), a solar collector 5×5 miles will be fixed on the surface of the satellite. Electricity so produced will be used to produce a micro wave beam. This microwave power will be transmitted to antennae on earth, and converted back into electric power. Such a system is shown below.



Proposed satellite solar power station designed to produce 10^7kW of electricity

FIG.1.15

2.4 Geothermal power generation:-

Geo-thermal comes from the Greek words: ‘geo’ meaning earth and ‘thermal’ meaning heat. So, geo-thermal energy which lies embedded within the earth.

There are four commercial types of geothermal power plants: a. flash power plants, b. dry steam power plants, c. binary power plants, and d. flash/binary combined power plants.

a. Flash Power Plant: - Geothermally heated water under pressure is separated in a surface vessel (called a steam separator) into steam and hot water (called “brine” in the accompanying image). The steam is delivered to the turbine, and the turbine powers a generator. The liquid is injected back into the reservoir.

Figure: Flash Power Plant Diagram

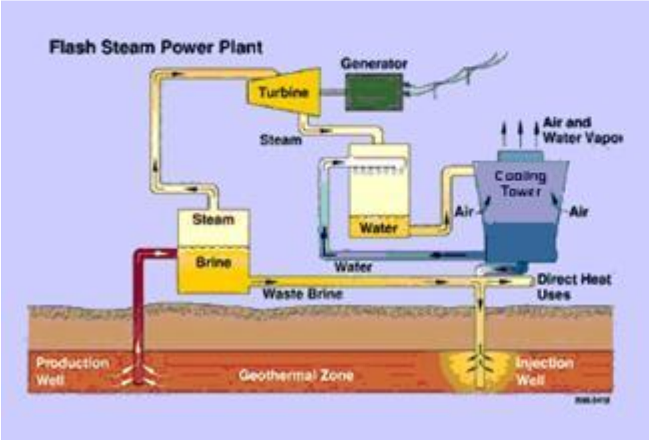


FIG.1.16

Figure: Dixie Valley, NV, Flash Plant

FIG.1.17

b. Dry Steam Power Plant: - Steam is produced directly from the geothermal reservoir to run the turbines that power the generator, and no separation is necessary because wells only produce steam. The image below is a more simplified version of the process

Figure: Dry Steam Plant Diagram

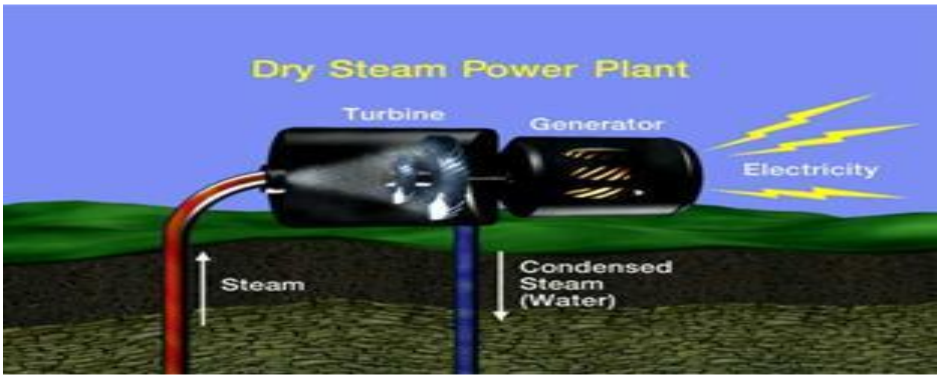


FIG.1.18

Figure: The Geysers, CA, Dry Steam Plant

FIG.1.19

c. Binary Power Plant: - Recent advances in geothermal technology have made possible the economic production of electricity from geothermal resources lower than 150°C (302°F). Known as binary geothermal plants, the facilities that make this possible reduce geothermal energy's already low emission rate to zero. Binary plants typically use an Organic Rankine Cycle system. The geothermal water (called "geothermal fluid" in the accompanying image) heats another liquid, such as isobutene or other organic fluids such as pentafluoropropane, which boils at a lower temperature than water. The two liquids are kept completely separate through the use of a heat exchanger, which transfers the heat energy from the geothermal water to the working fluid. The secondary fluid expands into gaseous vapor. The force of the expanding vapor, like steam, turns the turbines that power the generators. All of the produced geothermal water is injected back into the reservoir.

Figure: Binary Power Plant

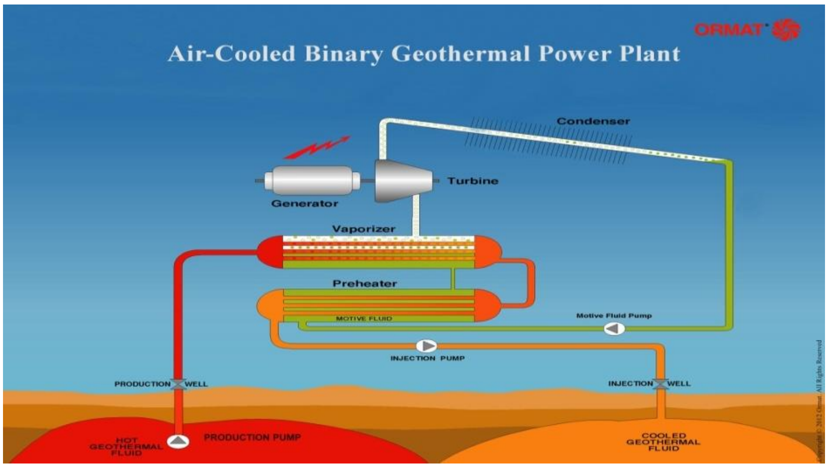


FIG.1.20

Figure: Burdett, NV, Binary Power Plant

FIG.1.21

d. Flash/Binary Combined Cycle: - This type of plant, which uses a combination of flash and binary technology, has been used effectively to take advantage of the benefits of both technologies. In this type of plant, the portion of the geothermal water which "flashes" to steam under reduced pressure is first converted to electricity with a backpressure steam turbine and the low-pressure steam exiting the backpressure turbine is condensed in a binary system.

Figure: Flash/Binary Power Plant Diagram

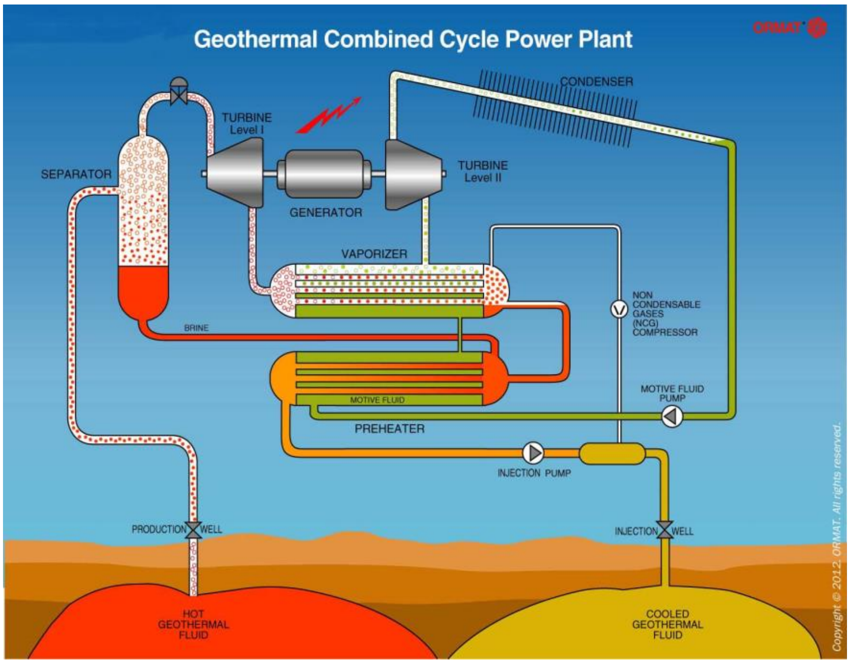


FIG.1.22

Figure: Puna, HI, Flash/Binary

FIG.1.23

3. ECONOMIC LOADING AND ECONOMIC ASPECTS

3.1 EXPLAIN FACTORS GOVERNING PLANT LOCATION:-

1) SELECTION OF SITE FOR A HYDRO ELECTRIC POWER PLANT :-

The following points should be taken into account while selecting the site for a hydroelectric 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 (i.e. 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 a 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.

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 facility: - the site selected for a hydro-electric plant should be accessible by a rail and rode so that necessary equipment and machinery could be easily transported.

v. Head of water: - the level of water is the reservoir for a hydro-electric power plant should always be within limits throughout the year. It is cleared from the above mentioned factors that ideal choice of site for a such a plant is near a river in hilly areas where dam can be conveniently built and large reservoirs can be obtained.

2) SELECTION OF SITE FOR STEAM POWER PLANT:-

i. Supply of fuel: - The steam power station should be located near the coal mines so that transportation cost 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 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 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 centre: - In order to reduce the transmission cost, the plant should be located near the centre of the load. This particularly important if D.C. supply system is adopted. However if a.c.supply system adopted, this factor becomes relatively less important. It becomes a.c. power can be transmitted at high voltage whit consequent reduced transmission cost.Therefore; it is possible to install the plant away from the load centres, provided other conditions are favourable.

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

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 important is being given to generation then transmission, a site away from towns may be selected. In particular, a site by a river side where sufficient water is available, no pollution of atmosphere occurs and fuel can be transported economically may perhaps be an ideal choice.

3) SELECTION OF SITE FOR NUCLEAR POWER STATION:-

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

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

ii. Disposal of waste: - The waste produced by fission in a nuclear power station is generally radioactive which must be disposed off in sea quite away from the sea shore. Therefore, the site selected for such a plant adequate arrangement for the disposal of radioactive waste.

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

iv. Transportation facility: - The site selected for a nuclear power station should have adequate facilities in order to transport the heavy equipment during the erection and facilitate the movement of the worker 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 from thickly populated area.

3.2 LOAD CURVE:-

The load demand on a power system is governed by the consumers and for a system supplying industrial and domestic consumers, its varies within limits, this variation of load can be consideration as daily,weekly,monthly,years.Typical load curves for a large power system are shown in fig. These curves are for a day and for a year and these show the load demanded by the consumers at any particular time. Such load curves are termed as"choronological load curves". If ordinates of the chronological load curves are arranged in the descending order of the magnitude with the highest ordinates onleft, a new type of load curve known as "load duration curve" is obtained. If any point taken on this curve then the abscissa of this point will shows the number of hours per year during which the load exceeds the value denoted by its ordinate. Another type of curve is known as "energy load curve" or the "integrated duration curve". The curve is plotted between the load in kW or MW and the total energy generated in kWh. If any point taken in this curve, abscissa of this point show the total energy in kWh generated at or below the load given by the ordinate of this point. Such a curve is shown in fig., the lower part of the curve consisting of the loads which are to be supplied for almost the whole number of hours in a year, represent the "Base load", while the upper part, comprising loads which are required for relatively few hours per year, and represents the "peak load".

Ideal and realized load curves: From the stand-point of equipment needed and operating routine, the ideal load on power plant would be one of constant magnitude and steady duration. However, the shape of the actual load curve (more frequently realized) departs far from this ideal. The cost to produce one unit of electric power in former case would be from ½ to ¾ of that for the latter case, when the load does not remain constant or steady but varies with the time. This is because of the lower first cost of the equipment due to simplified control and the elimination of varies auxiliaries and regulating devices. Also, the ideal load curve will result in the improved conditions whit the various plant machines (e.g., turbines and generators etc.) operating at their best efficiency. The reason behind the shape of the actual realized load curve is that the various users of electric power (industrial, domestic etc.) impose highly variable demands upon the capacity of the plant.

Effect of variable load on power plant design:

The characteristics and method of use of power plant equipment is largely influenced by the extent of variable load of the plant. Supposing the load on the plant increases. This will reduce the rotational speed of the turbo-generator. The governor will come into action operating a steam valve and admitting more steam and increasing the turbine speed to it normal value. This increased amount of steam will have to be supplied by the seam generation. The governor response from load to turbine is quite promot, but after this point, the governing response will be quite slowly.

The reason is explain as given below:

In most automatic combustion control systems, steam pressure variation is the primary signal used.

3.3 No. of unit load curves:-

The most important factor in the generation, transmission and distribution of electric energy is its economic production. For this, the power generating units should be loaded most economically. Economic loading is obtained by the application of the "incremental rate theory" .To understand this theory, the various definitions connected with it should be first of all known.

The performance of a generating machine is usually represented by input output curve shown in fig.3.2.1. For the steam turbine, steam generator or steam station as a whole, the diesel engine, or the gas turbine, the input I is expressed in, millions of kJ per hour and the output or load L in kilowatts. For water power plant, the input will be in terms of cubic metre per second of water flow and the load in kilowatts.

The efficiency at any load can be measured by taking the input from the curve at the same load. Then

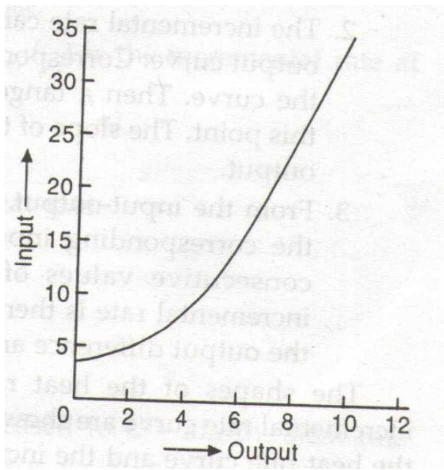


Fig 3.2.1 Input output curve

$n = \frac{3600L}{I} \times 100$ percent

Heat rate is defined as the ratio of the input to output i.e. $HR = \frac{L}{I}$ kJ/kWh

The incremental rate of a machine at any given output is the rate of change of the input with respect to the output. Numerically it is equal to the slope of the input-output curve at a point corresponding to that output. Mathematically, it is the first derivative of the input-output curve with respect to the output.

Supposing, at any point on the input-output curve, the output is 5 MW and the input is 19.7 units. If the output is increased to 6 MW, let us assume that the input increases to 21.4 units. Therefore,

Increase in input = Incremental input = 1.7

Increase in output = Incremental output = 1

Incremental input

Incremental input = --------------------------
Incremental output

= 1.7 = 1.7

More exactly, the incremental rate is the limit approach by the ratio of the incremental input to the incremental output as the latter approaches zero as a limit. The reciprocal of the incremental rate is termed as incremental efficiency. The incremental rates can be derived by one of the following methods:

1. If the equation of the input-output curve is given in the form of an algebraic equation, then, the incremental rate can be very easily determined by differentiating the equation with respect to the output. Supposing, the input-output curve is defined by

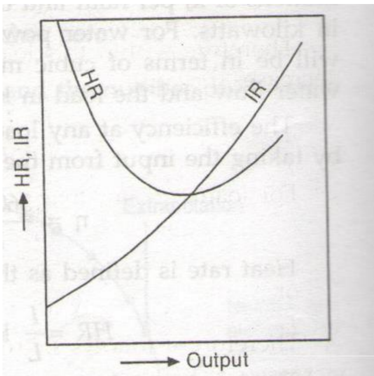
$$I = a + b\,L + c\,L^2$$

Then, incremental rate, $IR = \dfrac{dI}{dL} = b + 2cL$

2. The incremental rate can also be determined graphically, from the input-output curve. Corresponding to a given output, a point can be located on the curve. Then a tangent is drawn to the input-output curve through this point. The slop of the tangent gives the incremental rate at the given output.
3. From the input-output curves, a series of output values are chosen and the corresponding input values are taken. The interval between two consecutive values of outputs should be small and constant. The incremental rate is then calculated as the ratio of the input difference to the output difference and it is assumed to be a function of the mid-point.

The shapes of the heat rate curve and the incremental rate curve are shown in Fig. 3.3.2. Here, the heat rate curve and the incremental rate curve are plotted on the common co-ordinates. It is clear that the two curves cross each other at a point where heat rate is minimum. The reason for this is evident from the following analysis:

There will be one point on the input-output curve through which if a tangent is drawn to the curve, the tangent will pass through the origin, Fig. 18.3.3(a). The equation of this tangent will be



$I_m = m.L_m$

Fig 3.3.2 Heat rate increment rate curve

Where (I_m,L_m) are the co-ordinates of the point and m is the slope of the curve. Now at the load L_m, the heat is given as

$$HR = \frac{\text{Input}}{\text{Output}} = \frac{I_m}{L_m} = m$$

Now if the tangent is considered as input-output curve, the corresponding heat rate curve and incremental rate curve will be a horizontal line with a value of I_m / L_m, Fig.3.3.3 (b). Now as the actual input-output curve lies above the tangent for all values of loads other than L_m, it is clear that the heat rate curve will always be higher than the horizontal line for all the loads other than L_m. Hence heat rate is minimum when HR= m.

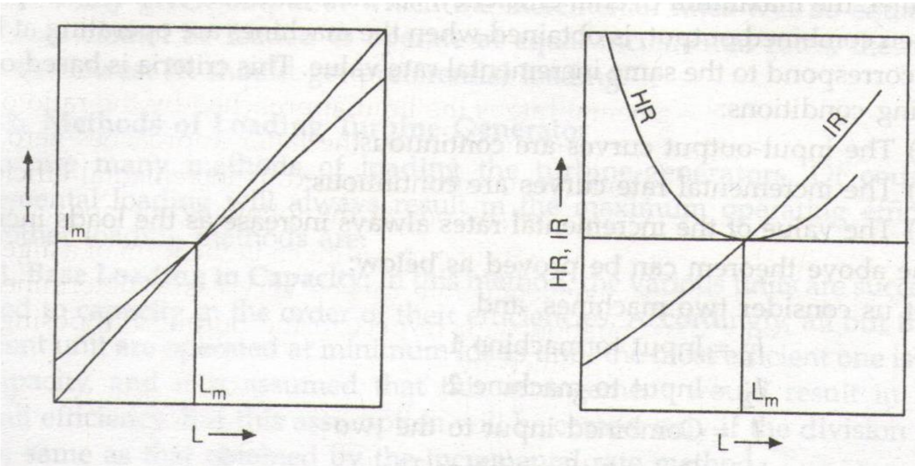


Figure 3.3.3 (a) figure 3.3.3 (b)

[Curve showing equality of heat and incremental rates at minimum heat rate]

Again, the slope of the curve at the point (I_m, L_m) is the incremental rate at the load L_m,

.: $IR = m$

But $m = HR$

.: $IR = HR$ at the minimum heat rate.

Now for any load between zero and L_m,

$IR < HR$

Or $$\frac{dI}{dL} < \frac{I}{L}$$

Therefore within this load range, if L is increased to $L + dL$, the heat rate decreases, because

$$(I/L) < (I + dI)/(L + dL)$$

For loads greater than L_m,

$IR > HR$

Or

$$\frac{dI}{dL} > \frac{I}{L}$$

Therefore it follows that if load is increased from L to $L + dL$, the heat rate increases, as

$$\frac{I}{L} < \frac{I + dI}{L + dL}$$

From the above analysis, it is clear that starting from zero load, the additional output results in decrease in the input. This persists until the load reaches the value where heat rate equals the incremental rate. After this point of minimum heat rate, it goes on increasing since incremental rate is continuously increasing.

3.4 Economic Division of Load

When a combined load is to be supplied by two or more machines operating in parallel, the maximum overall efficiency, *i.e.* the minimum combined input for the given combined output, is obtained when the machines are operating at loads which correspond to the same incremental rate value. This criteria is based on the following conditions:

(a) The input-output curves are continuous.
(b) The incremental rate curves are continuous
(c) The value of the incremental rates always increase as the loads increase

The above theorem can be proved as bellow:

Let us consider two machines, and

Let I_1 = Input to machines 1

I_2= Input to machines 2

I_c= Combined input to the two

L_1 = Output to machines 1

L_2= Output to machines 2

L_c= Combined output of both the *n*

Now $I_c = I_1 + I_2$

And $L_c = L_1 + L_2$

The problem is to find the values of $L_1$and$L_2$for any give of L_c, which will make L_c, a minimum.

Let the given value of $L_c$be L_a

.: $L_1 + L_2 = L_a$ = a constant.

Now $I_c$will be minimum when its first derivative with respect to output vanishes.

Thus
$$\frac{dI_c}{dL_1} = 0$$

But
$$\frac{dI_c}{dL_1} = \frac{dI_1}{dL_1} + \frac{dI_2}{dL_1} = \frac{dI_1}{dL_1} + \frac{dI_2}{dL_2} \times \frac{dL_2}{dL_1}$$

Again
$$\frac{dL_2}{dL_1} = \frac{d}{dL_1}(L_a - L_1) = \frac{dL_a}{dL_1} - \frac{dL_1}{dL_1}$$

$= 0 - 1 = -1$,since$L_a$is constant

Hence
$$\frac{dI_c}{dL_1} = \frac{dI_1}{dL_1} - \frac{dI_2}{dL_2}$$

But
$$\frac{dL_c}{dL_1} = 0$$

.:
$$\frac{dI_1}{dL_1} - \frac{dI_2}{dL_2} = 0$$

.:
$$\frac{dI_1}{dL_1} = \frac{dI_2}{dL_2}$$

Or, for given combined output, the combined input will be minimum when the incremental rates of the two units are equal. Also, there is only one pair of loads for any given output at which the incremental rates will be equals. If the machine cannot be loaded to operate at equal incremental rates, the machine with the lowest IR should get preferential loading.

Methods of Loading Turbine Generator

There are many methods of loading the turbine-generators. Of course, the incremental loading will always result in the maximum operating efficiencies.

The other loading methods are:

1. **Base Loading to Capacity:** In this method, the various units are successively loaded to capacity in the order of their efficiencies. Accordingly, all but the most efficient unit are operated at minimum loads until the most efficient one is loaded to capacity, But this assumption will be correct only if the division of load is the same as that obtained by the incremental rate method.
2. **Base Loading to Most Efficient Load:** In this method, the units are successively loaded to their most efficient loads in the ascending order of their heat rates. After that, all the units are loaded to capacity in the same order.
3. **Proportional to Capacity:** According to this method, the units are loaded in proportion to their rated capacity.
4. **Proportional to Most Efficient Load:** In this method, the units are loaded in proportion to their most efficient loads. After the units are loaded up to their most efficient loads, the additional loading on each will be in proportion to the difference between the rated capacity and the most efficient load.

Supposing there are three units A, B & C whose rated capacities are 40, 60 and 100 MW respectively and let their most efficient loads be 25, 50 and 75 MW respectively.

Therefore the loads on the three units will be in the ratio of 1: 2: 3 up to a total load of 150 MW. Beyond the total load, the load will be divided in the ratio of (40 – 25): (60 -50): (100 -75)

Or 15: 10: 25 or 3: 2: 5.

If L = Total Load in excess of 150 MW

Then load on A = 25 + 0.3 (L - 150) MW

Then load on B = 50 + 0.2 (L - 150) MW

Then load on C = 75 + 0.5 (L - 150) MW

Economic Loading of Diesel Engines

When there are several engines in the plants then consideration should be given to the problem of load division or load balancing. From Fig. 3.3.4 it is clear that the fuel consumption is good for all loads from one quarter to full load. But there is always a point at which an engine has its best fuel economy.

Therefore by proper division of load among several engines, the maximum fuel economy for the whole unit can be obtained.

Other factors to be considered are cost of lubrication oil and the maintenance charges. Labour and capital charges don't vary whether the engine is idling or operating at full load.

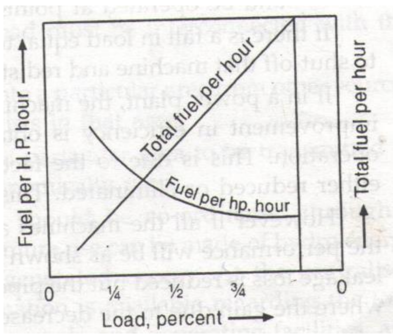


Fig 3.3.4 Fuel consumption curves of engine

Therefore to arrive at economic loading of diesel engine, the variation of fuel cost, lubrication oil cost, and maintenance cost, with the output must be known. Then a curve is plotted between the output and the combined total cost per hour. With the help of this curve, distribution of any plant load can be easily computed.

Supposing there are 500 kW diesel engines and the load to be met 900 kW. The problem is to distribute the load economically. The following distribution is possible:

Group 1	500, 200, 200 kW
Group 2	500, 250, 150 kW
Group 3	400, 300, 200 kW
Group 4	300, 300, 300 kW
Group 5	500, 400 kW
Group 6	450, 450 kW

From the cost curve, the cost per hour for each is noted. Then the total cost for each group is calculated. The group, for which the total cost comes out to be minimum, gives the most economical loading. It will be observed that Group 6, will give the most economical loading where to engines evenly divide the load. It is clear from the above analysis that the cost is minimum when the load is evenly divided among the fewest possible number of engines. This condition will exist in most plant where units are identical.

Sometimes cost is scarified in favour of reliability. A load of 1000 kW can be taken up by two of the 500 kW units. If there is sudden rise in load, this arrangement will have no reserve capacity. Therefore it will be advisable to run three engines each carrying 333.3 kW.

Economic Loading of Hydro Plants:

When a number of identical machines having identical input-output curves are installed in a hydro-plant, then the most economical method of operation can be obtained in the following ways:

1. One unit carries the load variations, while all the other units run at their points of maximum efficiency.
2. The more preferable method is that all the machines share the load equally and be operated at points of equal slope on their input-output curves.

If there is a fall in load equal to the capacity of one unit, it is for best economy to shut-off that machine and redistribute the load among the remaining machines.

If in a power plant, the machines are provided with individual penstock, the improvement in efficiency is obtained as units are added to those already in operation. This is due to the fact that the leakage loss in the standby units is either reduced or eliminated. This is shown in Fig. 3.3.5.

How ever if all the machines are provided with one common pipeline, then the performance will be as shown in Fig. 3.3.6. As additional units are added, the leakage loss is reduced but the pipe friction loss increases. A stage will be reached where the gain due to the decrease in leakage loss offset by the increased pipe friction loss. Hence, it is clear from the Fig. 3.3.6 that the plant will operate at the highest efficiency when only two units are in operation.

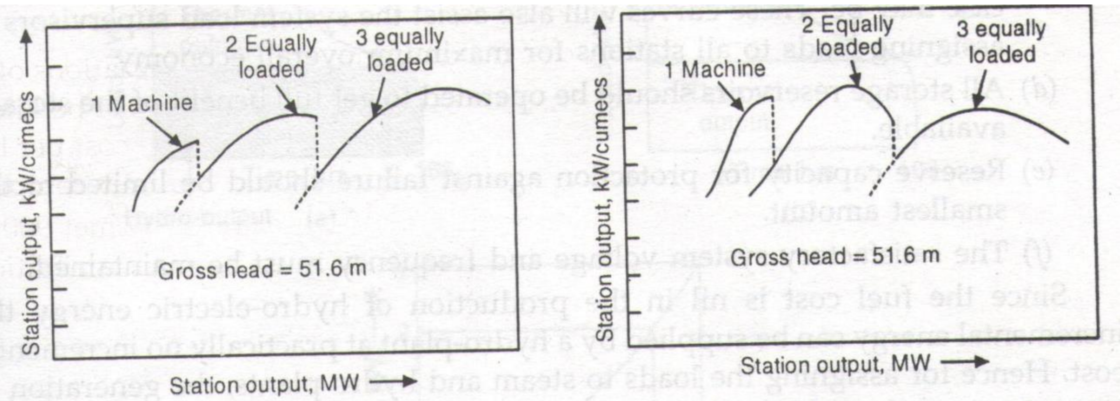


Fig 3.3.5 Performance curves for hydro stations Fig 3.3.6 performance curves for hydro station
With identical machines with a common
Pipe line
With Identical machine with separate
Penstocks

Economic Loading of Combined Stream and Hydro-Plant.

A combination of stream and hydro-plants is generally more economical than all hydro or all stream stations. Hydro-plants are specially suited for carrying fluctuating or peak loads and the stream plants for carrying the continuous or base load. The combined hydro and steam electric system required the use of operating methods based upon the principals of economic loading. The fundamental objectives of such an arrangement are:

1. An adequate and reliable supply of electric power at all times to all load areas.
2. The Maximum possible use should be made of all available hydro-resources. When these are utilised in combination with steam energy, will meet the varying requirements of the system load at a minimum overall cost to the system as a whole. This does not necessarily mean the most efficient operation of the hydro equipment, but in such a manner that would result in the least overall production costs. For this purpose, the effect of hydro generation on the production costs of the steam plant should be taken into account.

For the attainment of the above objective, the following requirements must be meet:

(a) The generation areas and all the load must be interconnected with the lines of sufficient capacity:

(i) To transmit the required energy into a particular area from other sources when a deficiency of energy exists in that area.

(ii) To allow the surplus energy of a particular area to be transmitted to other areas where it can be economically used.

(b) The operation of all the stations should be co-ordinated through a centralised supervision so that maximum use can be made of hydro energy resulting in conservation of fuel generated energy. At the centralised supervision place, complete information is available regarding the load requirements, availability of water supply and generating facilities, and the cost of power production from all sources.

(c) All the stations must be provided with input-output curves from which each station will be loaded with the minimum use of water or fuel as the case may be. These curves will also assist the system load supervisors in assigning loads to all stations for maximum overall economy.

(d) All storage reservoirs should be operated to get full benefit of the storage available.

(e) Reserve capacity for protection against failure should be limited to the smallest amount.

(f) The satisfactory system voltage and frequency must be maintained.

Since the fuel cost is nil in the production of hydro-electric energy the incremental energy can be supplied by a hydro-plant at practically no incremental cost. Hence for assigning the loads to steam and hydro-plants, the generation at steam stations should be displaced by available generation at the hydro-plants, so that the minimum decrement production costs will obtain at the steam plants.

Of course, this will depend upon the nature of the daily load curve for the system, the type of hydro-plants and the available water. Hydro-plants may be operated to supply the system base load, peak load or both. For best system operation, the hydro-plants should carry the peak loads at times of low river flow and the fuel stations run at base load. When there is ample river flow and the hydro-plants can carry the base load with the peak load supplied by the fuel that this plant would normally supply the base load of the system. Plant with storage or pondage facilities may be operated to supply either base or peak load, depending upon the best utilization of water flow.

How the load is actually shared between the hydro and thermal stations is explained with the help of Fig. 3.3.7, where the load-duration curve and the energy curve are shown for one week. At the time of maximum river flow, the hydro-station will take the base load, the peak load being supplied by the thermal station. This is explained in Fig. 3.3.7(a). The load x, kW is equal to the hydro-plant capacity or the energy in the river flow whichever is smaller. If during this period of maximum river flow, the load on the hydro-station drops below the plant capacity or energy in the river, the excess water can flow over the spillway if pondage or storage is not available.

During the periods of low river flow, the water should be used judiciously so that it is possible for the hydro-plant capacity to carry the peak load of the system. This is usually achieved by shutting down the hydro-plant during off peak periods and storing the available water as pondage or storage. This water may then be used at the time of peak load. It is very simple to know the point at which the hydro-station should be put into operation. The weekly load curve being known, the energy curve, Fig.3.3.7, can be drawn. Now supposing, the energy in the river is equal to (y'- z') kWh, then the hydro-station will be put into operation if the system load is more than 'z' kW. The hydro-plant will take up the available peak load while the thermal station would provide the constant base load. It is very important to see that the load (y - z) kW must not exceed the capacity of the hydro-station. If it does exceed, then the output of the thermal station will be increased at the time of peak load so that the hydro-station is not overloaded.

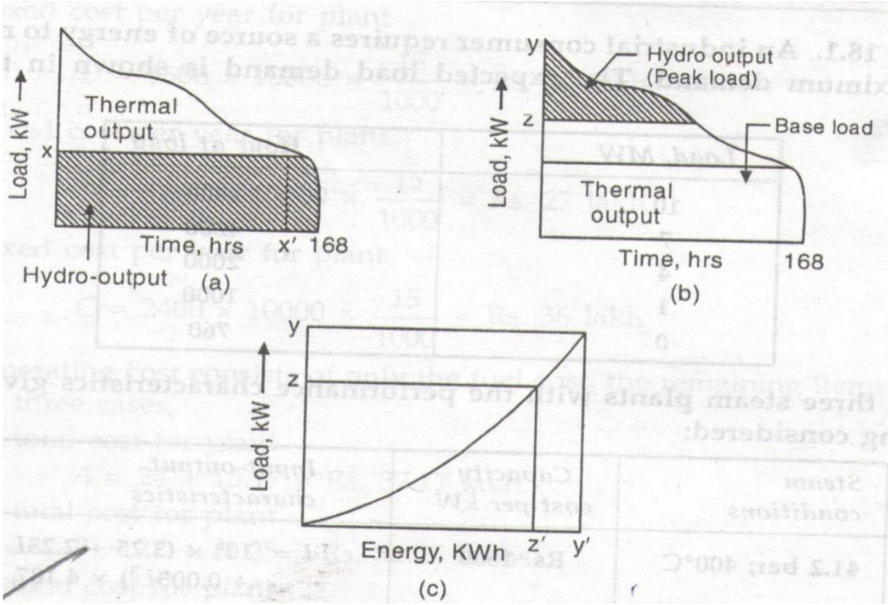


Fig 3.3.7 Load division between hydro and thermal stations

3.5 CAPACITY SCHEDULING

Capacity scheduling indicates the order and the total plant or system load at which the various units should be placed in operations. Certain generating units will be operated only at the time of peak load demand. To ensure the continuity of the power, sufficient generating capacity should be in operation at all times so that if one unit fails, there is no interruption in the energy supply. If the load on the plant is equal to or less than the capacity of one generating unit, then it is always advisable to run two units to supply the load to ensure the continuity of the supply. The order of putting the machines in operation depends upon their efficiencies. The machines are loaded in the descending order of the efficiency. The load a is divided among the various units on the basis of incremental rates.

The capacity of the unit in active operation is known as, the 'spinning' capacity. Spinning capacity should always be more than the load to avoid interruption. "Spinning reserve" is the difference between the spinning capacity and the load. The minimum magnitude of the spinning reserve is equal to the capacity of the largest unit.

4. MAJOR EQUIPMENT

4.1 ELECTRIC GENERATIOR

The electric generator consists of magnet and a coil of wire, in its simplest form. When relative motion occurs between these two components, lines of magnetic force cut coil and an e.m.f. is developed in it. The commercial electric generator or alternator consists of a system of electric magnets, and an armature composed of a number of coils of insulted conductor laid firmly in a laminated iron core.

There may be two constructions of the machine. Inone, magnets are stationary and the armature revolves in the magnetic field and in the second, the armature is fixed and the magnets are attached to a wheel which revolves round the coils. Both the machine produce alternating current. This alternating current can be converted in to direct current by using bushes and revolving contacts i.e. Commutator on the shaft of the mention machine.

Fig shows the principle of an alternator. The wheel with the electric magnets attach to its periphery is known as the rotor. Around the rotor is the stationary part of the machine known as stator, whose contain the coils of conductor. When the shaft of the rotor is coupled to that of a prime mover and it is revolved, the magnetic field cuts the stator and coil and induces an e.m.f in them.

The magnitude of the induced voltage depends upon the strength of the magnetic field. The speed of rotation and the number of stator coil in series. The rotor may be either in cylindrical type or non salient pole type, or of salient pole type. The rotor is provide with electro magnet and these are energized whit direct current from a small generator known as exciter. The exciter is driven from the alternator shaft. The alternator voltage is control by adjusting a rheostat in circuit with the exciter field.

The frequency depends on the number of poles, and the speed of rotation. If "p"is the number of poles and "n" the speed of rotation in revolution per minute, then the frequency 'f' is known as

F=pn/120cycle per second

For power transmission, a low frequency is best and for lighting an driving induction motor a higher frequency is preferable. For general power distribution purpose, a frequency of 50 c/s as used in UK an India and 60c/s I USA.

The machine shown in fig 1.24 is known as single phase alternator since it has one continuous stator winding. Such a machine would produce single phase current. If three separate adjacent windings are provided in the stator and these are brought out to three pairs of terminals, the machine will become a three phase type and it will produce a three phase current. There will be a phase difference of 120 electric degree between the currents in three windings. Three phase power is preferable to single phase for generating and transmitting power, since the generation of single phase involves more losses in the alternator. Moreover three phase motors are more satisfactory machines than the single phase once.

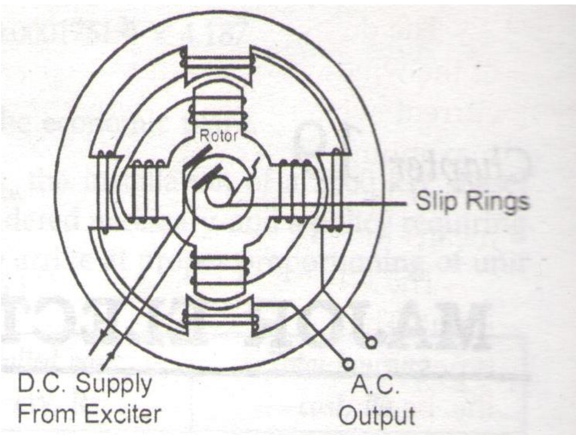


FIG.1.24 The alternator

The winding of the three phase alternator may be connected in, either the delta or star arrangement. Fig 4.2 .with star system two voltage scan be obtained. One is the line voltage V,between a and b ,b and c ,c and a.The other is the phase voltage between a,b or c and the neutral point O, and this is equal to V/√3 .The neutral point can be connected to earth and this facilitates the design of the protective system. In the event of a fault earthing one phase, the maximum voltage between two sound phase and earth is limited to phase voltage, i.e., V √3 .With delta system, an earth fault on one line, voltage i.e., √3 times the phase voltage, will be applied between the earth and the two healthy phase.

Thus in the event of a fault, the stress of insulation is greater in the case of a delta circuit. In the three phase circuit, the power in watts is given by

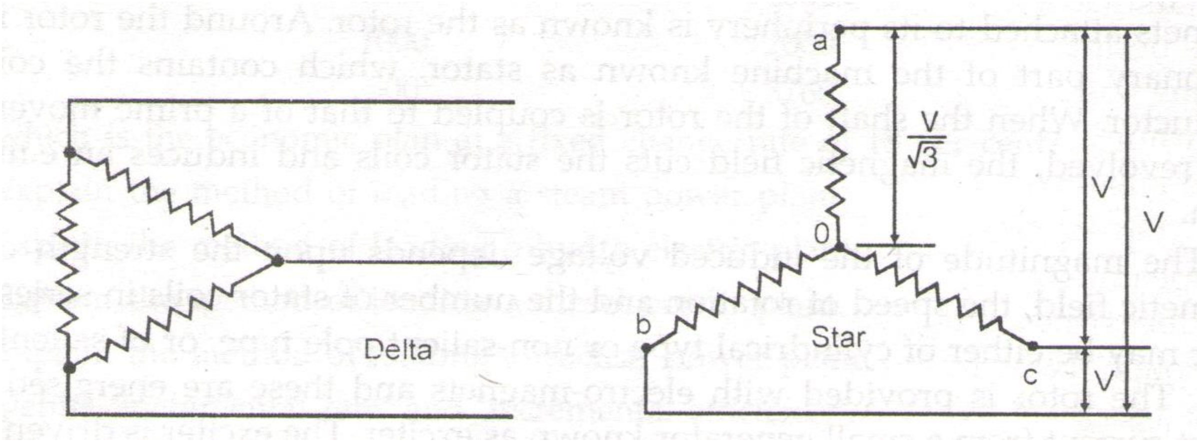


FIG.1.25

Where V=line voltage

I=current in amperes

Cosθ=power factor

Alternator are rated in kilo-volt amperes, kVA

Two methods of rating based on temperature rise and adopted:

- Maximum continuous rating, M.C.R.
- Economical rating

The maximum continuous rating indicates the maximum load it can carry continuously without overheating. The economical rating indicated a loading above which the is an over load capacity.

The output of an alternator is limited by the maximum working temperature of the winding. The amount of heat produced is dependent on the square of the current which is turn varies inversely with the power factor. Therefore the maximum permissible load will be less at low power factor than that at a high power factor. When the power output is referred in kilowatt capacity, it usually means the machine output at a specified power factor, and this is usually.

The efficiency of the alternator is the ratio of the useful output to the total input. The useful output is the total input minus the losses. The losses are of two types: mechanical and electrical. The mechanical losses include the windage and the bearing friction, while the electrical losses consist of eddy currents and hysteresis losses in the iron core, and the copper losses in the windings. The electrical losses get converted into heat and if for a large alternator, it is not removed away by the cooling system, the machine would overheat and the insulation becomes damaged.

To cool the alternator, two systems are employed:

- Close system
- Open system

In the close system, fans circulate air through the alternator and this warm air is cooled by water coolers before being recirculated. This system gives good protection against fire in alternator due to restricted air supply. Carbon dioxide can also be easily injected.

In the open system, the fans draw in air either from the station or from outside atmosphere through a duct. This air is forced through many small ducts between sections of the core and between windings, and becomes heated. For small machines, this hot air escapes into the station through small openings round the periphery of the stator. For large machines, the hot air is discharge into the outer casing surrounding the stator. From here it can either be used for station warming or led to the outside atmosphere through ducts. The fans for circulating the air may either be driven from the rotor shaft or separately driven.

Open system is cheaper. The close system is best from the point of view of appearance both inside and outside the station. It makes the station quite and reduces the amount of moisture which might, on the open system, being passed through the alternator during the wet and humid conditions. The system is chiefly used for larger machine and approximately 2.7 cub. m. of air per minute is needed for each kilowatt of loss in alternator the air velocity in the ducts is usually written 330 to 430 m/min.

The alternator use in steam power station are of rotating field type and are totally enclosed with “close air circuit”. Their chief characteristic is the high speed of rotation and voltage of generation. The rotor is of cylindrical or non-salient pole type. The rotors of the hydro-plant alternators are usually of salient pole type, and these have relatively slow speed as compared to steam plant alternator. But at the same time, the inherent danger of high run away speeds has to the guarded.

The alternator of diesel plant is of rotating field salient pole type. Its mechanical design is given special attention. This is done to avoid the possibility of torsional vibration being set up by the inherently uneven turning moment of the engine should be rigid to avoid torsional vibration of dangerous order or near the normal running speed.

4.2 EXCITERS

An exciter provides the direct current needed to excite the rotor field magnets. The source of existing must be absolutely reliable since its failure will shut down the alternators. The excitation circuit should be simple and the cables shorter and the apparatus should have fewer pieces. The higher load and more logging the power factor, the grater excitation is required.

There are two method of supplying excitation current. In one method, each alternator is provided whit its own exciter in the form of a small generator on an extension of the main shaft. In case of trouble, one spare exciter is provided. This system of direct driven individual exciters is simple and reliable. However the excitation current is effected by the variation in the speed of alternator. In the case of a very low speed plant, the exciter becomes large and costly. In the second method a centralize excitation system is provided. A small number of a large exciters supply the whole station. These are driven by electric motor but safeguard against the power failure, at least one exciter is coupled to the main shaft so that the station can be started of if the bus bares are dead. It is essential to have a spare unit. This system require more cabling and switching equipment. If there is any trouble, then the whole station is affected.

4.3 TRANSFORMERS

The power transformer consists of an iron core around which two independent coils or windings are wound. If one windings is connected to the a.c. supply, a magnetic flux is setup and its cut the other winding in which an alternating e.m.f. of the same frequency is induce. The winding connected to the supply is known as primary and that connect to the load is known as secondary.

A simple transformer is shown in fig. 4.3 the iron core in the form a close ring so that practically whole of the magnetic flux set up in the primary cuts the coil of secondary and induces a voltage in them. The voltage produced in one turn of primary and one turn of secondary will be equal since the same magnetic flux cuts both the primary and secondary winding. Thus depending of on the ratio of in the turns in the primary and the secondary, the voltage in the primary will be either step down or step up. This ratio is called the turned ratio, and may be expressed as

T=secondary turns/primary turns

=voltage of secondary/voltage of primary

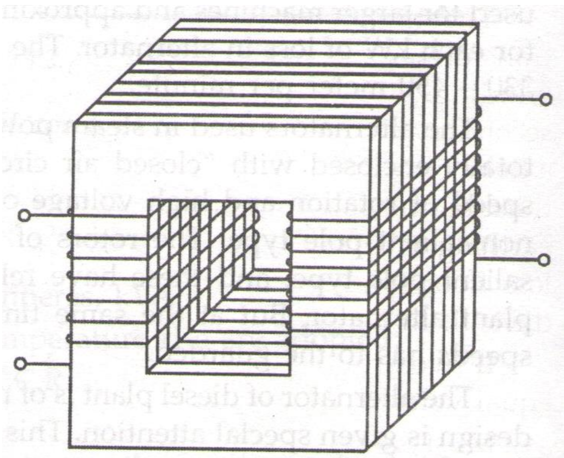


FIG.1.26 A simple transformer

Since there is merely a change of voltages, the energy deliver will be equal to the energy supplied, neglecting certain losses. This if the voltage stepped up five times, the current will get reduced to one-fifth of that in the primary.

The core of the transformer is made up of thin sheets or laminations of alloyed steel contenting a small quantity of silicon. The laminations are slightly insulated from each other to prevent eddy current. They are firmly clamped together to make the structure rigid and prevent vibration. There should be insulation between primary and secondary and between each winding and earth and also between the individual windings between coils and layers. The insulating material may be press board, paper or oil. Oils also as a coolant of the transformer.

The whole structure is immersed in oil in a steel tank. The oil used is highly refined and pure. It must possess the following properties:

- High dialectic strength
- High flash point
- Low viscosity to facilitate circulation
- It should be entirely free from moisture which has serious effect on insulation
- There should be no supended matter in the oil
- It should not any sludge
- It should not have any chemical action with metals and insulating materials

A steel drum known as oil expansion vessel or conservation is placed above the transformer tank and connected to it by means of a pipe. There is always some oil in this tank to ensure that the transformer tank is always full of oil .This drum also helps is preventing any absorption of moisture from atmosphere by the tank oil. The level of the oil in the conservator will fluctuate in accordance with the temperature of the transformer .There; there must be some provision for the expulsion and drawing in of air. To ensure that the air entering the conservator is dry, the moisture is removed by passing the air through calcium chloride or some other suitable material.

The number and capacities of transformers depend up on characteristic of station and the load is swerves. There are two methods of installing the transformer in one, a bank of transformer as inn insulted for each generating unit. This practice is as usually followed for station transmitting at low or medium voltage. When the transmission voltage is hugh, the bank of transformer should from unit whit the transmission line. In this case, each transmission line will terminate at the station in one of the units.

The transformer may be single phase or three phases. A single phase transformer shown in fig has a single primary winding and one secondary winding. A three phase transformer has three primary winding and three secondary winding but a common iron circuit. The primary windings have usually a delta circuit and the secondary windings a star circuit. This helps in eliminating third harmonic voltage and also the neutral of the secondary can be used for earthling or giving a four point supply. Three phase transformers are cheap, require less floor space and are easy to install. But in the event of a trouble it is more difficult to replace a three phase transformer than a single phase one.

If two or more transformers are to the operated in parallel, they should have equal voltages, turn ratio and the same percentage impedances.

Most switch board instruments are designed for normal operation at 110 volts and 5amp. Therefore, the high voltage and high current circuits must be connected to their instruments through transformers. Instrument transformers connected to voltage circuit are known as “voltage or potential transformer “and those connected to current circuits are called “current transformers”

Two types of losses occur in transformer: iron loss i.e. eddy currents and hysteresis which remain almost constant for all loads, and the copper loss which varies with load. Under no load conditions, the copper loss is negligible.

The efficiency of the transformer depends on the load and on power factor. At full load and unit power factor, the power transformers have efficiencies of 96 to 99 percent depending on the copper loss.

The transformer can be cooled in three ways:

- By oil
- By water
- By air blast

In the oil cooled or self-cooled transformer, the oil which becomes hot by its contact with core and windings, rises to the top in the transformer tank from which the heat is radiated in to the air. For this purpose, the tanks of such transformers are made up of corrugated steel sheets to provide maximum radiating surface. Oil cooled transformer are the most commonly used.

In water cooling system, pipes are immersed in the oil where it is hottest i.e., near the top of the tank. Water circulating through these pipes takes always the major proportion of heat. The remaining heat is dissipated to air as in the first case. The oil is maintained at higher pressure than the water, so that a leaking tube will not allow the water to enter oil.

In the air blast system, the transformer is cooled by forcing a blast of air thought ducts or spaces provided in the transformer structure.

4.4 SWITCH GEAR

Switch gear constitution the parts or appliances which make up complete equipment for controlling and measuring the electric energy output or input of an electric station or some electrical device. A switch board is that part of the switchgear equipment on which are mounted the meters, switch control handles, rheostat handles, and similar appliance. If a small amount of power at low voltage is to be controlled, then it is convent and economical to mount all of the switchgear on the switchboard. Such a board is said to be self-contained. If the power output is large or high voltage it is necessary to install certain components of the switch gear away from the location of the switchboard. Such a board is called as “remote control switchboard”.

Switchgear is a vital link in the insurance of reliability of supply whether for main or auxiliary services. Switch gear has got the following functions.

- By the operation of the protective equipment, the effects of faults are localized and the faulty plant is automatically disconnected from system.
- To break efficiently short circuit without giving rise to dangerous conditions.
- To facilitate redistribution of loads, inspection and maintenance on the system.

4.4.1 Type of switchgear

The various types of switch gear commonly used are briefly discussed below:

- **Cellular:** In this type, the components of the switchgear are enclosed in cells made of brick, concrete or molded stone. This type is cheap and all the components can be easily inspected and modifications can be made without any difficulty. However, the cellular type gear has the following disadvantages:
    - It occupies large space
    - Erection is usually a lengthy process
    - The interlocking schemes may be complicated

- **Cubicle:** In this case, the whole of the equipment is enclosed in steel plant cubicles with complete or partial sub-dividing barriers. Its requires relatively small floor area and presents a neat and simple layout.
- **Truck:** In this system, a movable trunk mounted on small wheels carries the circuit breaker, moving isolator contacts, and the potential and current transformers. The trunk has a front panel, whit the circuit breaker operating handle, relay, and instrument and fits into stationary steel cubical. This cubicle houses the bus bars, cable box, and fixed isolator contacts. For inspection, the truck is withdrawn from the cubical and the automatic shutters close off the live parts in the cubical. Withdrawal is prevented by interlocks, unless the circuit breaker is in the open position**.**
- **Metal clad:** In this type of switchgear, all conductor and insulators are enclose by an earthed metal case. With lower voltage units, the bus bars are usually left uninsulated in a metal chamber, but one higher voltage compound and oil filling is used. This type has following advantages:
    - Occupies less space, so saving in building cost.
    - Erection on site is simplified.
    - Since all the live parts are totally enclosed in metal, it ensures safety to operators, reduces maintenance charges and exclude dirt and vermin.
    - Simple and efficient interlocks can be installed to prevent operating mistakes.
    - The circuit breakers can easily withdraw and all the essential working part are easily and safety accessible which makes the maintenance work easy.

Metal called switchgear may be divided in to two classes:

- Horizontal draw out.
- Vertical draw out

Both types popular and are used for small and large units

E) **Outdoor switchgear:** This type requires large ground space but there is a saving in buildings cost. Maintenance work is at the mercy of the weather. Since the equipment is exposed, the damage from lighting is more likely. Birds cause fouling and in areas where there is soot or salt in the atmosphere, the cleaning of insulation will have to be done more frequently. Taitenace cost is more than for indoor switchgear.

4.4.2 Auxiliary switchgear

The switchgear used for the power station auxiliaries can be grouped in to three main categories:

- Circuit breakers
- Contactors
- Fuse gear

Circuit breaker must be capable of making and breaking under normal and breaking conditions. The function of the contactors is to carry only normal full load current and certain overloads. The short circuit current are interrupted by buses.

The switchgear most commonly used is of single bus-bar type. It is enclosed in metal frame. If voltage and current transform are connected to the switchgear, they should be located on the side of the circuit breaker, away from the bus-bar. The secondary winding of each transformer is earthed at one point, whereas the primary windings are connected to the switchgear through fuses and current limiting resistors.

To ensure safety and prevent faulty operation, interlocks are provided with the switchgear. For this purpose, auxiliary contact points can be provided to give alarms.

Fuse gear is always hand operated, whereas the switch gear can be design to be operated either manually or electrically. The electrically operated switch units can either be controlled locally or some remote control panel.

4.5 CIRCUIT BREAKES

This is the apparatus used for the prevention of dangerous current. The old method was to employ fuses in series with the circuit to be protected. This system was satisfactory for low voltage power transmission but is not suited to the present systems.Ofcurse, high tension fuse or fuse-switch are still often used due to their low cost but only for small consumers supplied through tapings from the main transmission line.

For the breaking of high voltage, alternating current circuit breakers are used. The circuit breaker may be oil circuit breakers or air circuit breakers. In oil circuit breakers, the circuit is usually broken by contacts which separate under the surface of oil in tank. It is well known that a.c. current passes through a zero value every half cycle and circuit can be broken if the current can be prevented from restating after it has reach the zero value. Oil circuit breakers have his valuable quantity of rupturing the circuit near the zero value of the current wave. When the contacts of the breaker separate, an arc is drawn out between them. This arc is rapidly cooled and compressed by the oil in the tank. For the air circuit breaker, the tendency to rupture will be maximum when the current is maximum. By its use oil is eliminated and main maintenance is easy. Moreover, contacts burn less in air than in oil. In the oil circuit breaker, oil is always present as an insulating material whereas air circuit breaker is expected.

Circuit breakers are mostly of the automatic type. They are provided with trip coils. Whenever there is a fault in the main circuit the trip coil gets energized by means of relays. When the circuit breakers are closed, considerable energy is stored in the springs. The parts are held together by means of toggles. To open the circuit breaker, only one small pressure is needed to be applied on a trigger. When the Tigger is actuated by the protective relay, it trips and the potential energy of the springs is released and then contact open in a fraction of a second.

4.6 CONTROL ROOM

The control room or the operating room us the nerve system of a power station. The various controls located in it are: circuit breakers, load and voltage adjustment, transformer tap changing, emergency tripping of the turbine etc. Also housed in it are the instruments for indicating the load, voltage, frequency, power factor, winding temperature and water level in case of hydro station and so on. Other equipment housed in the control room are: synchronizing equipment, voltage regulators, relay, Integrating meters and other appliance, as well as the mimic diagram and suitable integrating equipment to show the open or close position of the circuit breakers, isolators etc.

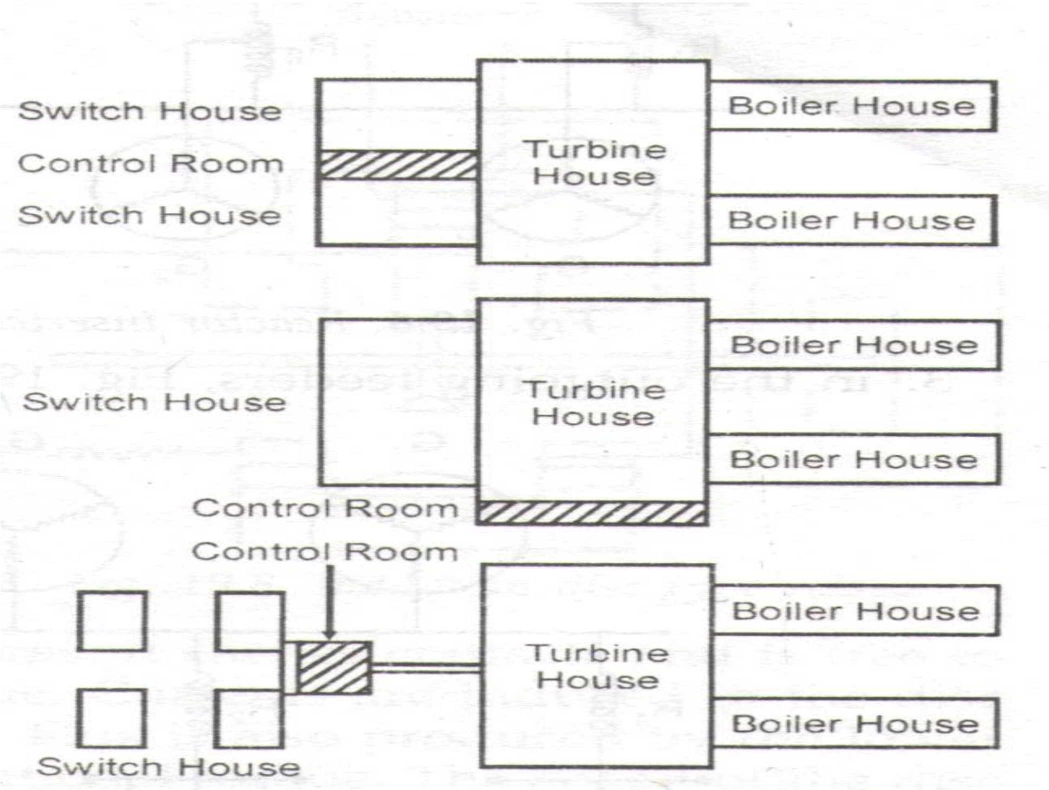


FIG.1.27 Location of control room

The location of the room in relation to other section of the station is of importance and suitable position should be obtained. It should be obtained. It should be located away from the sources of noise and it should be near the switch house to shorten the length of the multi core cables. Of course, if there is any fire in switch house, the control room should not be affected. Also there should be access from the control room to the turbine house. The various location of the control room relative to other section of the plant are shown in fig. The control should be cleancomfortable, well ventilated, well lighted and free from draughts. There should be no glare and the colour scheme should be soothing to eyes. The instruments should have clear scale properly calibrated and all the apparatus and circuit should be labelled so that they are clearly visible.

There are three forms of the control boards:

- Linear
- House shoe shaped
- Semi-circular

The latter two forms occupy more floor space but they enable all the instruments to be seen from one point. In some cases, the control board are of desk type in which the control and indication equipment are located on the front, and the relay and integration instrument place behind. A separate board can be provided for these instruments.

4.7 EXTERNAL REACTANCES

Reactors are used in many stations of large capacity to limit the current which may flow in a circuit under fault conditions. It is not feasible to provide sufficient reactance in high voltage turbo-generators. So for generators of large capacity of the above type, current limiting reactors may be used in the following manners:

- In the generator lead in
- Between the bus bar section in fig.1.28
- In the outgoing feeders in fig

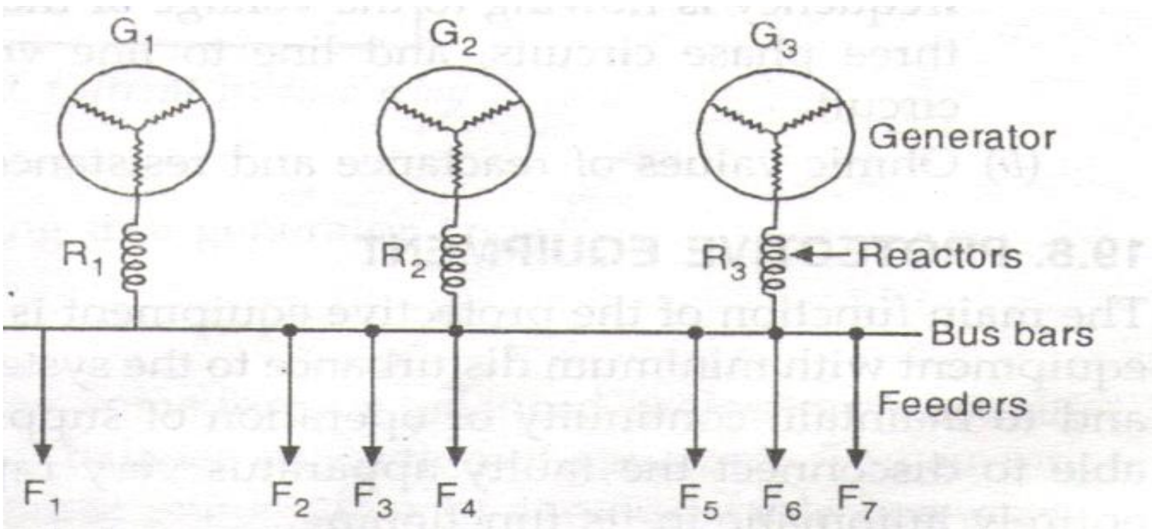


FIG.1.28

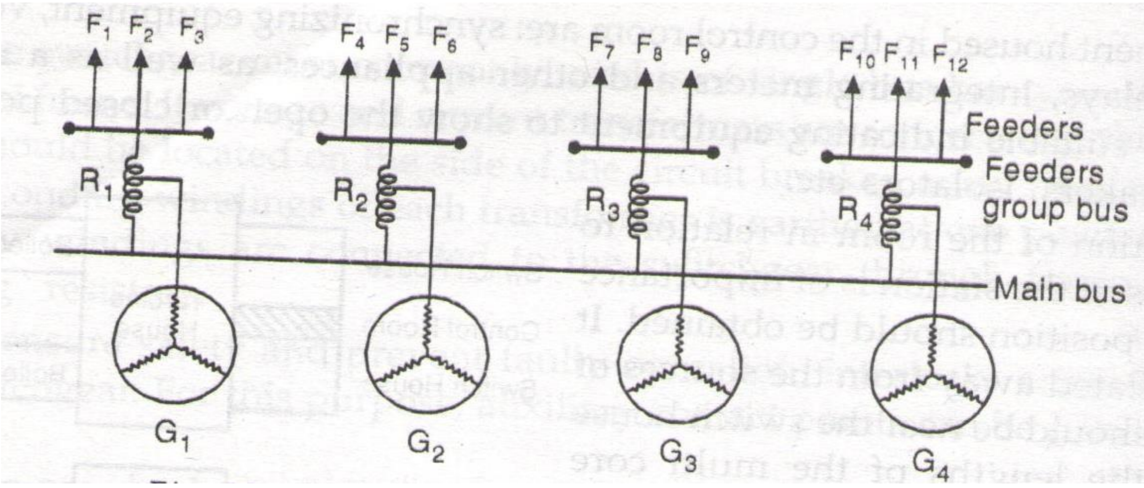


FIG.1.29

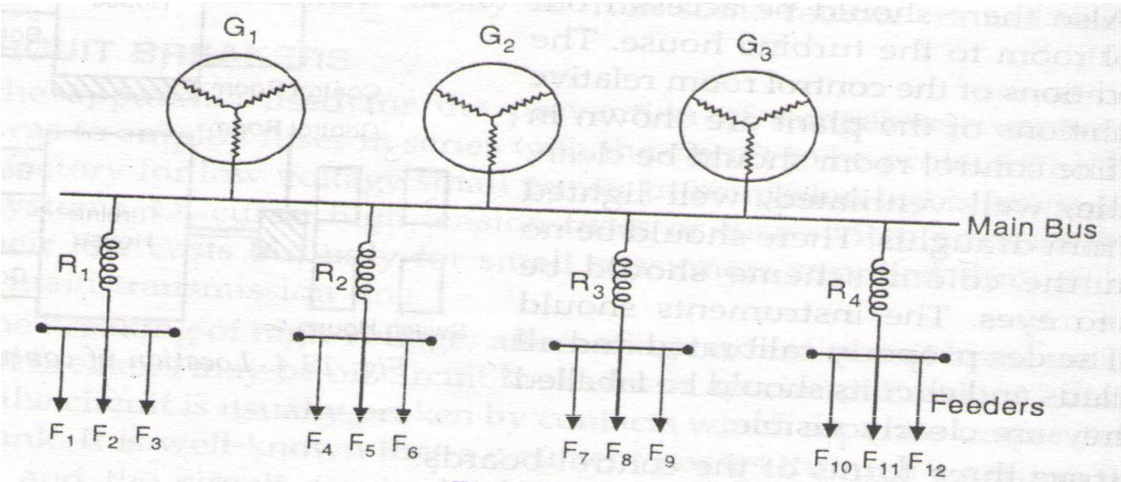


FIG.1.30

Reactors are of two types:

- Air core type
- Iron core type

Air core type reactors are constructed of several layers of standard copper conductor with either concrete or concrete separators. They are chipper than the iron core oil immersed reactors but are bulky. They give constant reactance for all current values.

Reactors are rated in two ways:

- Percentage reactors and resistant method: It is based up on the ratio of the drop across the reactor when the full current of the circuit at rated frequency is flowing to the voltage of the circuit. Line voltage is used on single phase circuit.
- Ohmic value of reactance and resistant.

4.8 PROTECTIVE EQUIPMENT

The main function of the protective equipment is to isolate or disconnected a faulty equipment with minimum disturbance to the system so as to minimize the damage and to maintain continuity of operation of supply. The protective gear must be able to disconnect the faulty apparatus very rapidly and for this it should be entirely automatic in its functioning.

4.8.1 Types of Relays

The most commonly used type of relays is the designed to operate on D.C. it consist of an armature which operates in a dc magnetic field. The armature carries one or more contacts which open or closed and it can be reset manually and automatically. The relays operating on A.C can be grouped under the following three classifications

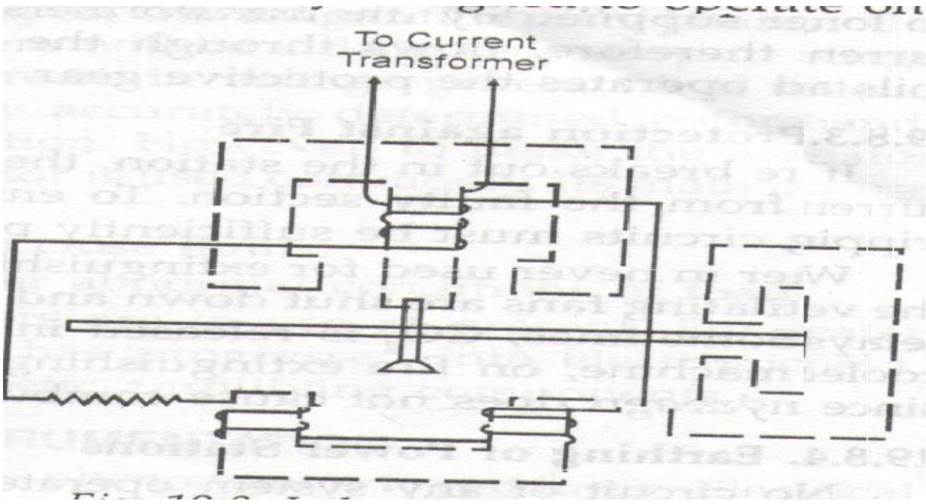


FIG.1.31 Induction disc type relay

- Induction over-current relays: - the most common type is induction disc type. This type of relays is shown in figure.

  The output of the current transformer is supplied to the windings on the centre part of the shaped core. The second winding from this place is connected to two windings on poles of the U- shaped core. The disc is mounted in between the cores. It carries contacts and is free to rotate against a mechanical restraining torque. Currents are induced in the disc due to magnetic flux across the air gaps. Flux is also produced by the lower magnet. The combined effect produces a rotational torque. The speed of the disc is controlled by using a brake magnet. The operating time varies inversely with the current supply to the relay by the current transformer.

- Attracted armature relays :

  The relays are high speed relays. It is simplest form, it consist of a single coil wound on a armature. The magnetic circuit on the armature is completed by an electric magnet carrying a contact. When the current exceeds a certain limit the relay will come in to operation.

- Current balanced relay :

  This type of relay will commonly used. It operates on the principle of the current balanced in which two currents are compared on proportionate basis. The principle of this type of relay is shown in this figure. 1.32.

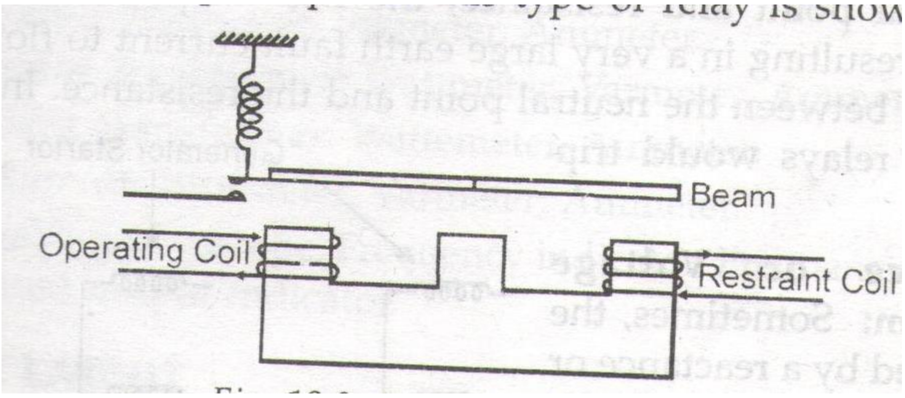


FIG.1.32 Current balance relay

4.8.2 PROTECTION OF GENERATOR:

The most faults likely occurring in a generator are

- Between phase.
- Between phase and earth.

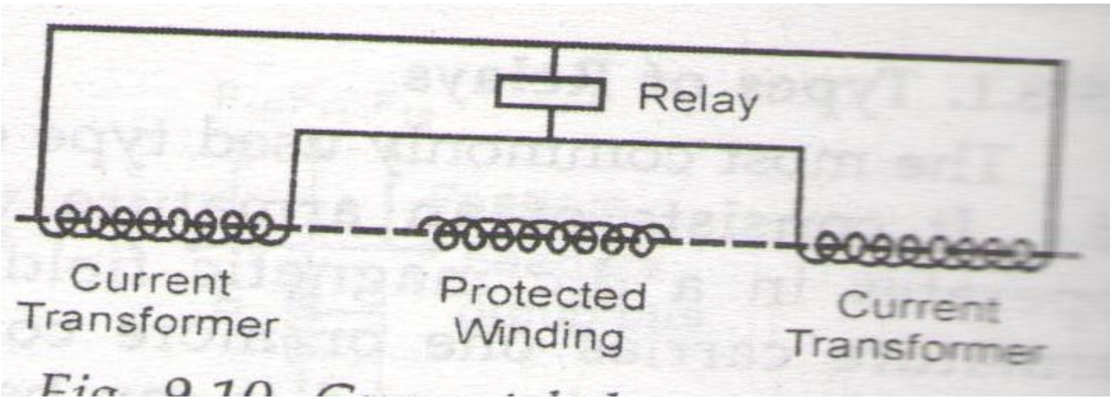


FIG.1.33 Current balance protection

To protect against these trouble, some form of balanced protection is usually employed. Figures show current balanced protection of generator. The currents transformer must be balanced against one another to another stable operation. Under normal condition, the currents does not flow through the relays coils. When fault occurs in the protected zone, the balanced is destroyed since equal current are no longer supplied by the transformers. The currents, therefore flows through the relays coils and operates the protective gear.

4.8.3 Protection against fire:

If fire breaks out in the station, the protective gear should at once cut off the current from the faulty section. To ensure this the protective gear, the relays and tripping circuit must be sufficiently protected against damage by fire.

Water is never used for extinguish the fire. If the machines are air cooled, the ventilating fans are shut down and the air dampers are closed by the tripping relays. Sometimes, CO_2 is released in to the generator. In the case of hydrogen cooled machine, on fire extinguish apparatus is needed inside the machine since hydrogen does not cause combustion.

4.8.4 Earthig of power station:

No circuit of any system operate with neutral point unearthed. The chief advantages of neutral earthing are:

- Persistent arcing grounds are eliminated.
- Use of sensitive protective gear is possible
- The system and apparatus are greatly saved from high voltage shocks. The high voltage is earthed mainly for the protection of the system while the low voltage neutral is earthed chiefly to reduce the possibility of danger to human life.
- Resister earth system: this is the most commonly used method. In this system a liquid resistance is connected direct from the neutral point to the earth. The resistance should be place as near as possible to the start point of the machine with open copper connections. Where ever possible, cable connection should be avoided, because if there is earth fault, the voltage of the neutral point rises to the line voltage momentarily, if there is a fault on the cable between the neutral point and resistance, the neutral point will be directly connected to the earth resulting in a very large earth fault current to flow. No circuit breaker is provided between the neutral point and the resistance. In the event of the earth fault, the relays would trip the machines.
- Reactance or voltage transfer system:
- Sometimes the resistance is replaced by a reactance or a voltage transformer. The chief objection to these systems is that oscillatory voltage conditions may arise at the neutral point. In the event of these conditions the machine insulation may be overstressed. The above methods of earthing are shown in fig 4.11

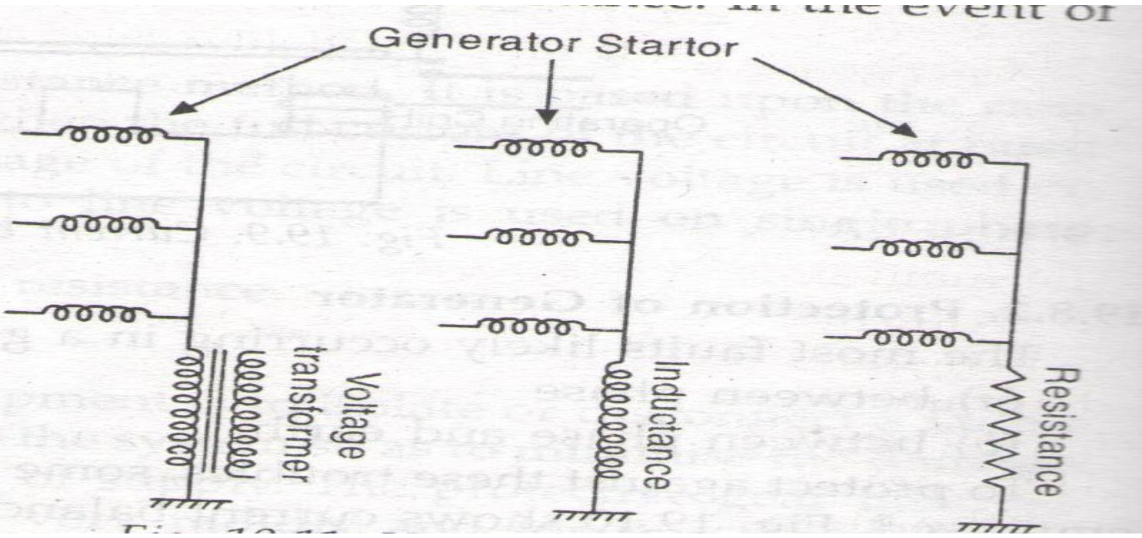


FIG.1.34

4.8.5 Automatic voltage regulation

The terminal voltage of an alternator supplying current is always fluctuating. The amount of fluctuation will depend upon the magnitude and phase of the current. If the power factor is lagging, there will be a drop in voltage and a leading power factor causes an increase in voltage generated. If the loads changed are slow and these can be fairly accurately determined before hand, adjustments can be made by hand regulation. However, to make the alternator self regulating, an automatic voltage regulator is used commonly. Its main purpose is

- To keep the correct voltage within the closed limits.
- The alternator remains stable under abnormal condition of load.

4.9 ELEMENTS OF ELECTRICAL INSTRUMENTATIONS

Electric power is measured in terms of the phenomenon it produces .electrical instruments mean the devices that measure quantitative changes by deflection of a pointer on a scale. The basic electrical measurement is of dc or ac. For the measurement of direct current, permanent magnet polarized moving coil instrument is most commonly used. If a rectifier is incorporated in it, can be used for the measurement of alternating current. The dc instrument follow the linear law i.e. the deflection of the pointer is quite nearly proportional to the value of the quantity. The dc instruments with the exceptions of wattmeter, follow the square law i.e. the angular deflection of the points is roughly proportional to the square of the value of the quantity. The ac instruments with the exception of wattmeter, follow the square law i.e. the angular deflection of the pointer is roughly proportional to the square of the value of the quantity. The following types operate on the square law: moving iron, electron dynamic and induction.

The various types of electrical instruments used in power station are

- Generator : wattmeter, varmeter, ammeter
- Generator transformer: wattmeter, varmeter, ammeter, voltmeter.
- Auxiliary transformer: wattmeter, ammeter.
- Grid circuit: wattmeter, voltmeter, ammeter
- General: synchroscope, frequency indicator, frequency comparator, total generated output indicator.

5. SUB-STATION PROTECTIVE EQUIPMENTS

5.1 Necessity & Arrangement of protective Devices

Power-system protection is a branch of electrical power engineering that deals with the protection of electrical power systems from faults through the isolation of faulted parts from the rest of the electrical network. The objective of a protection scheme is to keep the power system stable by isolating only the components that are under fault, whilst leaving as much of the network as possible still in operation. Thus, protection schemes must apply a very pragmatic and pessimistic approach to clearing system faults. For this reason, the technology and philosophies utilized in protection schemes can often be old and well-established because they must be very reliable.

Protection systems usually comprise five components:

- Current and voltage transformers to step down the high voltages and currents of the electrical power system to convenient levels for the relays to deal with
- Protective relays to sense the fault and initiate a trip, or disconnection, order;
- Circuit breakers to open/close the system based on relay and autorecloser commands;
- Batteries to provide power in case of power disconnection in the system.

- Communication channels to allow analysis of current and voltage at remote terminals of a line and to allow remote tripping of equipment.

For parts of a distribution system, fuses are capable of both sensing and disconnecting faults

A protective Device has to perform the function of carrying, making and breaking the normal load current like a switch and it has to perform the function of clearing the fault in addition to that it also has provision of metering and regulating the various parameters of electrical power system. Thus the switchgear includes circuit breaker, transformer, voltage, protection relay, measuring instrument, electrical switch, electrical, miniature circuit breaker, lightening arrestor or surge arrestor, electrical isolator and other associated equipment.

5.2 Protective Devices

5.2.1 Alternator

In a power plant, the protective relays are intended to prevent damage to alternators or to the transformers in case of abnormal conditions of operation, due to internal failures, as well as insulating failures or regulation malfunctions. Such failures are unusual, so the protective relays have to operate very rarely. If a protective relay fails to detect a fault, the resulting damage to the alternator or to the transformer might require costly equipment repairs or replacement, as well as income loss from the inability to produce and sell energy.

The Faults of ALTERNATOR & clearing of Fault is as follows

Stator Phase & Ground Faults (Merz-Price principle)

Phase and ground faults on the stator armature winding can be easily detected by a conventional percentage differential protection scheme as shown in Figure 8.5. This type of scheme is also known as *longitudinal differential scheme* in order to differentiate it from another differential scheme, known as *transverse differential scheme* which is used to detect inter-turn faults.

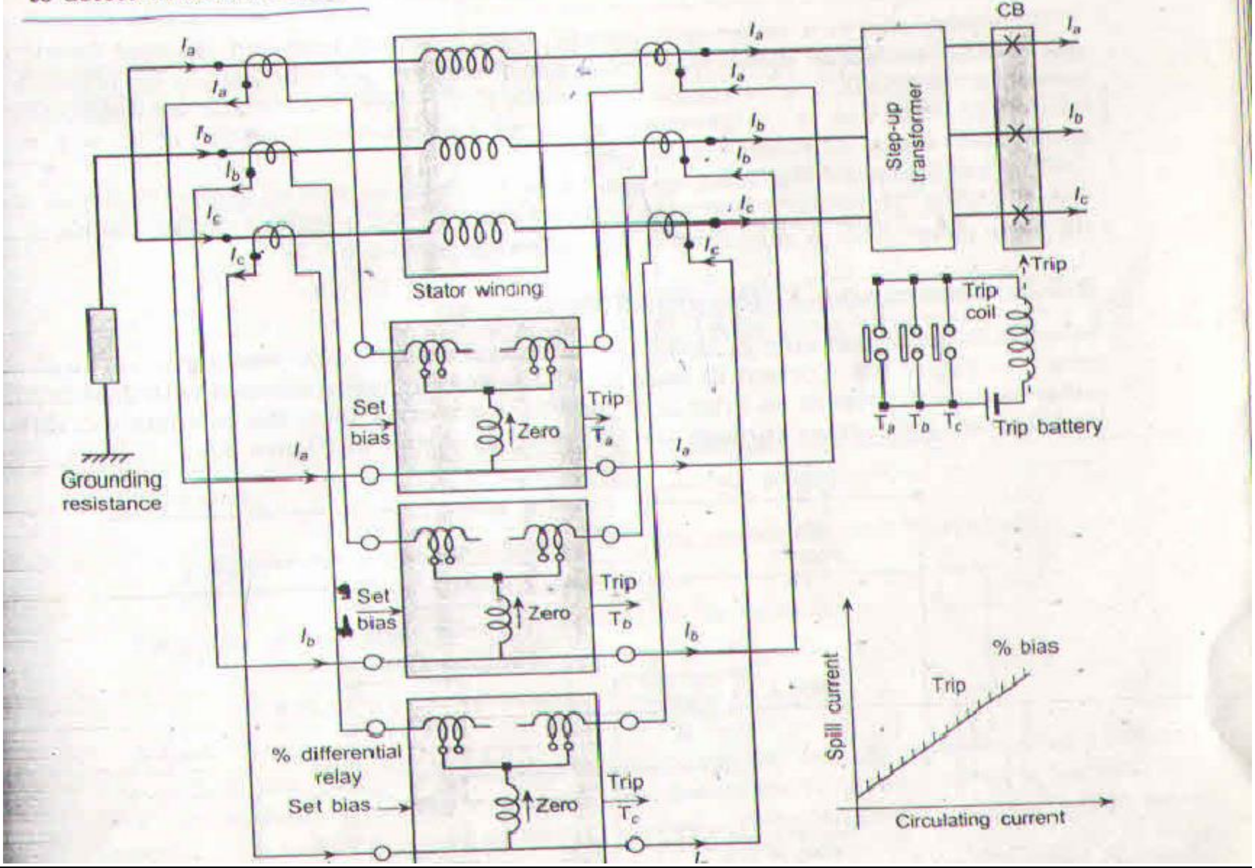


FIG.1.35

It may be noted that there are differences between the differential protection of a protection of a power transformer & that of a genertator.The percentage bias setting for the alternator differential relay is quite small as compared to that of power transformer.

Transverse differential protection:

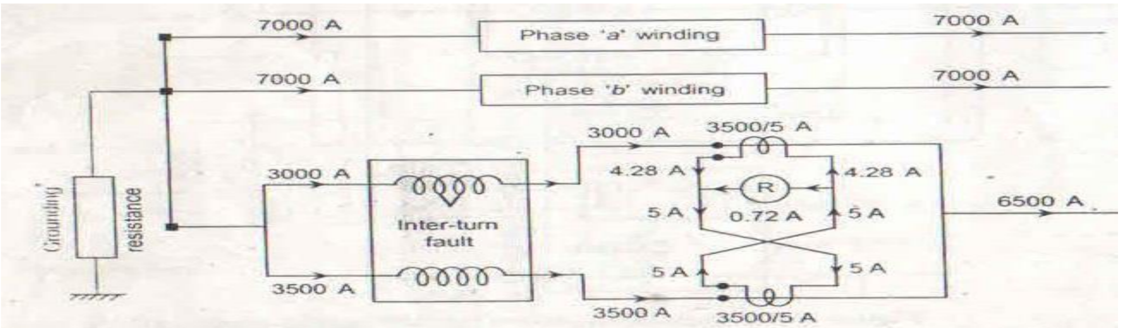


Figure 8.6 Transverse protection of generator winding.

FIG.1.36

In order to apply this type of protection a special type of split winding is required as shown in fig above. Current in each parallel section is now compared with that in other section. If there is an inter-turn fault in one section then the currents will differ and flow as spill current through the OC relay.

In above fig, only the winding with the inter-turn fault is shown in detail. The half of winding in which there is an inter-turn fault is shown to carry 3000A whereas the healthy half carries 3500 A .As seen from the figure, the current entering the phase c winding as a whole is 6500 A which is same as that leaving it. Therefore a longitudinal differential relay would be incapable of detecting such faults.

However because of the splitting and transverse connection of the CTs, there is a spill current of 0.72 A in the transverse differential relay. Thus a setting of say 0.5 A will be enough to detect such an inter-turn fault.

5.2.2 Transformer protection

Transformers are subject to a variety of faults. The most common being the winding to core faults because of weakening of insulation. Phase faults inside the transformer are rare. However such faults may take place outside the transformer, on the transformer terminals, which fall within the transformer protection zone.

Over current protection

Fig. below shows two nos of phase-fault over current relays and one ground fault over current relay for providing over-current protection to the star-delta transformer. Such a scheme may serve the purpose of providing either the primary protection for smaller transformers or the back-up protection for bigger transformers.

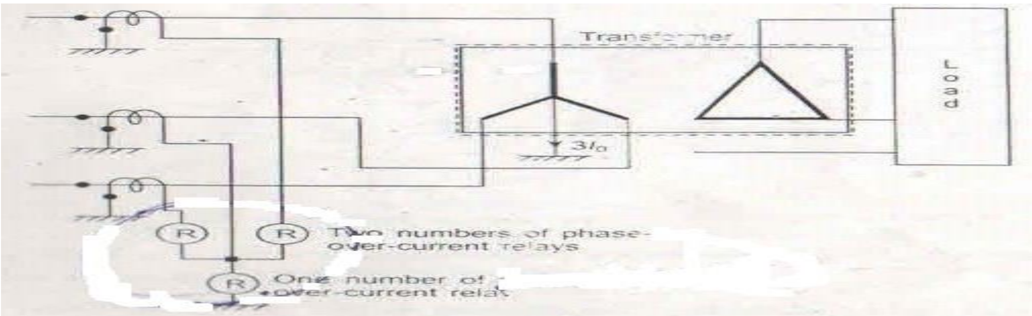


Figure 4.6 Over-current protection of a transformer.

FIG.1.37

The pick-up value of the phase –fault over-current units is set such that they do not pick up on maximum permissible overload, but are sensitive enough to pick up on the smallest phase fault. The pivk up of the earth fault relay, on the other hand is independent of the loading of the transformer.

Percentage Differential Protection of Transformers

External fault

Consider phase-c-to-ground external fault as shown in figure below.

It can seen that due to fault on phase –c there is an over-current in phase-c .this current is supplied through two of the lines on the delta side. Similarly due to the delta connections of CT secondary windings on the star side two of the pilot wires carry the fault current with the result that current circulates in two of percentage differential units and there is no current in the spill path.

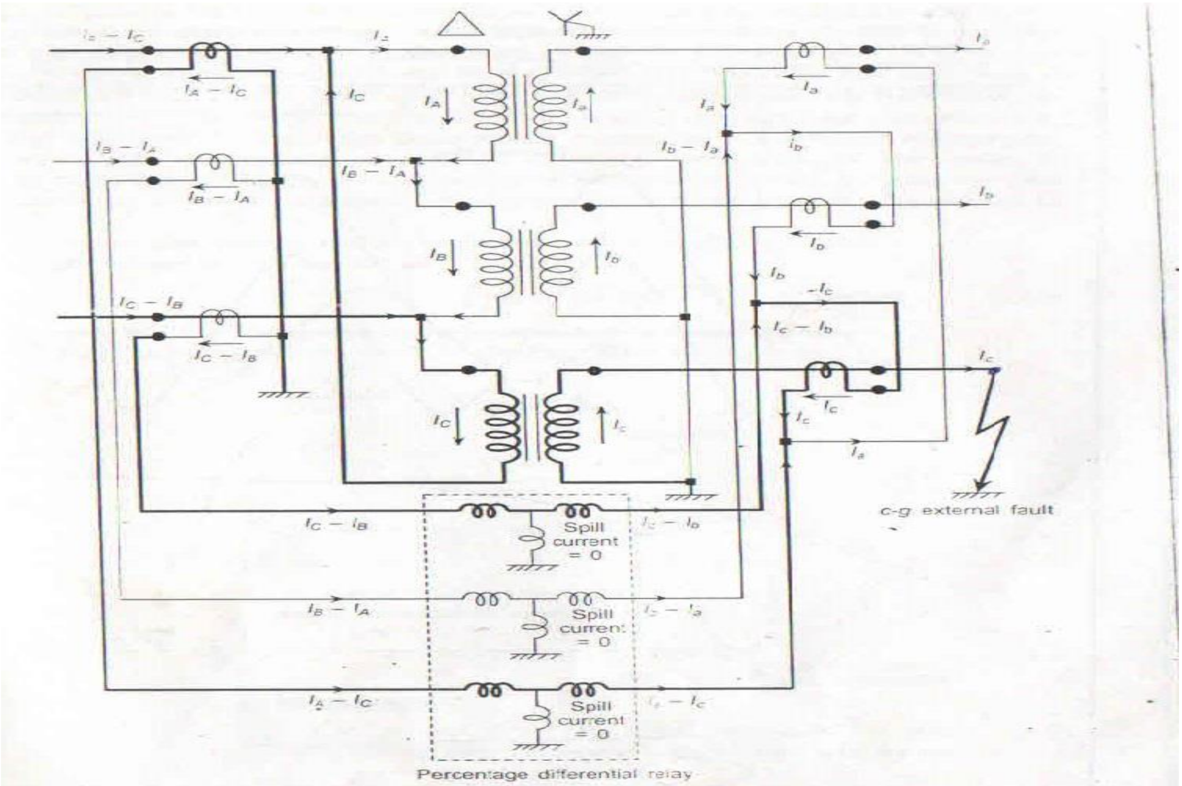


Figure 4.10 Phase c-to-ground (c-g) external fault.

FIG.1.38

Internal fault

A c –g internal fault is shown in below. The current on the delta side are exactly the same as those in case of c-g external fault .however since the fault is internal there is no fault current through primaries of CTs on the star side. The path of the fault current is shown in bold lines .it can be seen from the figure that the fault flows through the spill path in two of the percentage differential units causing them to operate thus tripping out the transformer.

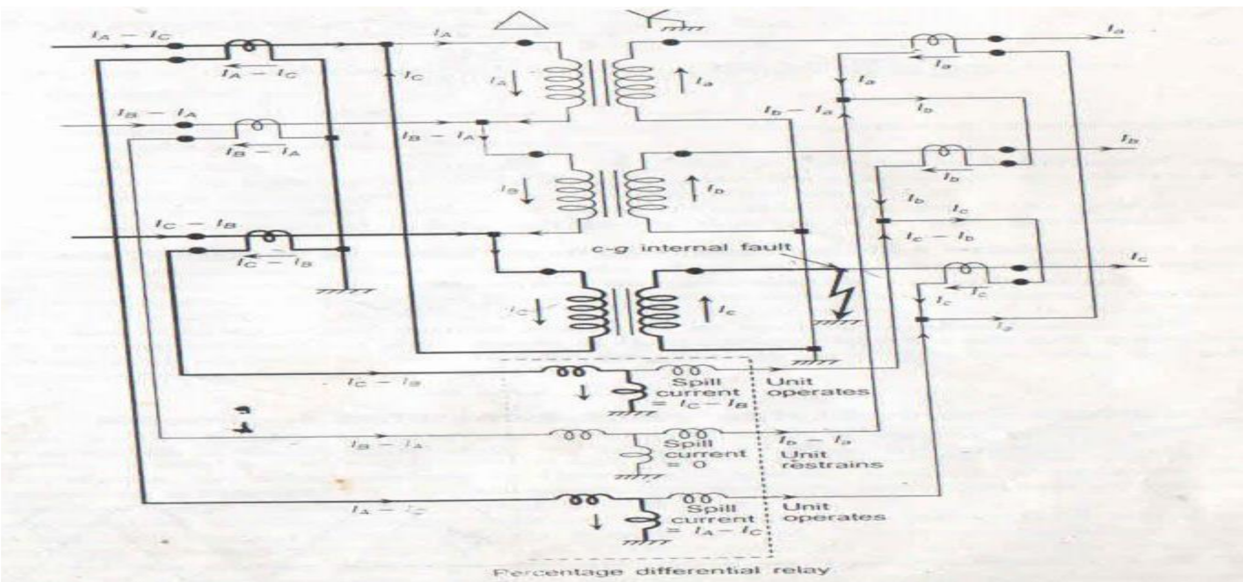


Figure 4.11 Phase c-to-ground (c-g) internal fault.

FIG.1.39

5.2.3 Bus Bar Protective Equipments

Bus-bar are the nerve system of power system where various circuits are connected together. These are the node of electrical circuit having a number of incoming line & out going lines.

A fault in a bus-bar may cause enormous damage hence protective scheme like differential protection (Mertz-price principal) for External & Internal detection of fault in bus-bar.

External Fault

The above figure shows the external fault. It can be seen that CTc, the CT on the Faulted feeder, has to carry the sum of all currents fed into the fault by various feeders. Therefore CTc sees a substantially larger primary currents than either CTa or CTb. In all likelihood, CTc will therefore become saturated. We can, therefore, no longer assume that CTc will faithfully transform the fault current. A for the sake of illustration, we have assumed that the secondary current of CTc is only 4A instead of 10A.It can be seen from above figure. & that cause spill current of 6A.

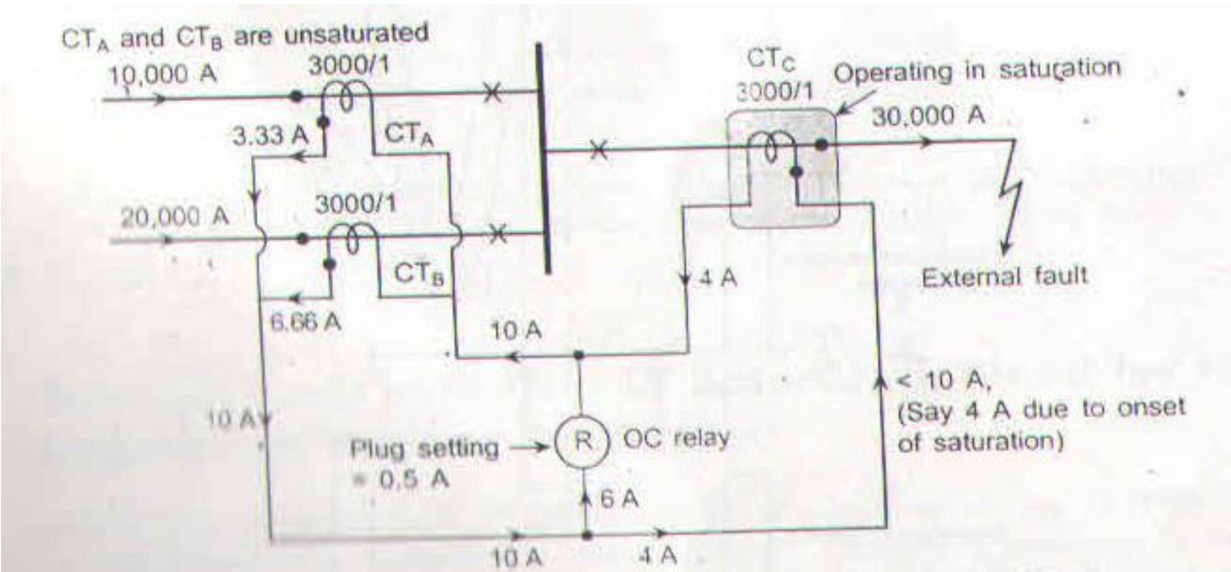


FIG.1.40

Internal Fault

As the fault shifts by a small distance to the left & becomes an internal Fault, still drawing the same current, the situation dramatically changes as far as CTc is concerned. This is depicted where in it can be seen that CTc naw does not carry any fault current. Since CTa & CTb are not carrying excessive primary currents, yhey transform the current without too much error. There is thus a spill current in the spill path & scheme operates as expected.

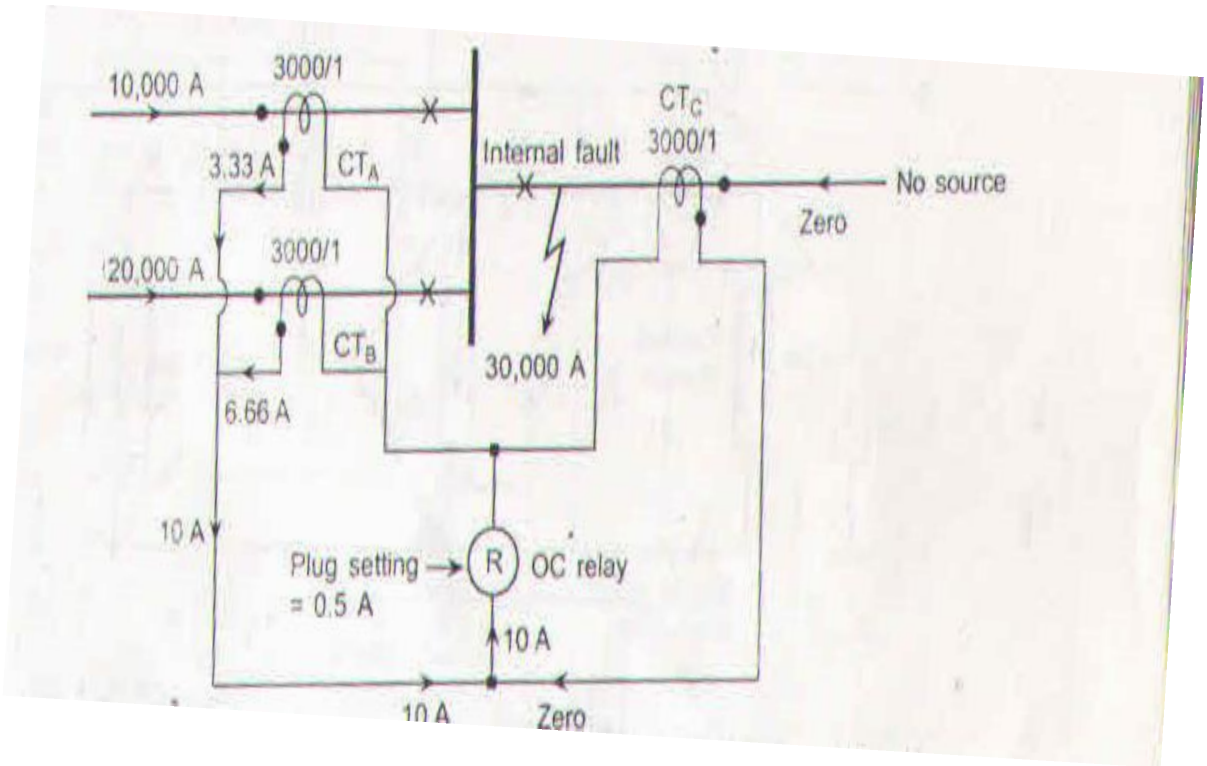


FIG.1.41

5.3 Different Types of Reactors & their Location.

The CBs connected in the power station must be capable of dealing with maximum possible short circuit currents that can occur at their point of connection. Generally the reactance of the system under fault conditions is low and fault currents may rise to a dangerously high value. In order to limit the short circuit currents to a value which the CBs can handle, additional reactance known as reactors are connected in series with the system at suitable pts.A reactor is a coil of number of turns designed to have a large inductance as compared to its ohmic resistance.

Location of Reactors

Short circuit current limiting reactors may be connected

1. In series with each generator.
2. In series with each feeder.
3. In bus-bars

Generator reactors

When the reactors are connected in series with each generator they are known as generator reactors.

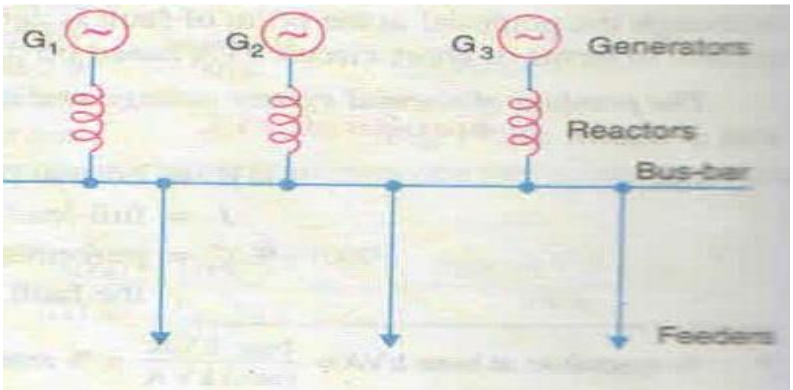


FIG.1.42

Feeder reactors

When the reactors are connected in series with each feeder they are known as feeder reactors. Since most of the short-circuits occur on feeders a large no. of reactors are used for such circuits.

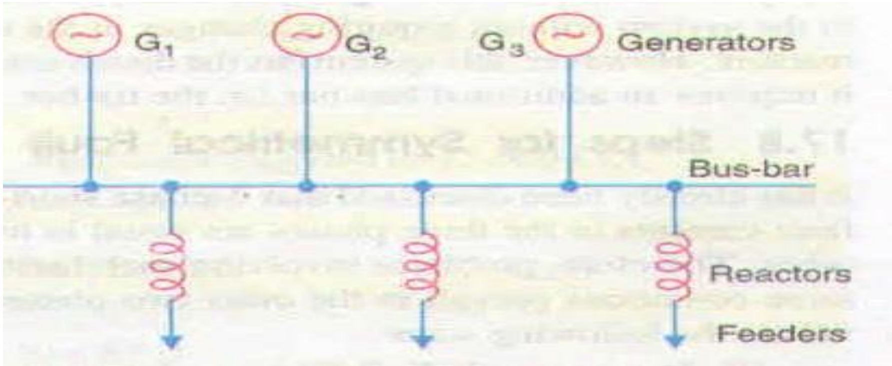


FIG.1.43

Bus-bar Reactors

The above two methods of locating reactors suffer from the disadvantage that there is considerable voltage drop and power loss in the reactors even during normal operating condition. This can be overcome by locating the reactors in the bus-bars.

Tie-bar system

There are effectively two reactors in series between sections so that reactors must have approximately half the reactance of those used in a comparable ring system.

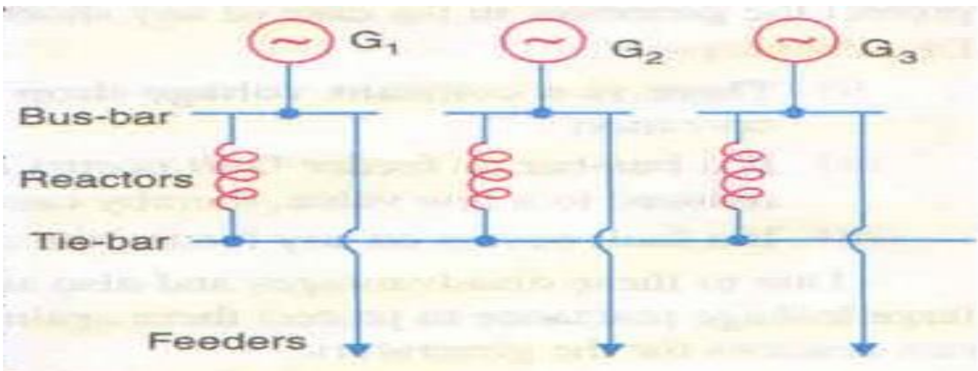


FIG.1.44

6. SUB - STATION

6.1 Control Panel Equipments

Control panels contain meters (Ammeters, Voltmeters, Wattmeter) , control switches and recorders (Frequency meter &Energy Meter) located in the control building, also called a doghouse. These are used to control the substation equipment, to send power from one circuit to another or to open or to to shut down circuits when needed. It keeps the watch over the entire circuit parameters of the substation.

Figure 1. Substation control panel

Figure 2. Substation control panel, detail

FIG.1.45

6.2 Commissioning & Testing

All new, replaced, or modified equipment and protection schemes installed in FirstEnergy substations must be properly commissioned before being placed in service. Commissioning services for equipment rated equal to, or greater than 100 kV, and the protection schemes that directly affect equipment rated equal to, or greater than 100 kV are performed by a corporate engineering department. Additionally, complete modular distribution substation configurations for all voltages (Mod Subs) are also included, since they contain a power transformer, not to mention all the elements of a complete substation in a smaller modular footprint. Mod Subs can be incorporated into an existing sub or used as a standalone sub. Finally, all power transformers greater than 2.5 MVA and all portable substations require commissioning by the corporate engineering group.

Commissioning is required for each of the following circumstances

- Installing new electrical equipment
- Installing new protection schemes
- Electrical equipment additions or replacements
- Protection scheme additions or replacements

- Electrical equipment modifications
- Protection scheme modifications
- Mod Subs (All voltages)
- Power Transformers (greater than 2.5 MVA)
- Portable Substations (all voltages)

The commissioning procedure is the general guideline that each engineer at FirstEnergy uses during the commissioning process. The procedure identifies a practical sequential approach that can be applied to every project. By following the individual steps, and applying all those which are applicable, the engineer insures that the commissioning process is always performed in a consistent and methodical manner. The steps of the commissioning procedure are as follows:

Review print package

- Confirm R&I (Relay and Instrumentation), AC, & DC schematics
- Confirm all demolition (Demo) prints
- Identify all additions and removals
- Mark prints to reflect functional test path requirements
- Mark prints to reflect voltage confirmation test requirements
- Develop a custom Checkout Guide
- Meet with all on site employees and inform them that you are the ONLY on site authority for making any changes to the prints or relay settings
- Deliver Checkout Guide to job site and affected crews
- Confirm relay and associated CT settings
- Perform new benchmark electrical equipment testing
- Perform new CT testing
- Perform CT current pushes (must be witnessed)
- Perform functional testing on all required paths (must be witnessed)
- Confirm test switch operation via negative confirmation
- Perform voltage confirmation testing
- Re-confirm proper relay settings are in correct relays
- Determine proper switching sequences and communicate with transmission and distribution dispatching authorities (TSO/DSO)
- Review all test data, Checkout Guide steps, and switching orders
- Perform switching (must be witnessed)
- Obtain load angles as required (must be witnessed)
- Inform region of follow up requirements
- Gather, organize, and file all test data and info on job (including marked up prints) in a three ring binder or other appropriate file

6.3 Substation

A **substation** is a part of an electrical generation, transmission, and distribution system. Substations transform voltage from high to low, or the reverse, or perform any of several other important functions. Between the generating station and consumer, electric power may flow through several substations at different voltage levels.

A substation may include transformers to change voltage levels between high transmission voltages and lower distribution voltages, or at the interconnection of two different transmission voltages. The word *substation* comes from the days before the distribution system became a grid. As central generation stations became larger, smaller generating plants were converted to distribution stations, receiving their energy supply from a larger plant instead of using their own generators. The first substations were connected to only one power station, where the generators were housed, and were subsidiaries of that power station.

Substations may be described by their voltage class, their applications within the power system, the method used to insulate most connections, and by the style and materials of the structures used. These categories are not disjointed; to solve a particular problem, a transmission substation may include significant distribution functions, for example.

Transmission substation

A **Transmission substation** connects two or more transmission lines.[2] The simplest case is where all transmission lines have the same voltage. In such cases, substation contains high-voltage switches that allow lines to be connected or isolated for fault clearance or maintenance. A transmission station may have transformers to convert between two transmission voltages, voltage control/power factor correction devices such as capacitors, reactors or static VAR compensators and equipment such as phase shifting transformers to control power flow between two adjacent power systems.

Distribution substation

A *distribution substation* transfers power from the transmission system to the distribution system of an area.[2] It is uneconomical to directly connect electricity consumers to the main transmission network, unless they use large amounts of power, so the distribution station reduces voltage to a level suitable for local distribution.

The input for a distribution substation is typically at least two transmission or sub transmission lines. Input voltage may be, for example, 115 kV, or whatever is common in the area. The output is a number of feeders. Distribution voltages are typically medium voltage, between 2.4 kV and 33 kV depending on the size of the area served and the practices of the local utility. The feeders run along streets overhead (or underground, in some cases) and power the distribution transformers at or near the customer premises.

.Collector substation

In distributed generation projects such as a wind farm, a collector substation may be required. It resembles a distribution substation although power flow is in the opposite direction, from many wind turbines up into the transmission grid. Usually for economy of construction the collector system operates around 35 kV and the collector substation steps up voltage to a transmission voltage for the grid. The collector substation can also provide power factor correction if it is needed, metering and control of the wind farm. In some special cases a collector substation can also contain an HVDC converter station.

Converter substations

Substations may be associated with HVDC converter plants, traction current, or interconnected non-synchronous networks. These stations contain power electronic devices to change the frequency of current, or else convert from alternating to direct current or the reverse.

Formerly rotary converters changed frequency to interconnect two systems; such substations today are rare.

Switching substation

A switching substation is a substation without transformers and operating only at a single voltage level. Switching substations are sometimes used as collector and distribution stations. Sometimes they are used for switching the current to back-up lines or for parallelizing circuits in case of failure. An example is the switching stations for the HVDC Inga–Shaba transmission line.

A switching substation may also be known as a switchyard, and these are commonly located directly adjacent to or nearby a power station. In this case the generators from the power station supply their power into the yard onto the Generator Bus on one side of the yard, and the transmission lines take their power from a Feeder Bus on the other side of the yard.

Classification by insulation

Switches, circuit breakers, transformers and other apparatus may be interconnected by air-insulated bare conductors strung on support structures. The air space required increases with system voltage and with the lightning surge voltage rating. For medium-voltage distribution substations, metal-enclosed switch gear may be used and no live conductors exposed at all. For higher voltages, gas-insulated switch gear reduces the space required around live bus. Instead of bare conductors, bus and apparatus are built into pressurized tubular containers filled with sulfur hexafluoride (SF_6) gas. This gas has a higher insulating value than air, allowing the dimensions of the apparatus to be reduced. In addition to air or SF_6 gas, apparatus will use other insulation materials such as transformer oil, paper, porcelain, and polymer insulators

Classification by structure

Outdoor, above-ground substation structures include wood pole, lattice metal tower, and tubular metal structures, although other variants are available. Where space is plentiful and appearance of the station is not a factor, steel lattice towers provide low-cost supports for transmission lines and apparatus. Low-profile substations may be specified in suburban areas where appearance is more critical. Indoor substations may be gas-insulated switchgear (at high voltages), or metal-enclosed or metal-clad switchgear at lower voltages. Urban and suburban indoor substations may be finished on the outside so as to blend in with other buildings in the area.

A *compact substation* is generally an unmanned outdoor substation being put in a small enclosed metal container in which each of the electrical equipment is located very near to each other to create a relatively smaller footprint size of the substation.

6.4 Outdoor Substation

Air Insulated Substation (AIS) or Outdoor Substations have all switchgear equipment, busbars and other switchyard equipment installed outside open to atmosphere. In earlier days for any voltage ratings AIS or outdoor substation is employed. Indoor Substation type is only employed in places where high pollution or saline environment exists. Indoor substations are of twotypes.

- Substation with conventional switchgear equipment enclosed in big building. Size of switchyard is similar to AIS Substation.

- Substation with SF6 enclosed modules (Gas Insulated Substation) in building which takes about 10% of the total AIS substation space.

Because of excellent properties of SF6 gas such as high dielectric strength, high electro negativity, for EHV substations more than 230kV now a day's Indoor Gas Insulated Substations (GIS) are employed in place of AIS substations. However the cost of GIS indoor substation is higher compared to AIS substation but it has some benefits which include high reliability, less space requirement and less maintenance.

Advantages of Outdoor Substation

- This type of substation arrangement is best suited for low voltage rating substations (step down substations) and for those substations where there is ample amount of space available for commissioning the equipment of the substation.

- The construction work required is comparatively less to indoor switch yard and the cost of switchgear installation is also low.

- In future the extension of the substation installation is easier.

- The time required for the erection of air insulated substation is less compared to indoor substation.

- All the equipment in AIS switch yard is within view and therefore the fault location is easier and related repairing work is also easy.

- There is practically no danger of the fault which appears at one point being propagated to another point for the substation installation because the equipment of the adjoining connections.

6.5 Bus Bar arrangements

Single Bus System

Single Bus System is simplest and cheapest one. In this scheme all the feeders and transformer bay are connected to only one single bus as show.

Advantages of Single Bus System

1) This is very simple in design.
2) This is very cost effective scheme.
3) This is very convenient to operate

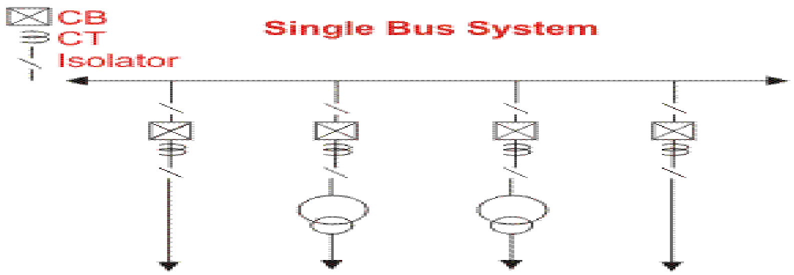


FIG.1.46

Single Bus System with Bus Sectionalizer

Some advantages are realized if a single bus bar is sectionalized with circuit breaker. If there are more than one incoming and the incoming sources and outgoing feeders are evenly distributed on the sections as shown in the figure, interruption of system can be reduced to a good extent.

Advantages of Single Bus System with Bus Sectionalizer

If any of the sources is out of system, still all loads can be fed by switching on the sectional circuit breaker or bus coupler breaker. If one section of the bus bar system is under maintenance, part load of the substation can be fed by energizing the other section of bus bar.

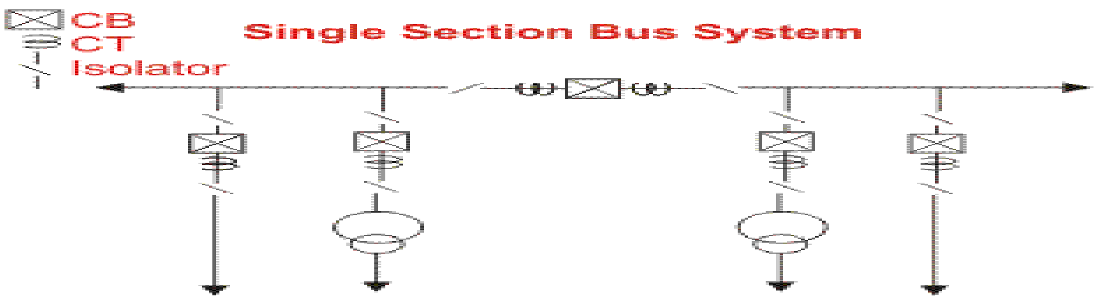


FIG.1.47

Double Bus System

1) In double bus bar system two identical bus bars are used in such a way that any outgoing or incoming feeder can be taken from any of the bus.

2) Actually every feeder is connected to both of the buses in parallel through individual isolator as shown in the figure.

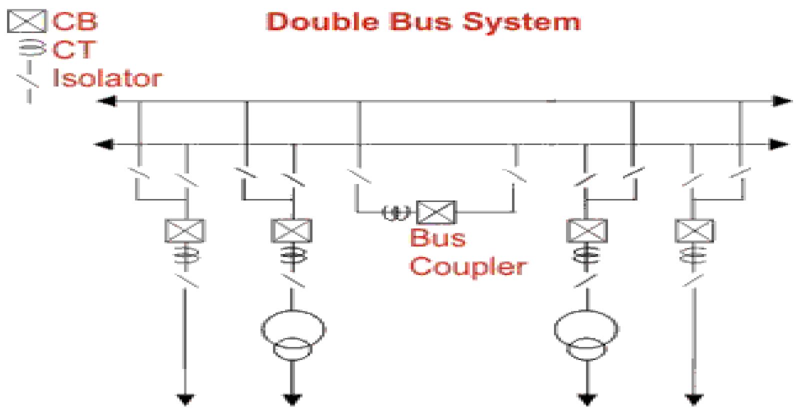


FIG.1.48

7. POLLUTION IN THE POWER PLANT

7.1 SOURSE OF POLLUTION

The major forms of pollution are listed below along with the particular contaminant relevant to each of them:

- Air pollution: - the release of chemicals and particulates into the atmosphere. Common gaseous pollutants include carbon monoxide, sulphur dioxide, chlorofluorocarbons (CFCs) and nitrogen oxides produced by industry and motor vehicles. Photochemical ozone and smog are created as nitrogen oxides and hydrocarbons react to sunlight. Particulate matter, or fine dust is characterized by their micrometre size PM_{10} to $PM_{2.5}$.

- Light pollution: - includes light trespass, over-illumination and astronomical interference.
- Littering: - the criminal throwing of inappropriate man-made objects, unremoved, onto public and private properties.
- Noise pollution: - which encompasses roadway noise, aircraft noise, industrial noise as well as high-intensity sonar.
- Soil contamination occurs when chemicals are released by spill or underground leakage. Among the most significant contaminants are hydrocarbons, heavy metals, MTBE,[19] herbicides, pesticides and chlorinated hydrocarbons.
- Radioactive contamination, resulting from 20th century activities in atomic physics, such as nuclear power generation and nuclear weapons research, manufacture and deployment. (See alpha emitters and actinides in the environment.)

- Thermal pollution, is a temperature change in natural water bodies caused by human influence, such as use of water as coolant in a power plant.
- Visual pollution, which can refer to the presence of overhead power lines, motorway billboards, scarred landforms (as from strip mining), open storage of trash, municipal solid waste or space debris.
- Water pollution, by the discharge of wastewater from commercial and industrial waste (intentionally or through spills) into surface waters; discharges of untreated domestic sewage, and chemical contaminants, such as chlorine, from treated sewage; release of waste and contaminants into surface runoff flowing to surface waters (including urban runoff and agricultural runoff, which may contain chemical fertilizers and pesticides); waste disposal and leaching into groundwater; eutrophication and littering.

7.2 Water Pollution control

Pollution control is a term used in environmental management. It means the control of emissions and effluents into air, water or soil. Without pollution control, the waste products from consumption, heating, agriculture, mining, manufacturing, transportation and other human activities, whether they accumulate or disperse, will degrade the environment. In the hierarchy of controls, prevention and waste minimization are more desirable than pollution control. In the field of land development, low impact development is a similar technique for the prevention of urban runoff.

Practices

- recycling
- reusing
- Waste minimisation
- mitigating
- preventing
- compost

7.3 Pollution control devices

- Dust collection systems
  - Baghouses
  - Cyclones
  - Electrostatic precipitators
- Scrubbers
  - Baffle spray scrubber
  - Cyclonic spray scrubber
  - Ejector venturi scrubber
  - Mechanically aided scrubber
  - Spray tower

  - Wet scrubber
- Sewage treatment
  - Sedimentation (Primary treatment)
  - Activated sludge biotreaters (Secondary treatment; also used for industrial wastewater)
  - Aerated lagoons
  - Constructed wetlands (also used for urban runoff)
- Industrial wastewater treatment
  - API oil-water separators[25][48]
  - Biofilters
  - Dissolved air flotation (DAF)
  - Powdered activated carbon treatment
  - Ultrafiltration
- Vapor recovery systems
- Phytoremediation

Air Pollution Control

Our air pollution control plants, pollution control systems, containing scrubbers control air pollution from stationary sources. It employs a liquid medium generally water, to remove particulate and gaseous contaminants from the exhaust by washing. From the application point of view, scrubbers can be classified in to 3 broad categories namely Fume Extraction Systems, Pneumatic Dust Handling Systems and Thermal Utility Systems.

For controlling air pollution we use device like Settling Chamber, Cyclone, Fabric Filter, Electrostatic Precipitator, Scrubbers or Wet Collectors.

Solid Waste Control

The solid wastes are control by this method.

Landfill

Disposal of waste in a landfill involves burying the waste and this remains a common practice in most countries. Landfills were often established in abandoned or unused quarries, mining voids or borrow pits. A properly designed and well-managed landfill can be a hygienic and relatively inexpensive method of disposing of waste materials. Older, poorly designed or poorly managed landfills and open dumps can create a number of adverse environmental impacts such as wind-blown litter, attraction of vermin, and generation of liquidleachate. Another common product of landfills is gas (mostly composed of methane and carbon dioxide), which is produced fromanaerobic breakdown of organic waste. This gas can create odor problems, kill surface vegetation and is a greenhouse gas.

Incineration

Incineration is a disposal method in which solid organic wastes are subjected to combustion so as to convert them into residue and gaseous products. This method is useful for disposal of residue of both solid waste management and solid residue from waste water management. This process reduces the volumes of solid waste to 20 to 30 percent of the original volume. Incineration and other high temperature waste treatment systems are sometimes described as "thermal treatment". Incinerators convert waste materials into heat, gas, steam, and ash.

Recycling

Recycling is a resource recovery practice that refers to the collection and reuse of waste materials such as empty beverage containers. The materials from which the items are made can be reprocessed into new products. Material for recycling may be collected separately from general waste using dedicated bins and collection vehicles, a procedure called kerbside collection. In some communities, the owner of the waste is required to separate the materials into various different bins (e.g. for paper, plastics, metals) prior to its collection. In other communities, all recyclable materials are placed in a single bin for collection, and the sorting is handled later at a central facility. The latter method is known as "single-stream recycling."[10][11]

The most common consumer products recycled include aluminium such as beverage cans, copper such as wire, steel from food and aerosol cans, old steel furnishings or equipment, polyethylene and PET bottles, glass bottles and jars, paperboard cartons, newspapers, magazines and light paper, and corrugated fibreboard boxes.

Sustainability

The management of waste is a key component in a business' ability to maintaining ISO14001 accreditation. Companies are encouraged to improve their environmental efficiencies each year by eliminating waste through resource recovery practices, which are sustainability-related activities. One way to do this is by shifting away from waste management to resource recovery practices like recycling materials such as glass, food scraps, paper and cardboard, plastic bottles and metal.

8. VOLTAGE CONTROL

8.1 Methods of voltage control by reactive power sharing:

The conventional means of reactive power injection are:

1. Shunt capacitors/reactors.
2. Series capacitors
3. Synchronous condensers.

These are discussed in this section

SHUNT REACTORS

Shunt reactors are either permanently connected to the transmission and distribution system or they are switched. Shunt reactors are used to compensate the effect of line capacitance, especially to limit voltage rise on light loads.

Assume a simple system with an EHV line shown in fig.8.1 and the phasor diagram in fig.

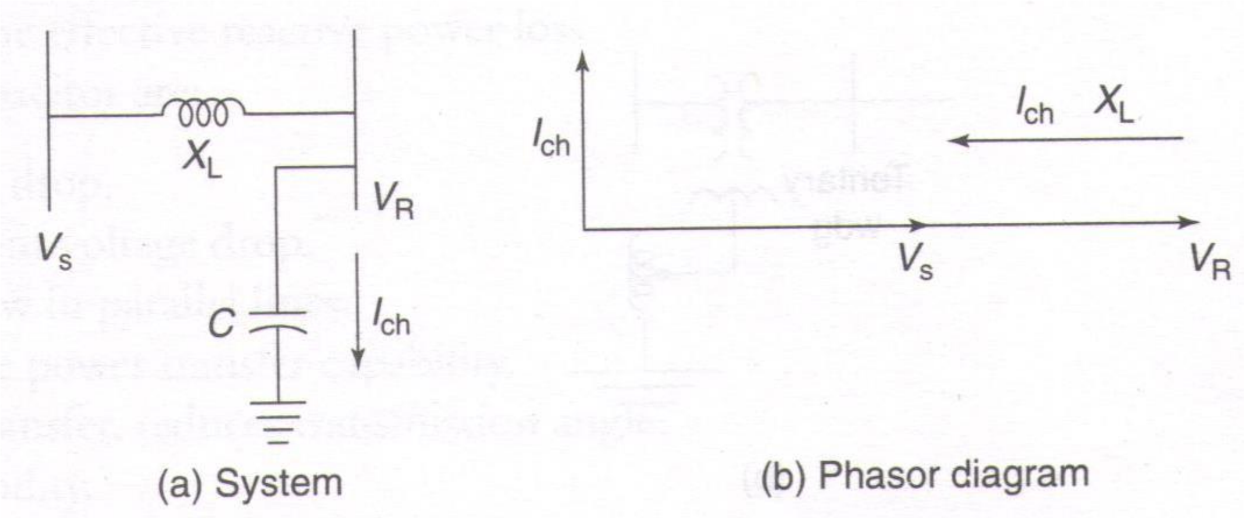


Figure.1.49

With the receiving end open, capacitive line charging current I_{ch} is drawn, which leads V_R

By 90°. This causes a drop $I_{ch}X_L$ gives V_s. we see that V_R>V_S. This voltage rise at the receiving end will also be present when an EHV line is supplied from a weak source and is called the Ferranti effect. To compensate for this voltage rise, shunt reactors have to be connected. Shunt reactors in EHV lines are connected as follows:

1. A shunt reactor of sufficient size must be permanently connected to limit fundamental frequency temporary overvoltage to about 1.5 Pu for less than 1s. These reactors are also useful in limiting overvoltages due to switching transistor.
2. Switched reactors are connected to the EHV bus to maintain normal voltage under no-load / light load condition.

The connection are shown in figure 8.2(a)

Shorter lines are supplied from strong systems do not need permanent rectors. Only switchable reactors are used. Trapped shunt reactors are also used as shown in figure 8.2 (b)

SHUNT CAPACITOR

Shunt capacitors supply reactive power at a bus and are used with lagging loads. They boost voltages and are used extensively throughout the system in a wide range of ratings and sizes. Their main advantage is low cost and flexibility. The reactive power output is proportional to the square of voltage which is a disadvantage.

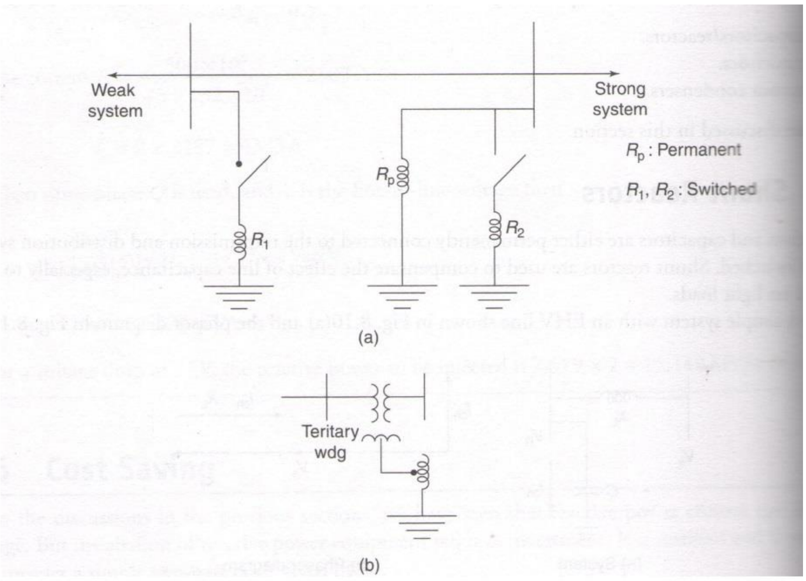


Figure.1.50

Shunt capacitor are extensively used in distribution feeders for power factor improvement and feeder voltage control. Connecting a capacitor at the load end compensates for the lagging current drawn by the load, thus improving the receiving end bus power factor. In atypical industrial plant, the power factor correction is done at different levels- plant, individual drives, and group of drives– as shown in fig 8.3

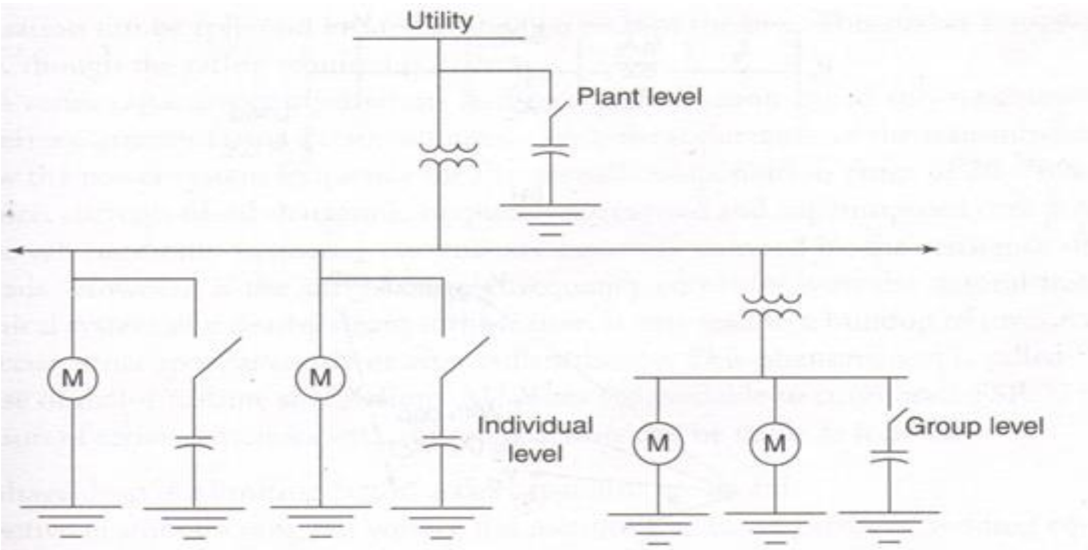


Figure.1.51

In order to compensate for I^2X losses in transmission lines, capacitors banks of appropriate sizes are connected to HV bus or tertiary winding of the main transformer. They are switched capacitor and provide a simple method of controlling transmission system voltages. The size of the capacitor is decided by performance detailed load flow analysis. The voltage rating of the shunt capacitor is normally slightly higher than the bus voltage.

SERIES CAPACITORS

Series capacitors are connected in series with line conductors to compensate the inductive reactance of the line. The power transfer from a bus voltage $V_1$to another bus voltage V_2, connected through a line of reactance X_{12} is given by

A series capacitor would partially compensate for X_{12} and thus increase maximum power that can be transmitted, reducing the effective reactive power loss.

The uses of series capacitor are:

1. Reduce line voltage drop.
2. Limits load dependent voltage drop.
3. Influences power flow in parallel lines.
4. Increase steady state power transfer capability.
5. For a given power transfer, reduces transmission angle
6. Increase system stability.

The line with the series capacitor and the corresponding phasor diagram is shown in fig 8.4

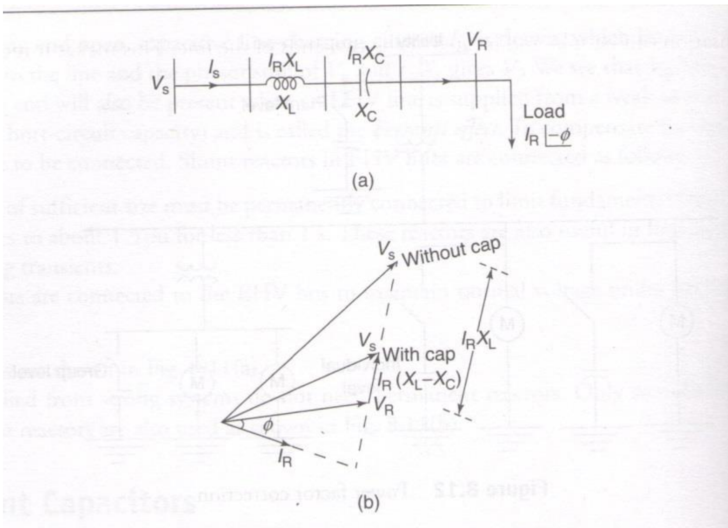


Figure .1.52

Series capacitors are subjected to high over-voltages produced when a short circuit current flows through the capacitor. The capacitor is protected using spark gaps and nonlinear resistor across it, as shown in figure 8.5. Since series capacitors are operate in line potential, they must be insulated from the ground some consideration in application of series capacitors are:

1. Rise in voltage on one side of capacitor due to line reactive current, during power swings or heavy power transfer. This may cause damaging stress on equipment on the side experiencing high voltage implying higher rating of them.
2. In case of short circuits in the line, the voltage across the capacitors will tend to much higher than the normal voltage across it. Hence it is not economical to design the capacitor for this rating. Therefore the capacitor is bypassed during a fault and re-inserted after clearing a fault. Provision should be made for the facility.

The commonly used schemes for protection and bypassing are shown in fig. 1.52

3. Location of series capacitor bank is influenced by cost, accessibility, fault level, relaying, voltage profile and power transfer levels. Mid-point of the transmission line is preferred when compensation is less than 50%. But this location is not convenient in terms of access for monitoring and maintenance.

   The compensation can be split and located at the two ends of the line. This makes it more accessible for maintenance, though the rating required is higher.

Lines with series capacitor compensation lead to a phenomenon called sub-synchronous resonance (SSR). The series capacitor forms a resonant circuit with the inductance of the transmission line of a frequency below the power system frequency for the normal compensation range of 20-70%. In the event of a disturbance, currents of sub harmonic

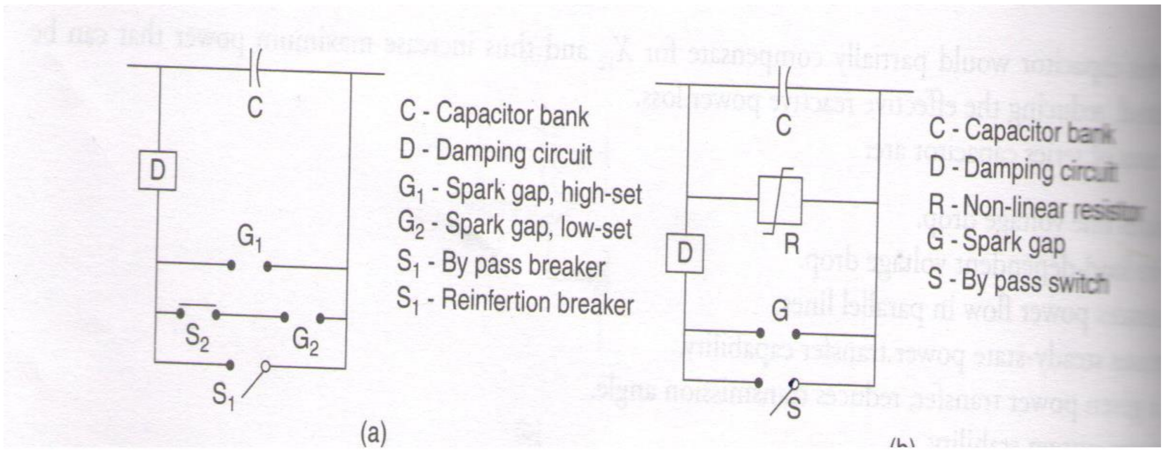


Figure.1.53

Frequency are excited and superimposed over power frequency currents. The sub-harmonic frequency currents are generally damped by the resistance of the line and the associated loads. However if sub harmonic frequency coincides with the natural frequency of the shaft mechanical system of a nearby steam turbine unit, it may lead to build up a torsional oscillations, which can occur either spontaneously or after a disturbance. This phenomenon is called SSR and has been cause of major turbine shaft failure. Measures are available to counteract SSR.

The compensation of series capacitors with shun capacitors can be made as follows:

1. If the line voltage drop is a limiting factor, series capacitor are useful.
2. They are effective I smoothening out voltage fluctuations due to arc furnaces, welding equipment etc.
3. Series capacitors are not useful if VAR requirement is small.
4. If thermal considerations are a limitation to the line current, shunt capacitors should be used.
5. If the line reactance is high, series capacitors should be used to improve the stability.

SYNCHRONOUS CONDENSERS (SYNCHRONOUS PHASE MODIFIERS)

A synchronous condenser is asynchronous machine running without a prime mover or a mechanical load. We can say that it is a synchronous motor running on no-load. When connected at a bus, it can control the bus voltage by absorbing or generating reactive power. If a load is connected at the bus and draws lagging current, the synchronous condenser can be made to compensate the lagging current by drawing a leading current, thus improving the power factor. The power factor of the synchronous condenser can be varying the excitation. A plot of the power factor versus field current for synchronous motor is shown in figure8.6. I_{f0} is the field current at which the power factor is unity.

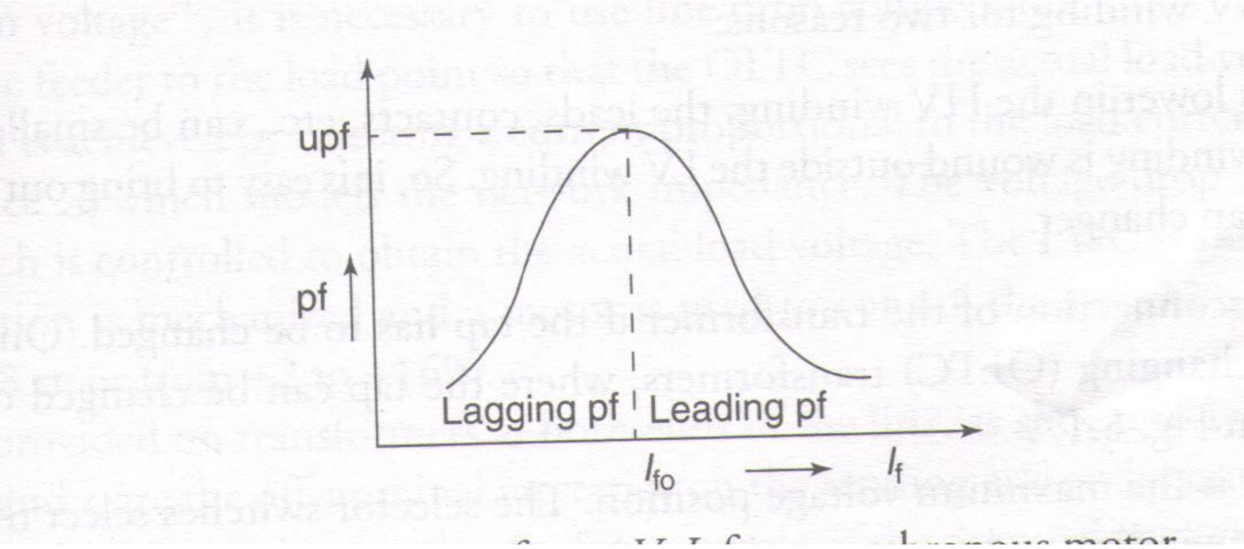


Figure.1.54

From figure 1.54 we see that for $I_f < I_{f0}$ (under excitation) the synchronous motor draws a lagging currents and for $I_f > I_{f0}$ (over excitation) it draws leading currents. With a voltage regulator, the excitation can be automatically adjusted to change the reactive power and thus maintain the bus voltage constant. Since, it is on no-load; the real power drawn is only to meet the losses. They do not produce excessive voltage levels and are not susceptible electrical resonance. They provide a good alternative to shunt capacitor. Synchronous condensers are also called synchronous compensator or synchronous capacitors. And added advantage is that being a rotating a machine, its stored energy is useful to ride through transient disturbances like voltage sags.