13

Power Systems

TOPICS DISCUSSED

- Sources of energy for generation of electricity
- Thermal power stations
- Hydroelectric power stations
- Nuclear power stations
- Electricity from solar energy, wind energy, biomass energy, tidal energy, ocean energy, and geothermal energy
- Mini/micro hydel power stations
- Transmission and distribution of electricity
- Domestic wiring, earthing, and protective devices
- Testing of installation and safety precautions
- Efficient use of energy

13.1 INTRODUCTION

We have known that energy is available in nature in different forms like in fossil fuel such as coal, gas, and oil; high-speed wind; falling

Electricity in large quantity is produced in power houses through a turbine–generator set. The turbines are rotated by pressurized steam or the potential energy of water. The generator is rotated by the turbine. The generator produces electricity which is sent for use to various places through transmission lines and distribution networks. An electrical power system consists of generation, transmission, distribution, and utilization of electricity.

The first electric supply system was set up in 1882 in New York City, USA. The system involved electricity generation through a dc generator driven by a steam engine. The electricity generated was distributed for local use by underground cables for lighting purpose only. Gradually, power systems started growing in size. Large size ac generators were installed in power houses to generate electricity in the Mega Watt range and at higher voltage. By using transformers, the generated electricity was stepped up to high voltages such as 132 kV, 220 kV, 480 kV and so on. The magnitude of stepping up of voltage depended upon the distance to which the generated electricity had to be transmitted for use. Thus, high-voltage and extra-high-voltage transmission systems came into existence. At the receiving end of the transmission line, the voltage level is brought down for distribution to different distribution substations where the voltage level is further brought down for supplying to consumers. The distribution system is constituted by overhead lines and underground cables.

A number of control devices are used at various stages of the power system for safe, efficient, reliable, and economic use of electricity. The control devices include different types of relays, switchgear, switch, fuse, etc.

Transformers are used at various places in the power system for stepping-up or stepping-down the system voltage. The voltage level of the power system has been designated as follows.

Extra high voltage, i.e., EHV: above 220 kV and upto 800 kV.

High voltage, i.e., HV: above 66 kV and upto 220 kV.

Medium voltage, i.e., MV: above 1 kV but less than 66 kV.

Low voltage is LV: 1 kV or less than 1 kV.

The power system can broadly be divided into three sub-systems, i.e., *generation*, *transmission*, and *distribution* excluding the utilization part. These are discussed in some detail as follows.

13.2 GENERATION OF ELECTRICITY

Electricity for commercial use is generated in power houses by converting primary sources of energy to electricity. The sources of energy are either *non-renewable* or *renewable*. For example coal, oil, gas, etc. are non-renewable sources of energy. They get exhausted once used. On the other hand, solar energy, energy of river water, and wind are renewable sources of energy. They do not get exhausted. The various sources of energy are mentioned in the following section.

generator which produces electricity. Use of coal leaves a huge quantity of ash and produces fuel gases. They pollute the environment, and therefore need to be handled carefully.

2. *Fuel oil*: Fuel oil is a product of oil refinery after the crude oil has been processed. Fuel oil produces no ash. The design of its furnace is simpler as compared to a coal-fired one.
3. *Gas*: An important energy source, it contain's into methane (CH_4). Liquefied petroleum gas (LPG) is one of the petroleum products produced in oil refineries.
4. *Solar*: Electricity using the sun's rays can be produced through the photovoltaic system or through solar thermal technologies. Solar photovoltaic system converts the sun's energy directly using solar cells (semiconductor device). Solar thermal technologies convert radiant energy of the sun into thermal energy and then into electricity.
5. *Wind*: Wind energy system converts the kinetic energy of wind into electricity by using wind turbines coupled with a generator. The wind velocity of a particular location depends on the height and the nature of the terrain. Wind results from temperature gradients between the Equator and the Poles, and between land and sea.
6. *Water*: The potential energy stored in water can be utilized as the water is allowed to fall from a higher to a lower level. This can be achieved by constructing a dam on a river at a suitable place where the gradient is high. Another energy source is from the kinetic energy and the potential energy of ocean waves. A tidal energy of water is extracted by creating a dam at a suitable place, using a turbo-generator and a sluice gate in the dam to allow the tidal flow to enter or leave the tidal basin.
7. *Biomass*: These are agricultural and forestry wastes, municipal wastes, the waste from the crushing of sugar canes (bagasse) etc. Biomass is burnt to produce steam which will feed a turbo-generator to produce electricity. Alternatively, biomass may be processed to produce gaseous output to run a gas turbine–generator set.
8. *Geothermal*: Steam and hot water produced inside the earth can be used to generate electricity.

The different technologies used to produce electricity from various energy sources are discussed in brief in the following section.

13.4 THERMAL POWER GENERATION FROM FOSSIL FUEL

In a thermal-power-generating station the heat energy from coal, oil or gas is utilized to produce steam and run steam turbines. The steam turbines are coupled with generators to produce electrical power output. A coal-based thermal plant is described in brief in the following section.

13.4.1 Coal-fired Thermal Power Stations

Coal is first powdered, i.e., pulverized and burnt in a furnace and the heat energy is used to boil water in the boiler to produce steam. The steam from the boiler is taken to the turbine. The turbine works as a prime mover (drive) to the generator. Thus, the mechanical energy of the turbine is converted into electricity. The generated electricity is transmitted to various places through transmission lines and other types of losses at various stages of conversion. Fig. 13.1 shows a schematic representation of a coal-fired power station. As can be seen from the figure, the steam after passing through the turbine goes to a condenser where it is condensed into water. This water is again fed to the boiler for producing steam. The heat from the used steam is taken out and dissipated in the cooling tower.

In coal-fired stations, the coal is brought from the coal storage area through the coal conveyer to the coal hopper placed near the boiler. The coal is then pulverized, i.e., made into powdered form so that complete combustion of coal takes place in the furnace. The pulverizer may be a rotating drum grinder or other type of grinders.

Sufficient air is required in the furnace for combustion. Air is drawn from the atmosphere by the use of a forced draft fan (FD Fan). The FD fan takes air from the atmosphere and the air is preheated before injecting through air nozzles on the furnace inside wall. The induced draft fan (ID Fan) assists the FD fan by drawing out combustible gases from the furnace and maintaining a certain negative pressure in the furnace. Maintaining a certain negative pressure inside the furnace avoids any backfiring through any opening. An *electrostatic precipitator* is used before the ID fan (not shown in the figure) to collect the fine dust particles so that these are not thrown into the atmosphere along with the flue gases and pollute the atmosphere. This is a must requirement provided by the environmental protection law, and the power stations have to abide by this requirement of installing dust collectors from the flue gases.

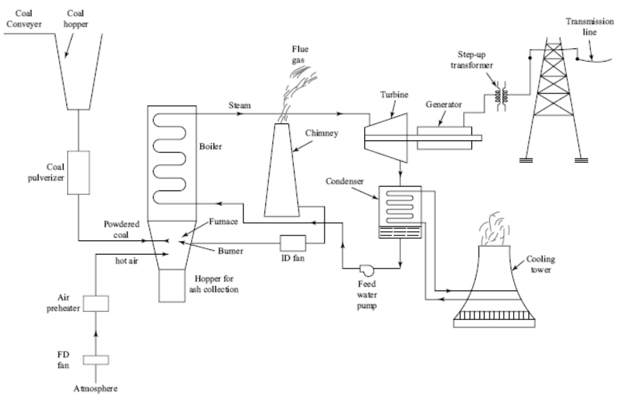


Figure 13.1 Schematic diagram of a coal-fired thermal power plant

Steam is taken out continuously from the boiler to the turbine. At the other side of the turbine, used steam is condensed to water and fed back to the boiler through a feed water pump. Thus, there is continuous withdrawal of steam and continuous return of condensed water to the boiler. However, there is some loss of water in the form of steam due to leakage, etc. This has to be made up by adding make-up water to the boiler water system. Boiler water has to be treated to remove calcium, magnesium, and other salts otherwise these may form undesirable deposits in the water flow system. A water treatdreds of megawatts are installed to reduce the capital cost per kilowatt of energy produced.

It may be noticed that in a thermal power station, steam and hot water are produced along with electricity. The waste heat in the form of hot air and steam can be used in certain process industries like paper mills, textile mills, food-processing industry, chemical industries, etc. When the otherwise waste heat is used, the overall plant efficiency is increased.

The system where electricity, steam, and hot water are simultaneously made available, is called *cogeneration*. The efficiency of a thermal power plant is around 40 to 50 per cent. Cogeneration increases the overall efficiency.

13.4.2 Gas-fired Thermal Power Stations

Natural gas is used as the source of energy to generate electricity. A gas turbine is the prime mover which will drive the generator. The hot gases exhausted from the turbines can be passed through a *heat exchanger* to produce steam. This steam can be used to run a steam turbine which would drive another generator. This way, the total thermal efficiency of the plant can be increased. This method is called the *combined-cycle method of generation of electricity*. If it is decided not to use the hot gases exhausted from the gas turbine for further generation of electricity, the hot gases can be used to produce steam for use in various industrial processes. Gas-fired stations are more environment friendly as compared to coal-fired power stations, as the flue gases emitted contain almost zero sulfur dioxide. As can be imagined, the installation cost of gas-fired stations would be less than the coal-fired ones. However, the operational cost of gas-fired stations will be high due to the higher cost of fuel, i.e., the gas used. In the state of Rajasthan in India, Kota is the place where all types of power stations like nuclear, thermal (coal fired and gas fired), and hydro are in operation.

13.4.3 Oil- and Diesel-oil-fired Thermal Power Stations

In oil refineries, the oil left behind after processing the crude oil can be used in an oil-fired steam power station installed near the refinery. The crude oil pumped out of an oil well can also be used directly to generate steam to run the steam turbine which will rotate the generator to produce electricity.

Diesel oil can be used to run an IC engine which will drive the generator. Due to the high cost of diesel, diesel-oil-fired stations are mostly used for standby power supply.

13.5 HYDROELECTRIC POWER-GENERATING STATIONS

Energy from falling water is used to run water turbines. Water turbines are coupled with electrical generators to produce electricity. Hydroelectric power generation depends upon the height of the falling water and the quantity of the falling water. The first use of water power to produce electricity was a water wheel on the Fox River in Wisconsin, USA in the year 1882. Thereafter, many hydroelectric power plants were constructed including one in Niagara falls in USA. These days hydroelectric power plants are constructed as mega projects with the generating capacity of over 1000 megawatts MW. The initial investment on a hydroelectric power plant is huge be-flooded with water and creates a water storage area. For example, the dam constructed on the river Satluj at Bhakra–Nangal has created a large water storage area in the form of a lake, called Govind Sagar Lake. This water is used in a controlled way to produce electricity on a continuous basis using water turbine–generator sets installed in the power house at the lower area of the dam. Since a large area gets flooded in the upstream area when a dam is constructed on a river, the people living in such areas are to be shifted permanently from there. Further, there is an environmental impact on the construction of dams in hilly areas due to which the builders often find it difficult to construct new hydroelectric plants in certain areas. However, looking at the large potential of hydroelectric power and its negligibly small running cost, new projects are coming up in many countries. In India, the installed capacity of hydroelectric power generation was over 25,000 MW by 2001. In a hydroelectric power plant, water at a higher elevation flows downward through large pipes called penstocks. This falling water rotates turbines which drive the generators thus converting the mechanical energy into electrical energy.

The advantages of hydroelectric power is that it produces no pollution and is continually renewable. Water is continuously available because of rain and melting of snow, and never gets exhausted. Just to get an idea of how much electricity gets generated from falling water, someone calculated that four litres of water falling from a height of 30 meters each second could produce 1 kW of electricity which could run ten 60 W light bulbs and five ceiling fans.

Hydroelectric power plants are of three types, namely high- and medium-head-storage type, run-of-river type, and pumped-storage type.

Storage-type hydroelectric installations use a dam to block and store water in a reservoir. The stored water in the reservoir is released to run the turbines to generate electricity. The flow of water is controlled as per the requirement of output.

In the run-of-river type, use is made of the natural flow of water of a river to run a turbine. This type of installation may not require a dam to be constructed. A low-head diversion structure to direct the water flow to the penstock may be used.

Hydroelectric power plant with pumped storage facility use specially designed turbines. These turbines will drive the generator in a conventional way when water from the reservoir is allowed to flow through the turbines via the penstock, and thereby generate electricity during the day when there is huge demand on electricity from the supply system. However, during night when there is less demand for electricity, some of the turbines can be used as pumps to lift water from the outlet area back to the reservoir for future use. Fig. 13.2 shows the schematic diagram for a high-head-reservoir-type hydroelectric power plant. The generated power, P in a hydroelectric plan can be expressed as $P = 9.81\ \rho\ Q\ h\ \eta \times 10^{-6}$ M, where, ρ is the specific weight of water in 1000 Kg/m^3, Q is the quantity of discharge of water through the turbine in m^3/second, h is the head of water in metres, and η is the combined efficiency of the turbine–generator set.

2. Many hydroelectric plants provide flood control and water supply for drinking and irrigation.
3. The big reservoir in the form of a lake creates recreational facilities like swiming, boating, water-skiing, camping, picknicking, sightseeing, fishing, etc.
4. Operation cost of hydroelectric plants is low as there is no fuel cost.
5. Maintenance cost is low.
6. Life of a hydroelectric plant is long.

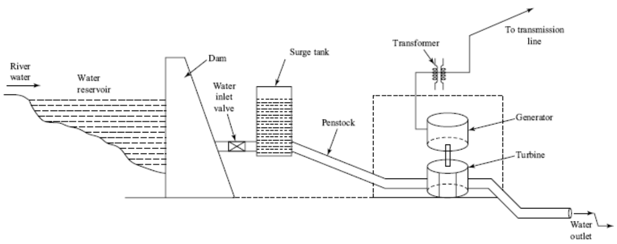


Figure 13.2 Schematic representation of a hydroelectric power plant

Table 13.1 A Few Hydroelectric Plants in India

Location	Units	Total capacity(MW)
• Bhakra, Himachal Pradesh	5 × 108; 5 × 157	1325
• Dehar, Himachal Pradesh	6 × 165	990
• Salal, Jammu & Kashmir	6 × 115	690
• Sardar Soravar, Gujrat	6 × 200; 5 × 1406 × 200; 5 × 140	1450
• Nagarjun Sagar, Andhra Pradesh	1 × 110; 7 × 100.8; 5 × 30	965
• Idukki, Kerala	6 × 130	780

However, there are certain demerits of hydroelectric plants like heavy investment required for the construction of dam, etc.; time taken to instal a plant is high; opposition from environmentalists and the people living on the land to be used as a reservoir; cannot be constructed anywhere, i.e., near the load centre, etc.

The first hydroelectric power plant was installed in USA in the year 1882 followed by Sweeden and Japan. In India, the first hydroelectric power plant was installed in 1897 in Darjeeling area in West Bengal.

We have known that in a thermal power plant, the heat required to produce steam is obtained by burning coal, oil, or natural gas.

In a nuclear power plant the required heat is produced by a process called fission of uranium atoms. Fission or splitting of uranium atoms takes place in a nuclear reactor. Uranium is therefore called nuclear fuel. Nuclear fuel consists of two types of uranium, namely U=238 and U=235. U=235 splits easily, i.e., its nucleus, which is composed of protons and neutrons, break up and release heat as well as neutrons. This splitting of atoms is a chain reaction. Fission in U=235 is started by bombarding it with neutrons. In the fission reaction, neutrons are released and heat is generated. When neutrons hit other uranium atoms, these atoms also split releasing neutrons as well as heat. These neutrons strike other atoms of uranium. Thus, one fission (splitting of uranium atom) leads to more fission, and hence creates a chain reaction. This makes the fission self-sustaining once the process is started.

This chain fission reaction once started will become an uncontrolled one unless some control mechanism is used. In a nuclear reactor, fission reaction of uranium is controlled using control rods which are inserted or withdrawn to slow or accelerate the fission reaction.

In a nuclear power plant, the nuclear reactor replaces the steam boiler used in a thermal power plant using coal or oil as a fuel. Many other components are similar to those used in a coal or oil (fossil fuel) power plant.

Nuclear fuel enrichment. U=235 is more desirable for fuel than U=238 because it is easier to split U=235 atoms than U=238 atoms. In the uranium ore, however, the percentage of U=235 is less (low enrichment). It is therefore necessary to enrich the fuel to be used by U=235 in relation to the number of U=238 atoms. This is called the enrichment process. After enrichment, the uranium is fabricated into pellets and stacked into long metal tubes. The filled rod is called a fuel rod. Schematic diagram of a nuclear power plant has been shown in Fig. 13.3.

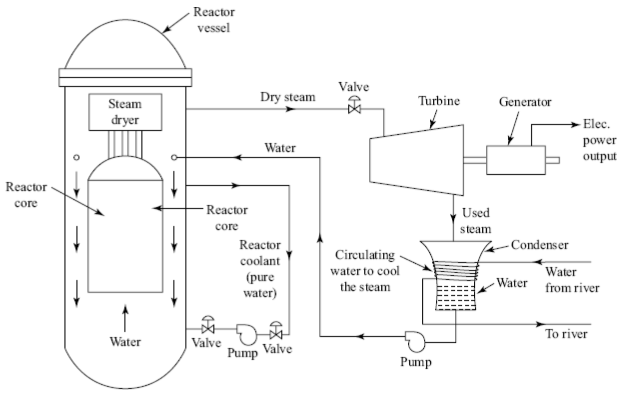


Figure 13.3 Schematic diagram of a nuclear power plant

called the reactor core. The boiling water reactor operates the same way as a boiler in a fossil fuel power plant.

Pure water called reactor coolant moves upwards through the reactor core absorbing the heat generated because of nuclear fission. Due to heat this water becomes steam but contains some water particles. This steam and water mixer moves up and enters the steam dryer and moisture separator. Dry steam, also called saturated steam leaves the reactor vessel through a steam line (insulated pipes) to the steam turbine. The turbine rotates due to the pressure of the steam. Since the generator is coupled with the turbine, the generator also rotates and produces electrical power which is stepped up and transmitted through transmission lines to various places for use. The exhausted steam is collected into the condenser where it is cooled into water. The condensed water is reused for which it is pumped out of the condenser back to the reactor vessel using a number of pumps. The coolant flow through the core can be varied to change the reactor power as and when required. If a nuclear power plant is not situated near a river, the excess heat of the circulated water is removed by using a cooling tower for transferring some of the heat to the air.

As compared to a coal-fired thermal power plant, the quantity of fuel required in a nuclear power plant is much less. The transportation cost of fuel is therefore less as compared to the transportation of coal or oil. Therefore, a nuclear power station can be built near the place where power is to be utilized, i.e., near the load centre. In a nuclear power plant, radioactive fuel waste has to be removed with outmost care and precaution.

Some of the nuclear power plants in India with their installed capacity are shown in Table 13.2.

Table 13.2 Some Nuclear Power Plants in Operation in India

Location	Units	Total capacity (MW)
• Kaiga, Karnataka	220 × 3	660
• Kakrapur, Gujarat	220 × 2	440
• Kalpakkam, Tamil Nadu	220 × 2	440
• Narora, Uttar Pradesh	220 × 2	440
• Rawatbhata (near Kota), Rajasthan	100 × 1 200 × 1 220 × 2	740
• Tarapur, Maharastra	160 × 2 540 × 2	1400

In total, 4120 MW nuclear power is being generated. Over 3000 MW generating capacity projects are under construction.

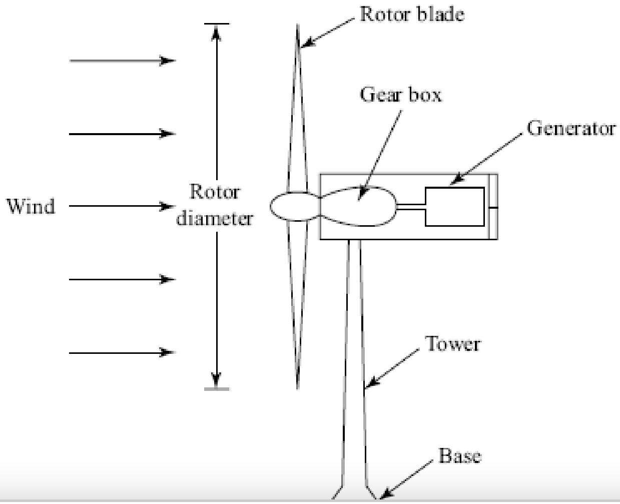
As these are renewable sources of energy, efforts are being made to generate more and more electricity from these resources. These are being described in brief in the following sections.

13.7.1 Solar Electricity Generation

Sun's heat energy is the readily available energy that can be used for heating water, cooking food, pumping water, and for generation of electricity. The energy received from the sun on earth is so much that someone calculated it as equivalent to about 15,000 times the world's annual energy requirement. In India solar energy is available for 300 to 330 days a year, and hence should be utilized to the full through two different ways, i.e., for heating purpose and for generation of electricity. For generation of electricity *solar photovoltaic cells* are used. Solar photovoltaic uses sun's heat to produce electricity for lighting, running pump motors, and running of electrical appliances. Solar cell, or photovoltaic cell converts sunlight directly into electricity.

Photovoltaic (PV) is the technical term for Solar electric. PV cells are made of silicon. Silicon releases electrons when exposed to light. The amount of electrons released from silicon depends upon the intensity of light falling on it. One PV cell or Solar cell produces about 1.5 W of electricity when exposed to bright sun. Individual solar cells are connected together to form a panel or module capable of producing upto about 100 W of electric power. A number of such panels are then connected in series and parallel to produce a considerable amount of electricity. Common applications of PV systems are found in street lighting and indoor lighting, particularly in far flung and hilly areas where conventional electric supply may be expensive because of its long route.

Commercial solar cells producing electricity have an efficiency of about 15 per cent only. Low-efficiency system means larger arrays would be required for electricity generation, and hence would cost more. However, research is being conducted to improve the efficiency of solar cells so as to make the system economically viable. Government of India provides subsidy to manufacturers and users of solar appliances to encourage their use.



13.7.2 Wind Energy to Produce Electricity

When solar radiation enters the earth's atmosphere, due to the curvature of the earth, different regions of the atmosphere are heated differently. The equator region gets heated the most and the polar region the least. Since air tends to flow from warmer region to cooler region, air flow takes place. The energy of this air flow is utilized in the wind mills and wind turbines to produce usable power.

Wind energy is converted into electrical energy through wind turbines coupled with a generator. Wind electric generator converts the kinetic energy in wind to electrical energy by using a rotor, a gear box, and a generator is shown schematically in Fig. 13.4.

Due to flow of wind at a considerable speed, the rotor blades rotate which converts wind energy into rotational shaft energy which in turn rotates the generator through the gearbox arrangement. Wind energy generators of rating from nearly 200 kW to 1000 kW have been installed in different parts in India. Wind speed is the most important factor influencing the amount of energy a wind turbine will produce. The rotor is placed on top of towers to take advantage of strong winds available high above the ground.

India is one of the most promising countries for wind power development with an estimated potential of 20,000 MW. Financial and technical assistance is provided by government of India for wind power development. As on March 2009, the installed capacity of wind power in India was 10,254 MW. Tamil Nadu is the state with most wind-power-generating capacity of 4301.63 MW.

13.7.3 Electricity from Biomass

In most bio power plants, steam is produced by burning of bio-waste material. Bio energy feedstocks are burnt directly in a boiler to produce steam. The saturated steam drives the steam turbine which rotates the generator coupled with it. In certain industries the steam produced in the boiler is also used in manufacturing processes or to heat the buildings. These are called combined heat and power facilities. For example, in a paper industry, the waste wood is used to produce both electricity and steam.

The decay of biomass produce methane gas which can be used to produce electricity. By burning methane, steam can be produced in a boiler and this steam will run a turbine coupled with a generator.

13.7.4 Mini/Micro Hydel Power Generation

In hilly areas there is tremendous potential of generation of electricity where there are hydel (water) resources in the form of falling water. The Himalayan belt in India is gifted with such hydel resources. Mini and micro hydel set (turbine–generator set) can be installed on such falling water resources to generate electricity for local use. These small turbine–generator sets are compact and require no maintenance. Instead of using diesel generator sets, small turbine–generator sets can be used in hilly remote areas for the benefit of small cluster of villages to supply electrical power to farms, schools, houses, etc. The mini hydel plants are rated for 10 kW to 1000 kW. Upto a rating of 100 kW, the plants are called micro-generating plants.

sea shore. The incoming and outgoing tidal waves of varying heights can be blocked by the barrages. A tidal wave height of atleast 7 m is required for economical generation of electricity using water turbines. Tidal power station will fill the reservoirs by opening the sluice gates behind the embarkment along the seashore and use the water height to run turbines. Tidal power stations are constructed across an estuary or a bay. Bay of Bengal in India provides the opportunity to set up such power-generating stations.

13.7.6 Electricity from Ocean Energy

Almost two-third of earth's surface is ocean. The surface water gets heated up due to sun's energy. The sun heats up the surface of the water a lot, and hence the water surface of the ocean works as a solar collector. The warm surface water of the ocean can be used to generate electricity. The warm water of the ocean can be used to vaporize a working liquid of low boiling point such as amonia. The vapour will expand and can run a gas turbine which will drive a generator.

13.7.7 Electricity from Geothermal Energy

Heat energy is trapped in rocks inside the core of the earth. Water absorbs the heat from these rocks and gets converted into steam. This steam when available on earth's surface at specific places can be used to run steam turbines, and thereby generate electricity. Not much has been achieved in tapping geothermal energy so far. In India, in Ladakh area, feasibility study for construction of a 1 MW power station has been made. Geothermal means heat from the earth's interior.

Geothermal energy is generated in the earth's core about 6400 km below the surface of the earth. Temperatures higher than the temperature of the sun is produced in the core of the earth by slow decay of radioactive particles.

The centre of the earth is of solid iron core and its outer is made of very hot melted rock called magma. The magma is surrounded by rock and magma which is also called mantle. The crust is the outermost layer of the earth. The crust forms the land and ocean floors. See Fig. 13.5.

The crust on land area is about 25 to 55 km thick and on oceans 5 to 8 km thick.

Inside the earth the rocks and water absorb heat from the magma. When magma comes closer to the surface it heats up the water trapped in porous rocks or the water running along fractured rocky areas. Such naturally formed hydrothermal resource is called a geothermal reservoir.

Electricity generation in power plants requires steam at very high temperature.

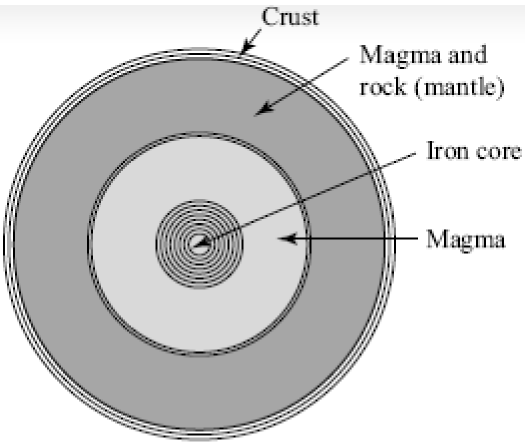


Figure 13.5 The interior of the earth showing source of geothermal energy

Geothermal power plants are built where geothermal reservoirs are available within a depth of a few km from the earth's surface. This requires drilling into the earth to extract hot water and dry steam. California in USA produces the most electricity from geothermal energy. Other uses of geothermal energy is to use hot water from the reservoir or naturally available hot springs for heating buildings, bathing, etc. In India, although electricity generation from geothermal energy is at an initial stage, use is made of hot springs for bathing as many believe that taking bath in mineral-rich natural hot water will have a healing effect.

13.8 TRANSMISSION AND DISTRIBUTION OF ELECTRICITY

Electricity generated in power stations are brought to the consumer premises through transmission and distribution systems. Power transmission is from the substation near the power plant to the substation near the populated area or industrial area. In substations, the voltage level of the power generated is either stepped up or stepped down using step-up or step-down transformers. Power is transmitted at high voltage using transmission lines. Fig. 13.6 shows the schematic diagram of a power system.

The distribution system includes overhead lines and underground cables drawn from the transformer substation and taken to the consumer premises, i.e., to industries, commercial establishments, and residential areas.

Power transmission lines at a national level or even at an international level are connected through additional paths and lines so that power can be routed from one power plant to any place where there is need. Surplus power from one station can be supplied to deficit areas. Such a network allowing transmission of power nationwide is called a *national grid*.

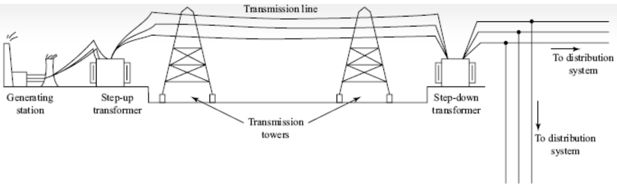


Figure 13.6 Shows the schematic diagram of power transmission at high voltage

The power transmitted is proportional to the square of the voltage $\left(\because P = VI\cos\phi = V\frac{V}{Z}\cos\phi = \frac{V^2}{Z}\cos\phi\right)$. Thus, it is desirable that transmission voltage be made as high as possible to be able to transmit maximum power through a line. However, the height of the lines above the ground has to be increased to keep them away from the ground level. Thus, there is practical limitation to the level of high-voltage transmission. In India, the highest level of transmission voltage at present is 400 kV. In some countries the highest level is 765 kV.

13.8.1 AC Versus DC Transmission

As we have known, P = VI cos ϕ. If the voltage level of transmission is increased, the current level goes down. The cross-sectional area of transmission line conductors get reduced, and hence the cost gets reduced. For economical bulk power transmission, the generated voltage level is stepped up. It has been roughly calculated that most economical transmission voltage is 1 kV per 1.6 km or 1 kV per mile. Thus, the most economical transmission voltage for a distance of around 600 km, works out around 400 kV. In India, the transmission voltage varies from 66 kV to 400 kV. For transmission of power to distances more than 600 km, it has been calculated that dc transmission becomes more economical than ac transmission. Electricity is generated by using an alternator, i.e., an ac generator at 11 kV or more. For ac transmission, the three-phase lines from the generator are connected to the primary side of a step-up transformer. The secondary terminals are connected to the transmission lines.

For dc transmission, the alternating voltage is first converted into dc using an ac to dc converter, and is then connected to the transmission lines. At the receiving end of the transmission lines dc is converted to ac and distributed to the consumers through distribution lines, step-down transformers and underground cables. It may be mentioned here that transmission of power is done in two stages. In the first stage, the voltage level may be 220 kV and in the second stage the voltage level is brought down to 132 kV or less. The level of transmission may be brought down even to 33 kV. The first stage of transmission is called primary transmission while the second stage of transmission, at voltages ranging from 132 kV to 33 kV, is called secondary transmission.

13.8.2 Distribution System

substation. Heavy industries are supplied with 11 kV or even higher voltages, who in turn step down the voltage using their own transformers. For other consumers electricity is supplied at 415/230 V. Three-phase supply is provided at 415 V and single-phase supply is made at 230 V.

Thus, the part of power system which provides electricity to the customers is called the distribution system as shown in Fig. 13.7.

13.8.3 Overhead Versus Underground Distribution Systems

The distribution system can be installed through overhead lines or through underground cables. Overhead lines are generally mounted on concrete or steel poles. The distribution transformer (11 kV/400 V) is mounted on poles. Supply is taken out from the secondary of the transformer through cables. In an underground system cables are laid below the ground level along the street by the side walk. The choice between overhead lines and underground cables depends upon a number of factors like initial cost, ease of location of any fault, safety consideration, maintenance cost, aesthetics, etc.

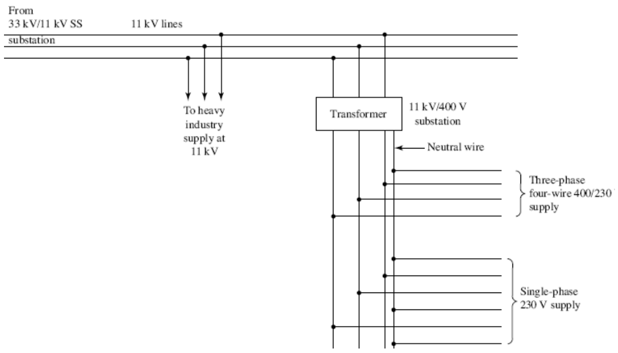


Figure 13.7 Distribution of power to industries and residential complexes

13.8.4 Connection Schemes of Distribution System

The distribution network consist of feeders, distributors, and service mains.

Feeder is a cable which feeds the distributor. From the distributor, connections are taken to supply the consumers. Such connections are called service mains. Two types of arrangements are made. These are called the radial system and the ring main system. Fig. 13.8 shows the difference between feeder, distributor, and service mains. Generally, no tappings are taken from the feeder. From the distributor, connections are taken through low-voltage cables to supply the consumers.

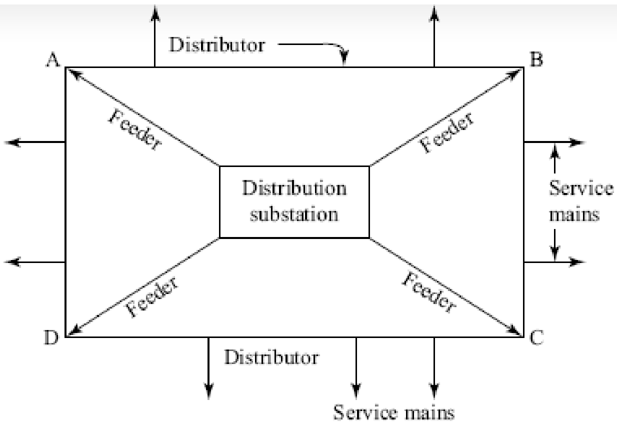


Figure 13.8 Use of feeders, distributors, and service mains

The radial system of distribution and the ring main system of distribution are illustrated through schematic diagrams in Fig. 13.9 (a) and (b).

The radial distribution system is commonly used in less populated areas where the primary feeder branches out to reach the total area to be served. Distribution transformers are connected to the feeders and laterals. CB represents the circuit breakers installed to disconnect the system in case of any fault. The service reliability of this system of distribution of electric power is low as in case of any fault on a particular line, the whole area gets effected, i.e., gets switched off. The advantage of the ring main system over the radial system is that it is more reliable. In case of any fault, an alternate route is available for the maintenance of power supply.

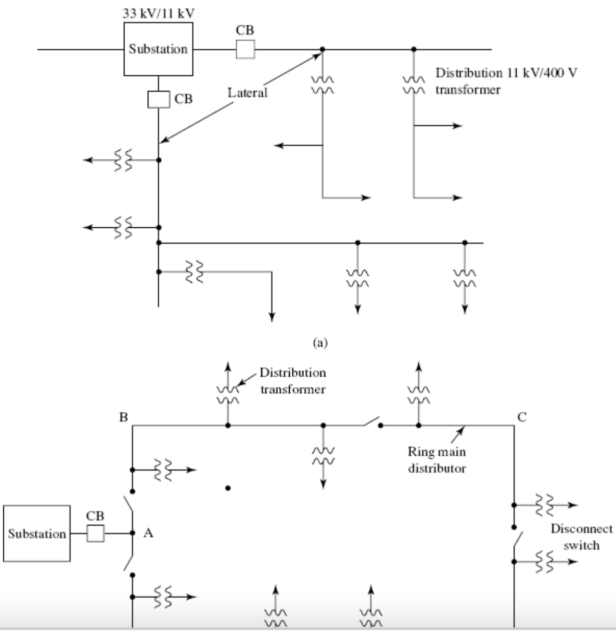


Figure 13.9 (a) Radial distribution system; (b) ring main distribution system

13.9 DOMESTIC WIRING

Electricity distribution authorities supply power to the consumers at the following two voltages. Single-phase supply: 230 V, 50 Hz, two-wire, three-phase supply: 415 V, 50 HZ, four-wire. In a two-wire single-phase supply there is one phase or live wire and the other is called the neutral wire. Single-phase supply is required for electrical appliances like fan, tube light, lamp, washing machine, refrigerator, electric iron, room heater, room air-conditioner, kitchen electrical appliances like mixer, grinder, microwave oven, etc.

In a four-wire, three-phase supply, power is supplied through three live wires and a neutral wire. The neutral wire is normally at zero potential and is earthed at the substation. Three-phase loads like three-phase induction motors used for water lifting are supplied with three-phase supply. In such a case all the phases get equally loaded. Three-phase supply can also be used to feed single-phase loads as shown in Fig. 13.10. Single-phase electrical loads are connected between the phase or live wires and the neutral wire in such a way that all the phases are equally loaded.

As shown in Fig. 13.10, supply from the secondary of a three-phase transformer is taken through feeder wires to the busbars (busbars are thick copper strips). From the busbars both single-phase supply and three-phase supply are taken out and are connected to the loads.

13.9.1 Service Connection

Electricity supply authorities supply power to the domestic loads, i.e., residential houses through a low-voltage three-phase four-wire distribution system. The distribution system is formed either through overhead lines or through underground cables. In modern cities, only underground cables are used for electric power distribution system. From the electricity supplier's distribution system, power is brought to the premises of the consumer through a cable called the service line or service connection. The service line is normally an underground PVC cable. The service cable is brought to the consumer's distribution board.

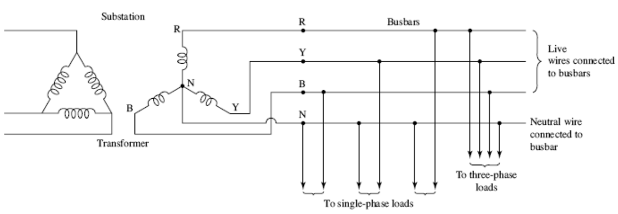


Figure 13.10 Three-phase four-wire distribution system

In the main distribution board installed in the premises of the consumer, an energy meter is connected so as to measure the amount of electricity consumed by the customer. Thus, the incoming service cable is connected to the energy meter at the distribution board. A cutout, i.e., a fuse wire is connected in the line which will blow off in case the consumer draws more current than the current for which he has been supplied with. In the cutout of proper rating is not provided, the meter will get burnt in case of heavy loads (more than the rated load) drawn by the consumer. For example, if the consumer install more air-conditioners in his house than permitted, the meter may get burnt. The cutout can only be replaced by the electricity supply authority. The consumer must not tamper with the cutout. The supplier may disconnect supply by removing the cutout in case the energy bill is not paid by the consumer.

13.9.3 Distribution Board for Single-phase Installation

The service mains is connected to the input terminals of the single-phase energy meter at the distribution board as shown in Fig. 13.11. Before the energy meter is placed the electricity supply authority's cut-out. The consumer's main switch-fuse is connected after the meter. From here the supply is fed to the distribution fuse board through a busbar and neutral link.

It is to be noted that all fuses should be placed only in the live or phase wire and not in the neutral wire. All switches should be connected on the live lines and not on the neutral line.

13.9.4 Neutral and Earth Wire

The neutral wire is taken out from the star point of the secondary of the distribution transformer. The star point is earthed. The lines are taken out from the terminals R, Y, B of the three-phase windings and the neutral point N. Each phase wire and the neutral wire constitutes single-phase supply.

In addition to the four wires taken out from R, Y, B, and N terminals, a fifth wire, called earth wire is provided. The earth wire is provided for the purpose of protection of persons using electrical appliances. In case of any leakage in the system, the persons using any equipment will not get any electric shock if the body of all electrical appliances are connected to the earth terminal.

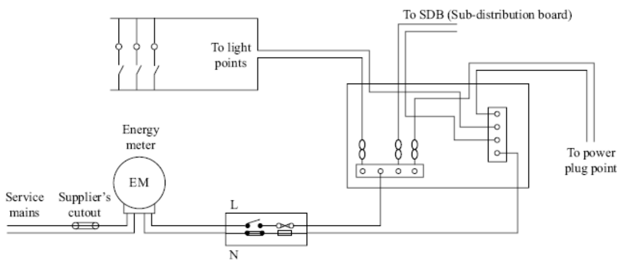


Figure 13.11 Layout of distribution board for single-phase installation

solid earthing point at the substation and runs along the supply lines. This wire is earthed along its run once in every 1.6 km.

13.9.5 Earthing

All metal parts of electrical appliances are always connected to the earth through an earth wire. If the earth wire is not provided and any part of the current-carrying live wire touches a metal frame, the frame will acquire the same voltage as the live wire. Any person touching the body of the appliance will get a severe electric shock. If a low-resistance earth wire is provided, in case of any fault in the circuit, a large amount of current will flow through the circuit. This will cause the fuse provided in the live wire to blow and protect the circuit as well as the person touching the electrical appliance, gadget or equipment, as the case may be.

As shown in Fig. 13.12, the live and the neutral wires are used to supply power to an electric device, say a heater. The metal case of the heater is connected to the earth wire of a three-core cable supplying power to the heater. The earth wire from the distribution board is connected to the main earth terminal of the building as has been shown. This earth terminal in turn gets connected to the earth electrode at the substation through the general mass of the earth (earth is the conducting media). Thus, in case of any electric fault, if the live wire touches the metal case, it gets connected to the earth electrode at the substation. At the substation, the neutral point is earthed.

Method of earthing

Earthing means connecting the earth terminal solidly and securely on the ground through an electrode. Conductivity of earth depends on the moisture content of the soil and its chemical composition. The soil near the earth electrode should have low resistivity (i.e., high conductivity). Before placing the earth electrode, the soil around is made highly conducting by adding some agents like common salt, i.e., NaCl, calcium chloride, i.e., CaCl, sodium carbonate, i.e., Na_2Co_3, soft coke, etc.

Earth electrode

Places where there is a network of underground cables, the earth terminal is obtained by making connections with the lead sheath or steel armour of the underground cable. The lead sheath or the steel armour of the cable will serve as the earth electrode. However, where such underground cable is not available, earth electrodes are laid on the ground to get the earth terminal. To avoid corrosion, the material chosen for the earth electrode, either a pipe or a plate, should be made of copper or zinc-coated iron. Typical installation of two types of electrodes, viz the rod or pipe electrode and plate electrode are made. A rod-type electrode has been shown in Fig. 13.13.

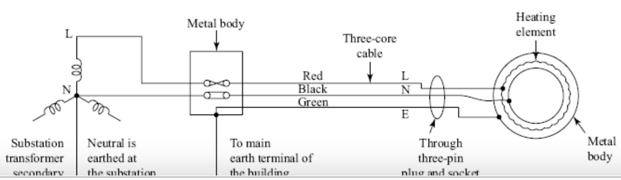


Figure 13.12 Shows the use of earth wire as an essential requirement to protect against electric shock

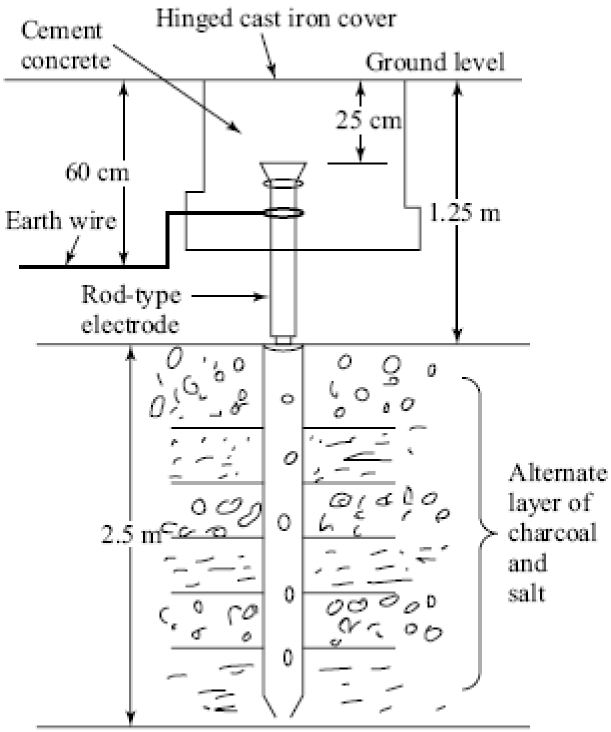


Figure 13.13 Earthing terminal from a pipe or rod-type electrode

In the case of plate earthing, the plate electrode is made of galvanized iron or steel. The size of the plate electrode should be 60 cm × 60 cm and should be burried atleast 1.5 m below the surface of the soil.

All earth wires should be made of copper, galvanized iron, steel or aluminum. Interconnections of earth continuity conductors should be such that good electrical connections are permanently made. The neutral conductor should not be used as earth wire.

Neutral and earth wire

Low-voltage supply at 230 V for single-phase supply and 415 V for three-phase supply are obtained from the distribution transformer. The distribution transformer is a step-down transformer whose primary windings are delta connected and the secondary windings are star connected. The neutral point, i.e., the star point of the secondary is earthed and the neutral wire is taken out from the star point. Thus, the output from the distribution transformer is brought out by three live wires named as R, Y, B, and one neutral wire denoted as N. Supply is taken out through a four-core underground cable or through four-wire overhead conductors.

The earth wire while running along the overhead lines is not insulated from the poles. The earth wire originates from a solid earth at the substation and also earthed at not less than four equally spaced points every 1.6 km of the distribution line. The neutral wire is connected to the neutral point of the transformer which is earthed only at the substation. In a single-phase supply system, the neutral wire carries the return current. In a three-phase supply system the neutral wire does not carry any current if the load on all the phases are balanced. In case of unbalanced load on the three phases, the balance current flows through the neutral wire. The earth wire, under normal conditions, does not carry any current. However, if any earth fault occurs, the earth wire will carry large current which will cause the fuse on the live wire to blow, thereby protecting the life of the operator and the equipment. The earth wire should never be used as neutral wire to supply any single-phase load.

13.9.6 System of Wiring

Electricity supply authority, i.e., the State Electricity Boards provide electric supply upto a point outside the consumer's premises.

From this point the consumer will take connection to his main switchboard. Insulated electrical wires will then be taken out to various places in the premises to supply power to different types of electrical loads like lights, fans, refrigerators, room coolers, heaters, etc. There are different types of wirings used. The choice of wiring will depend upon a number of factors.

The various types of internal wirings are

1. cleat wiring
2. wood casing wiring
3. batten wiring
4. conduit wiring

Cleat wiring

Cleats are made of porcelain and are fixed on walls or ceiling at intervals of 0.6 m. The insulated wires, i.e., the cable is taken through the holes of each cleat. Thus, the cleats support the wire, such a cleat wiring is cheap and is used for temporary installation.

Wood casing wiring

In wood casing wiring, the cable is run through a wood casing having grooves. The wood casing of a required length is fixed on the walls or ceiling with screws. The cables are placed inside the grooves of the casing. A capping, also made of wood with grooves, is used to cover the cables.

The casing and capping are made from well-seasoned teak wood. The casing should be fixed with flat-headed wooden screws to wooden plugs at an interval of 90 cm. After all the insulated cables are laid inside the grooves of the casing, the capping should be attached to the casing by rust-resistant screws; care should be taken in fixing the screws on the cappings so that the insulation of the cables inside is not damaged. Wood casing–capping wiring system is used in dry places like Rajasthan.

Batten wiring

The clips are fixed on the battens with rust-resistant nails. Batten wiring is widely used for indoor installations. Batten wiring is cheap and takes comparatively less time to install.

Conduit wiring

Conduit wiring consists of PVC wires taken through either steel conduit pipes or through PVC conduit pipes. Conduits are run over the surface of walls and ceiling or are concealed under masonery work. When conduits are run over the surface of walls, the wiring is called surface conduit wiring. When the conduits are run inside the walls, the wiring is called concealed conduit wiring. Surface conduit wiring is used in factories for installation of heavy motors and other electrical equipment. The system is water proof and replacement of defective wires is easy.

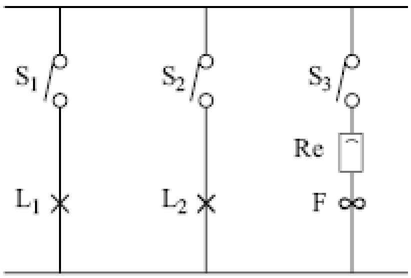


Figure 13.14 Light and fan control circuit

In concealed conduit wiring, a chase or groove is cut on the wall to place the conduit pipes. In case of buildings under construction the chase should be provided on the wall and ceilings for laying the conduit pipes before plastering of walls and ceiling is done. Suitable inspection boxes are provided to permit the inspection and replacement of wires, if necessary. Concealed conduit wiring is used in almost all modern residential, commercial, and public buildings. The appearance of buildings from inside look good with concealed conduit wiring as compared to batten wiring.

13.9.7 System of Connection of Lights, Fans and Other Electrical Loads

All electrical loads are connected in parallel and not in series. There are separate circuits for light and fan loads and for heavy electrical loads like heaters, air conditioners, etc.

Fig. 13.14 shows the connection scheme for two lamps and one fan circuit. Each is operated by an independent switch. The fan is controlled by a regulator to change its speed.

As per Indian Electricity Rules, the number of light and fan points that can be put in one circuit is restricted to eight. This includes the 5 A plug points which are provided to plug-in some small electrical loads like a battery charger, a mosquito repeller, a tape recorder, a TV, etc. For comparatively heavy loads, 15 A plug points are to be

Example 13.1 Draw the wiring diagram for a single tube light circuit.

Solution:

For a tube light circuit, in addition to an On/Off switch we will require a choke and a starter. The choke and the starter help in developing a high voltage across the tube during starting so that the flourescent tube gets illuminated.

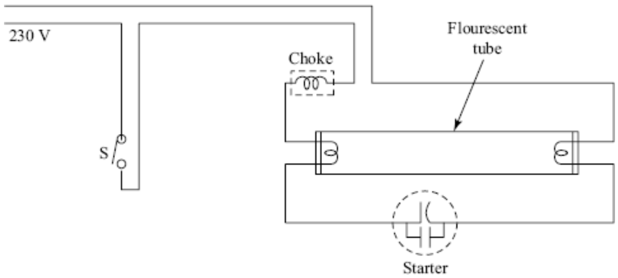


Figure 13.15 A tube light circuit

Example 13.2 Draw the circuit for a staircase lamp controlled from two positions. It should be possible to switch-on or switch-off the lamp by any of the two switches, one located upstairs and the other located downstairs.

Solution:

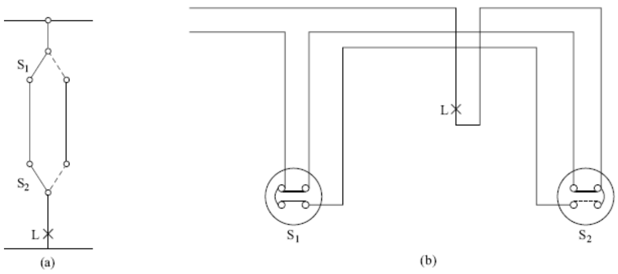


Figure 13.16 Staircase lighting circuit

Two two-way switches have been used to control the lamp L. Fig. 13.16 (a) shows the schematic diagram whereas Fig. 13.16 (b) shows the actual wiring diagram. Switch S_1 is fixed on the ground floor near the staircase while switch S_2 is fixed on the first floor. While going up S_1 is operated to switch on the light L as shown. After reaching the first floor, switch S_2 is operated. The switch contact moves to position shown by the dotted line. The lamp gits switched off as power supply to the lamp is now cut off.

Solution:

The schematic circuit is shown in Fig. 13.17.

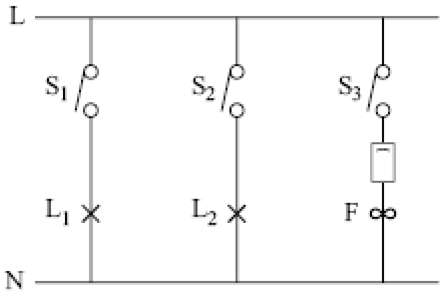


Figure 13.17 Schematic diagram of a light and fan circuit

Example 13.4 Draw the schematic diagram for one lamp to be switched on and off from any of the three positions.

Solution:

In this case we need to use a two two-way switch and an intermediate switch. S_1 and S_3 are the two-way switches and S_2 is an intermediate switch. The working of the single-way, two-way and intermediate switches have been shown in Fig. 13.18 (a), (b), and (c). These have been used to make the circuit as shown in Fig. 13.18 (d).

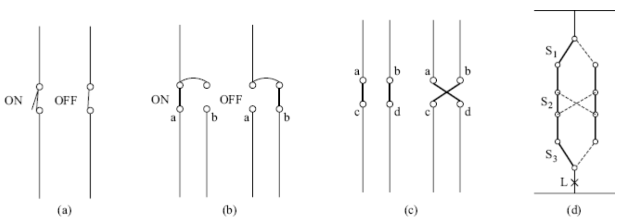


Figure 13.18 (a) One-way switch; (b) two-way switch; (c) intermediate switch; (d) schematic diagram for a lamp controlled from any of the three positions

13.10 CIRCUIT PROTECTIVE DEVICES AND SAFETY PRECAUTIONS

Circuits should be protected against any abnormal condition like overload and short circuit which may be due to any fault conditions or excess load connected to the circuit. Protective devices like fuses and circuit breakers are used, which help protect the circuit from burning out under abnormal conditions.

An important protective device used in all electrical installations is the fuse.

A fuse is a device that, by fusion of one of its specially designed and

A rewirable fuse consists of a length of wire made either of tinned copper or some other metal of such size that while it will carry the rated current, it will fuse, i.e., melt, and thus break the circuit if the current rises above the value for which the circuit is rated. Rewirable fuse has the disadvantage that the wire can be replaced by any other wire of any size, which will defeat the purpose for which a fuse is used. Often the user may replace a fuse by a thicker wire which is not desirable at all.

A rewirable fuse also gives an external flash when blown off.

The performance of a fuse is improved by having the fuse wire in a sealed cartridge packed with filler material. Such a fuse is called a cartridge fuse. There are two types of cartridge fuses, viz diazed-type fuse, or simply D-type cartridge fuse and high rupturing capacity, or HRC cartridge fuse. In cartridge fuses, the cartridge, which carries the fuse wire has to be replaced by another cartridge of the same rating. A cartridge of some other rating will not fit into the base. This restricts the user in replacing the fused cartridge by another cartridge of the same rating

For the protection of a power system against any fault condition, e.g., single-phase-to-ground fault or phase-to-phase fault or three-phase fault, protective devices like *relays* and *circuit breakers* are incorporated in the system.

A circuit breaker will break the circuit automatically under any fault conditions. Circuit breakers can be operated by remote control with the help of relays. Relays detect the fault and initiate tripping of the circuit breaker. Under fault conditions the electrical quantities like current, voltage, and frequency become abnormal and is sensed by the relay. There are various types of relays, like distance or impedance relay, induction-type over-current relay, differential relay, etc.

13.10.1 Safety Precautions in Using Electricity

Electricity has to be used very carefully. Careless use may lead to severe consequences to the person using electricity or to the system. Every circuit should be given supply through a switch–fire arrangement. The phase provided should be of the proper rating. No connection should be taken directly using naked wires. All metallic parts of electrical equipment should be earthed.

13.11 EFFICIENT USE OF ELECTRICITY

Electrical energy is used in almost every place like in running electric trains and metro-rails, heating and cooling of buildings, creating cold storage facilities, illuminating building interiors, street lighting, etc. The demand for electricity is increasing day by day. Non-renewable energy resources like coal and gas are getting depleted. It is therefore important that we save electricity by reducing losses and misuse.

Energy efficient technologies, gadgets, and appliances are to be developed and the less efficient ones be replaced. For example, gradually, electric filament lamps will be replaced by CFLs (compact fluorescent lamps). Electronic fan regulators have already replaced the traditional variable-resistance-type regulators. For saving energy on heating and cooling, the losses due to leakage have to be heating is not done. The persons using electricity need to be made aware of the need for efficient use of electricity.

A subject with the name of Energy Management deals with the reduction of losses in the transmission and distribution system, use of energy efficient technologies, conservation of energy, more and more emphasis on non-conventional sources of energy for generation of electricity, and energy audit to reduce losses, etc.

13.12 REVIEW QUESTIONS

A. Short Answer Type Questions

1. What are the various sub-systems of an electrical power system? Explain the significance of each of them.
2. What are the various ways of generation of electricity from natural resources? What are their limitations?
3. Draw and explain how electricity is generated in a coal-fired thermal power plant.
4. Explain the basic principle of generation of electricity in a nuclear power plant.
5. What is meant by renewable energy sources? Give two examples.
6. What is the basic principle of solar electricity generation. What are the requirements and limitations?
7. Give brief descriptions of generation of electricity from non-conventional energy sources.
8. Explain how electricity is brought from the generating stations to the consumers of electricity.
9. Compare dc and ac transmission systems.
10. Compare overhead versus underground distributions systems.
11. Explain the function of neutral wire and earth wire in an electrical distribution system.
12. Explain the importance of earthing of electrical systems.
13. Explain the method of earthing.
14. Explain the various types of electrical wiring.
15. Draw the schematic diagram of stair case lighting, i.e., one lamp controlled from two positions. Also draw the wiring diagram.
16. Draw the wiring diagram of a tube light circuit.
17. What are the protective devices used in power systems?

B. Multiple Choice Questions

1. The voltage range at which power is generated in power stations is
    1. 440 V to 1 kV
    2. 11 kV to 30 kV
    3. 33 kV to 66 kV
    4. 66 kV to 132 kV.
2. The generated voltage is transmitted through transmission lines after stepping up the voltage so that
    1. the voltage drop in the transmission lines is reduced
    2. for the same power transmitted the current flowing through the lines is reduced, there by reducing the transmission losses
    3. the transmission lines are kept far away from the

    3. above 400 kV
    4. 66 kV 400 kV.
4. Which of the following is used as a prime mover in a nuclear power station?
    1. Water turbine
    2. Gas turbine
    3. Steam turbine
    4. Diesel engine.
5. Which of the following is renewable energy?
    1. Coal
    2. Oil
    3. Gas
    4. Solar.
6. Which one of the following is not used as a source of heat energy in a thermal power station?
    1. Gas
    2. Oil
    3. Uranium
    4. Coal.
7. In which of the following places in India, a nuclear power plant has not yet been constructed?
    1. Tarapur in Maharastra
    2. Rawatbhata (near Kota) in Rajasthan
    3. Mehrauli in Delhi
    4. Kalpakkam in Tamil Nadu.
8. Cogeneration means
    1. the system where electricity, steam, and hot water are simultaneously produced
    2. the system of generating electricity using both coal and diesel oil
    3. the system of converting heat into mechanical energy at a very high temperature
    4. the system of generating electricity and other forms of mechanical energy from any primary source of energy.
9. Which of the following is not true for the amount of power generated, P, in a hydroelectric power plan?
    1. P depends on the quantity of water discharged
    2. P depends on the head of water being discharged
    3. P depends on the specific weight of water
    4. P depends on the capacity of the water reservoir.
10. Which of the following is not the location of a hydroelectric power station in India?
    1. Salal in Jammu and Kashmir
    2. Nagarjun Sagar in Andhra Pradesh
    3. Dehar in Himachal Pradesh
    4. Faridabad near Delhi on river Yamuna.
11. Commercial solar cells producing electricity has an efficiency of the range.
    1. 10 to 15 per cent
    2. 20 to 40 per cent
    3. 50 to 70 per cent
    4. above 70 per cent.
12. Which of the following is not a part of the electricity distribution network?
    1. Feeder
    2. Distributor

2. The neutral wire is taken out from the star point of the secondary of a step-up transformer
3. Each phase wire and the neutral wire constitute single-phase supply
4. The neutral wire is taken out from the star point of the secondary of the distribution transformer and is earthed of the substation.

14. In a distribution transformer
    1. the primary windings are star connected and the secondary windings are delta connected
    2. both the primary and secondary windings are delta connected
    3. the primary windings are delta connected and the secondary windings are star connected
    4. both the primary and secondary windings are star connected.
15. Which of the following types of wiring is used for purely temporary installations?
    1. Concealed conduit wiring
    2. Surface conduit wiring
    3. Wood casing–capping wiring
    4. Cleat wiring.
16. The function of choke and starter in a tube light circuit is to
    1. create a high voltage across the tube during starting
    2. improve the power factor of the tube light circuit
    3. reduce the power consumed by the tube light circuit
    4. help draw very high current during starting.

Answers to Multiple Choice Questions

1. (b)
2. (b)
3. (d)
4. (c)
5. (d)
6. (c)
7. (c)
8. (a)
9. (d)
10. (d)
11. (a)
12. (c)
13. (b)
14. (c)
15. (d)
16. (a)