LECTURE NOTES

ON

ELECTRICAL POWER GENERATION SYSTEM
(AEEB14)

IV-SEMESTER

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UNIT – I

CONVENTIONAL POWER GENERATION SYSTEMS

Theory of Thermal Power Station

The theory of thermal power station or working of thermal power station is very simple. A power generation plant mainly consists of alternator runs with help of steam turbine. The steam is obtained from high pressure boilers. Generally in India, bituminous coal, brown coal and peat are used as fuel of boiler. The bituminous coal is used as boiler fuel has volatile matter from 8 to 33 % and ash content 5 to 16 %. To increase the thermal efficiency, the coal is used in the boiler in powder form.

In coal thermal power plant, the steam is produced in high pressure in the steam boiler due to burning of fuel (pulverized coal) in boiler furnaces. This steam is further supper heated in a super heater. This supper heated steam then enters into the turbine and rotates the turbine blades. The turbine is mechanically so coupled with alternator that its rotor will rotate with the rotation of turbine blades. After entering in turbine the steam pressure suddenly falls and corresponding volume of the steam increases. After imparting energy to the turbine rotor the steam passes out of the turbine blades into the condenser. In the condenser the cold water is circulated with the help of pump which condenses the low pressure wet steam. This condensed water is further supplied to low pressure water heater where the low pressure steam increases the temperature of this feed water, it is again heated in high pressure.

For better understanding we furnish every step of function of a thermal power station as follows, First the pulverized coal is burnt into the furnace of steam boiler. High pressure steam is produced in the boiler. This steam is then passed through the super heater, where it further heated up.This supper heated steam is then entered into a turbine at high speed.

Line Diagram of Power Plant:

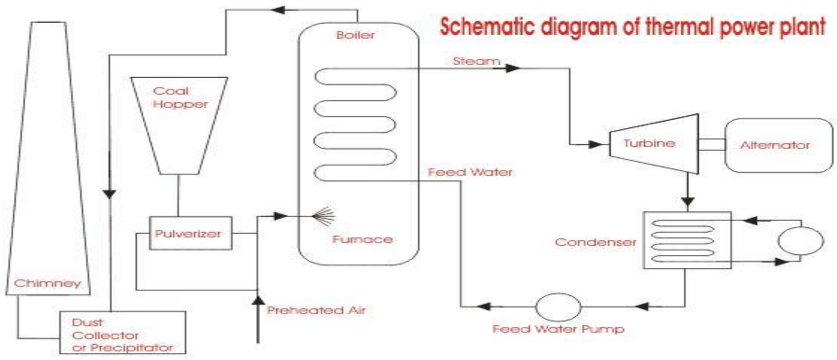


Figure: Line Diagram of Power Plant

After rotating the turbine blades, the steam has lost its high pressure, passes out of turbine blades and enters into a condenser. In the condenser the cold water is circulated with help of pump which condenses the low pressure wet steam. This condensed water is then further supplied to low pressure water heater where the low pressure steam increases the temperature of this feed water, it is then again heated in a high pressure heater where the high pressure of steam is used for heating. The turbine in thermal power station acts as a prime mover of the alternator.

Figure: Steam Turbines

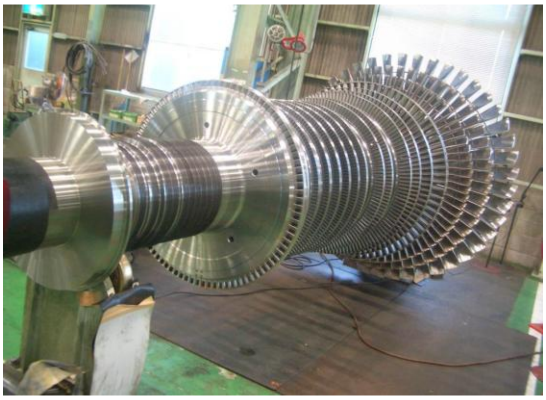


Figure: Steam Turbines

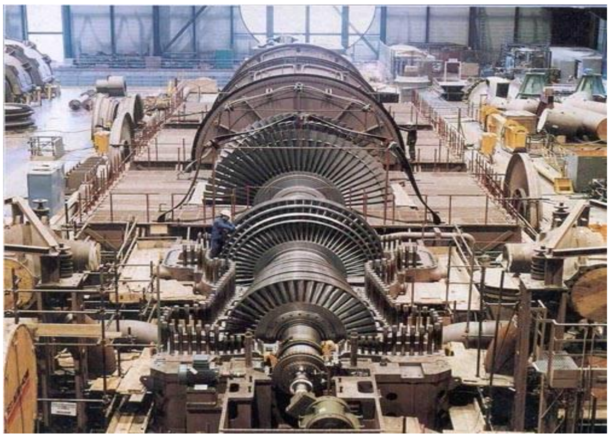


Figure: Steam Turbines

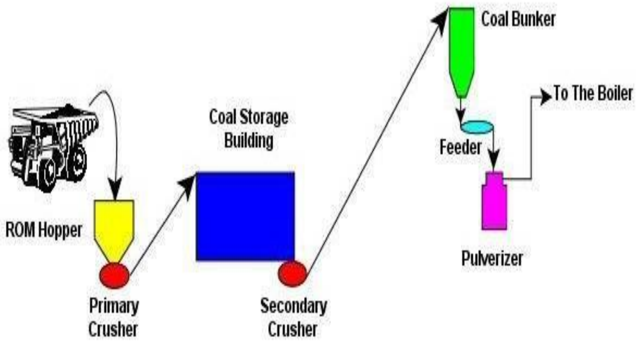


Figure: Processes in Coal Handling Plant

Boiler:

A boiler (or steam generator) is a closed vessel in which water, under pressure, is converted into steam. The heat is transferred to the boiler by all three modes of heat transfer i.e. conduction, convection and radiation.

Major types of boilers are:

- fire tube boiler and
- water tube boiler

Fire Tube Boiler:

The boiler is named so because the production of combustion passes through the tubes which are surrounded by water.

Depending on whether the tube is vertical or horizontal the fire tube boiler is divided into two types:

- Vertical tube boiler
- Horizontal tube boiler

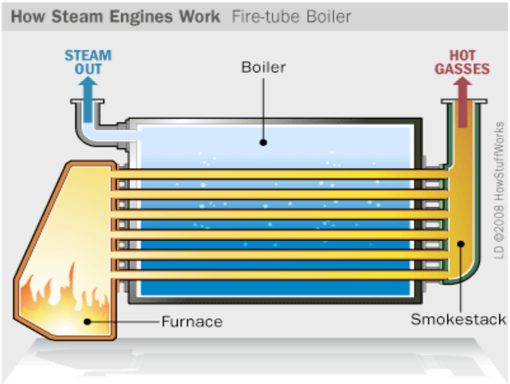


Figure: Water Tube boilers

In this boiler, the water flows inside the tubes and hot gases flow outside the tube.

Water tube boilers are classified as:

- Vertical tube boiler
- Horizontal tube boiler
- Inclined tube boiler

The circulation of water in the boiler is may be natural or forced.

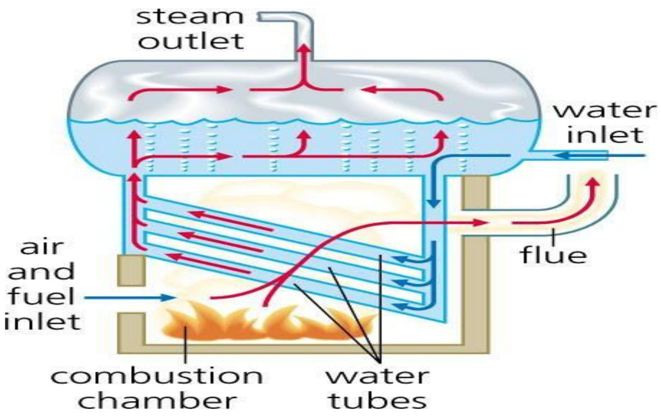


Figure: circulation of water in the boiler

Super heater and Reheaters:

- Super heated steam is that steam which contains more heat than the saturated steam at the same pressure. The additional heat provides more energy to the turbine hence power output is more.
- Superheated steam causes lesser erosion of the turbine blades and can be transmitted for longer distance with little heat loss
- The function of the super heater is to remove the last trash of moisture from the saturated Steam.
- A super heater may be convention type, radiant type or combination

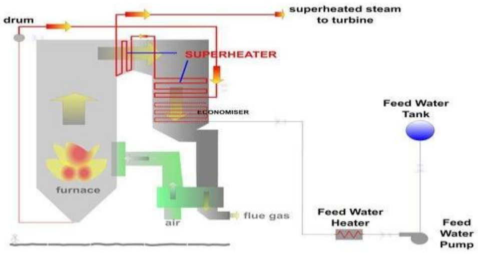


Figure: Functions of superheater

Feed Water Heaters:

- Feed Water heating improve overall efficiency.
- The dissolved oxygen which would otherwise cause boiler corrosion are removed in the feed water heater.
- Thermal stresses due to cold water entering the boiler drum are avoided.
- Quantity of steam produced by the boiler is increased.
- Some other impurities carried by steam and condensate, due to corrosion in boiler and condenser, are precipitated outside the boiler.

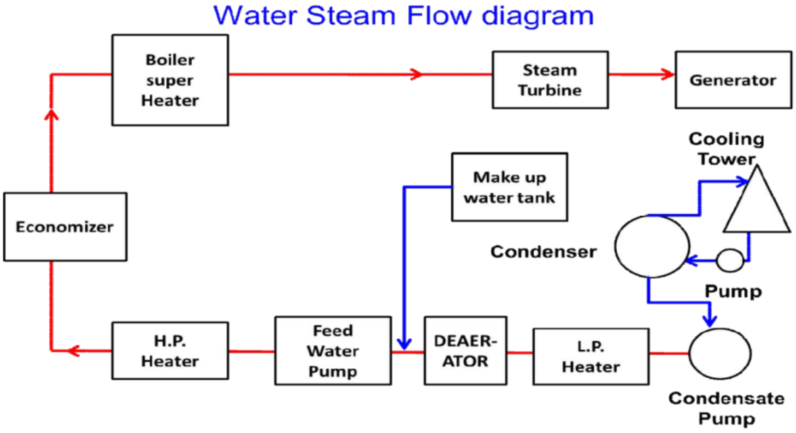


Figure: Water steam flow diagram

Economizer:

- Boilers are provided with economizer and air pre-heaters to recover heat from the flue gases. An increase of about 20% in boiler efficiency is achieved by providing both economizer and air pre-heaters.
- Economizer alone gives only 8% efficiency increase. The feed water from the high pressure heaters enters the economizer and picks up heat from the flue gases after the low temperature super heater.
- Economizer can be classified as an inline or staggered arrangement based on the type of tube arrangement

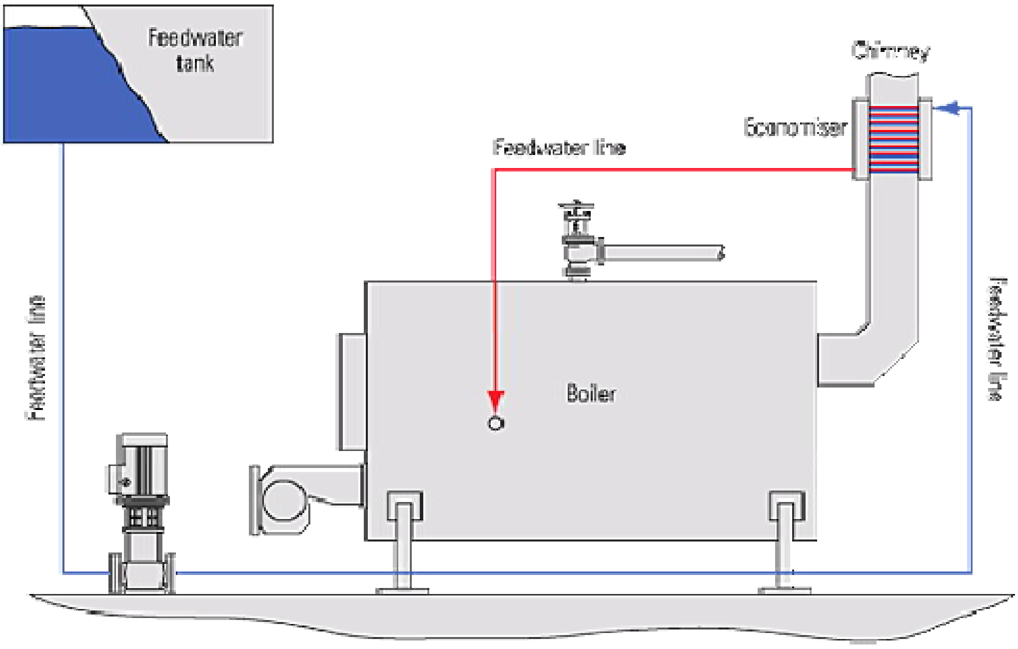


Figure: Economizer

Air Preheaters:

After the flue gases leave economizer, some further heat can be extracted from them and is used to heat the incoming air for combustion.

Air preheaters may be of following types:

- Plate type
- Tubular type
- Regenerative type

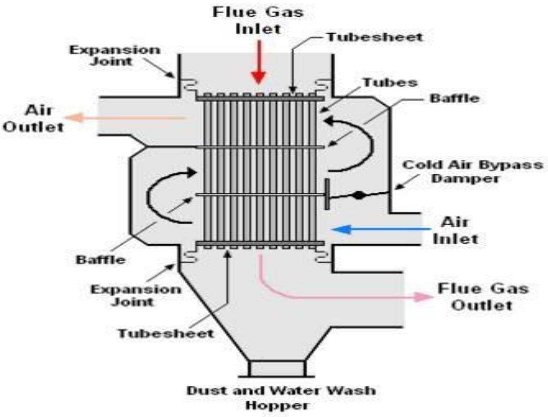


Figure: Air Preheater

Steam Turbines

- Steam entering from a small opening attains a very high velocity. The velocity attained during expansion depends on the initial and final content of the steam.
- The difference in initial and final heat content represent the heat energy to be converted to kinetic energy.

There are two types of steam turbines:

Impulse	Reaction
Expansion happens in a nozzle	Expansion happens in turbine blades
High speed	Low speed
Sufficient number of impulse stages are provided.	

Condensers:

- The function of the condenser is to condense the steam exiting the turbine.
- The condenser helps maintain low pressure at the exhaust.

Two types of condensers are used:

Jet condenser (contact type)	Surface condenser (non-contact type)
Exhaust steam mixes with cooling water.	Steam and water do not mix.
Temperature of the condensate and cooling water is same while leaving the condenser.	Condensate temperature higher than the cooling water temperature at outlet.
Condensate cannot be recovered.	Condensate recovered is fed back to the boiler.
Heat exchanged by direct conduction	Heat transfer through convection.
Low initial cost	High initial cost.
High power required for pumping water.	Condensate is not wasted so pumping power is less.

Table 5: Jet and Surface Condensers

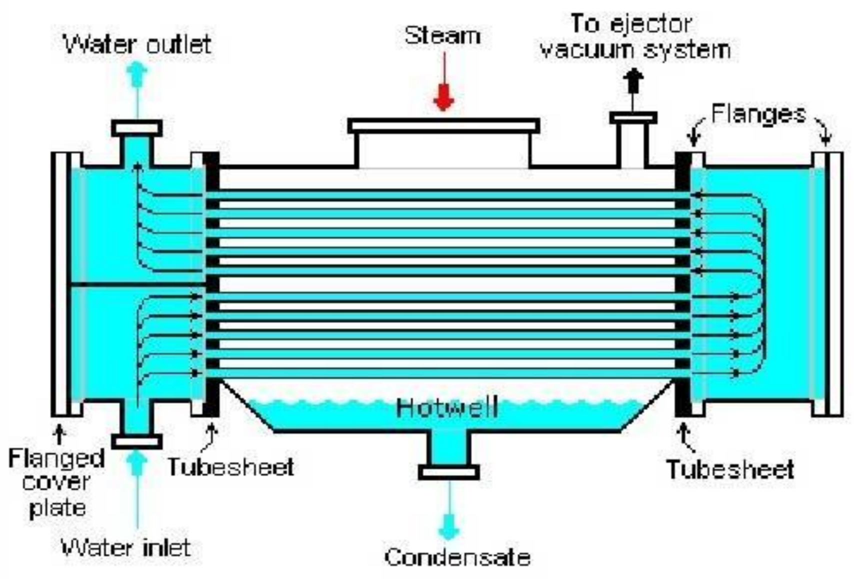


Figure: Surface Condenser

Cooling Towers and Spray Ponds:

- Condensers need huge quantity of water to condense the steam.
- Water is led into the plants by means of circulating water pumps and after passing through the condenser is discharged back into the river.
- If such a source is not available closed cooling water circuit is used where the warm water coming out of the condenser is cooled and reused.
- In such cases ponds and cooling towers are used where the water loses heat to the atmosphere

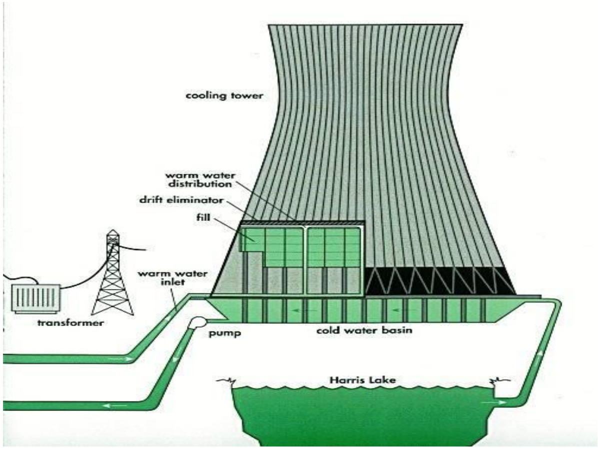


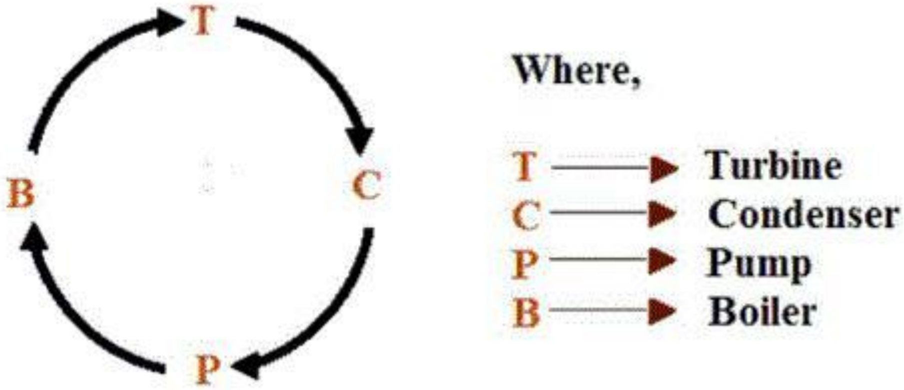
Figure: Cooling Tower

Figure: Cooling Tower

Figure: Belt Conveyor System

Figure: Ash Storage

Overview of Thermal Power Plant:



The working fluid is water and steam. This is called feed water and steam cycle. The ideal Thermodynamic Cycle to which the operation of a Thermal Power Station closely resembles is the Rankine Cycle.In steam boiler the water is heated up by burning the fuel in air in the furnace & the function of the boiler is to give dry super heated steam at required temperature.The steam so produced is used in driving the steam Turbines. This turbine is coupled to synchronous generator (usually three phase synchronous alternator), which generates electrical energy.

The exhaust steam from the turbine is allowed to condense into water in steam condenser of turbine, which creates suction at very low pressure and allows the expansion of the steam in the turbine to a very low pressure. The principle advantages of condensing operation are the increased amount of energy extracted per kg of steam and thereby increasing efficiency and the condensate which is fed into the boiler again reduces the amount of fresh feed water.

The condensate along with some fresh make up feed water is again fed into the boiler by pump (called the boiler feed pump).In condenser the steam is condensed by cooling water. Cooling water recycles through cooling tower this constitutes cooling water circuit. The ambient air is allowed to enter in the boiler after dust filtration. Also the flue gas comes out of the boiler and exhausted into atmosphere through stacks. These constitute air and flue gas circuit. The flow of air and also the static pressure inside the steam boiler (called draught) is maintained by two fans called Forced Draught (FD) fan and Induced Draught (ID) fan. The total scheme of a typical thermal power station along with different circuits is illustrated below.

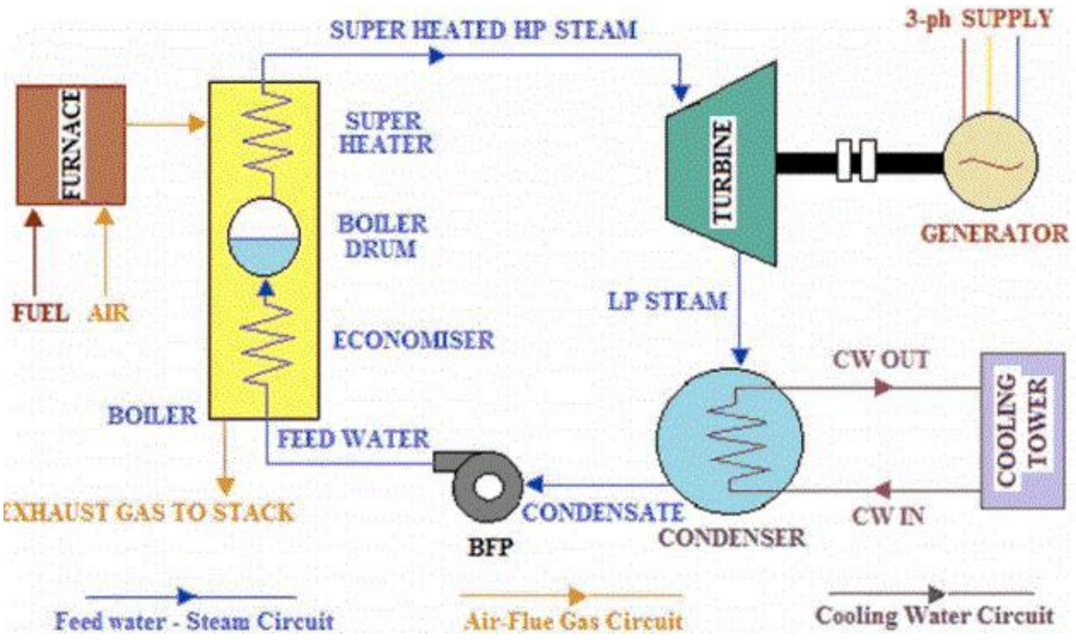


Figure: Steam flow diagram.

Inside the boiler there are various heat exchangers, viz.' Economiser', 'Evaporator' (not shown in the fig above, it is basically the water tubes, i.e. down comer riser circuit), 'Super Heater' (sometimes 'Reheater', 'air preheater' are also present).In Economizer the feed water is heated to considerable amount by the remaining heat of flue gas. The Boiler Drum actually maintains a head for natural circulation of two phase mixture (steam + water) through the water tubes.

There is also Super Heater which also takes heat from flue gas and raises the temperature of steam as per requirement.Efficiency of Thermal Power Station or Plant. The overall efficiency of a thermal power station or plant varies from 20% to 26% and it depends upon plant capacity.

Electrostatic Precipitators:

An electrostatic precipitator (ESP), or electrostatic air cleaner is a particulate collection device that removes particles from a flowing gas (such as air) using the force of an induced electrostatic charge.

The basic idea of an ESP:

- Charging
- collecting.
- removing
- Every particle either has or can be given a charge—positive or negative.
- we impart a negative charge to all the particles in a gas stream in ESP.
- Then a grounded plate having a positive charge is set up.
- The negatively charged particle would migrate to the grounded collection plate and be captured.

- The particles would quickly collect on the plate, creating a dust layer. The dust layer would accumulate until we removed it.

The structural design and operation of the discharge electrodes (rigid-frame, wires or plate) and collection electrodes.:

- tubular type ESP
- plate type ESP

The method of charging:

- single-stage ESP
- two-stage ESP

The temperature of operation:

- cold-side ESP
- hot-side ESP

The method of particle removal from collection surfaces

- wet ESP
- Dry ESP

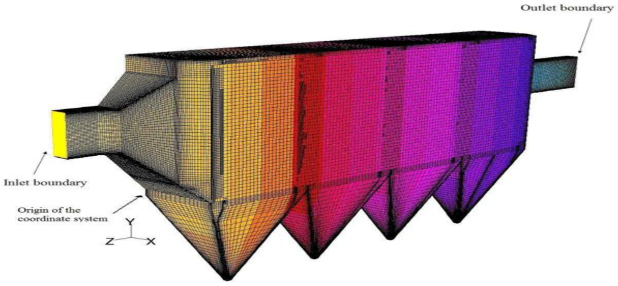


Figure: Electrostatic Precipitator

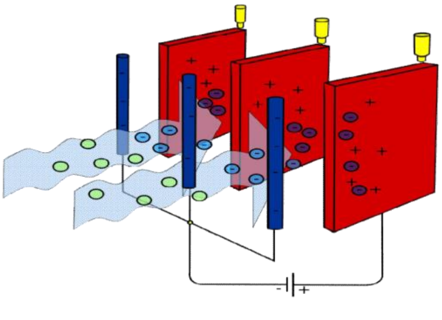


Figure: Electrostatic Precipitator

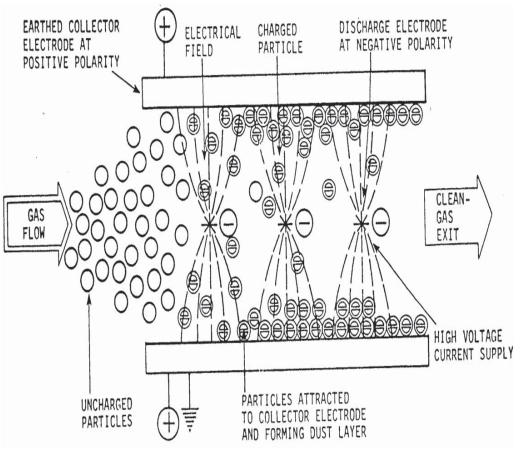


Figure 66: Electrostatic Precipitator

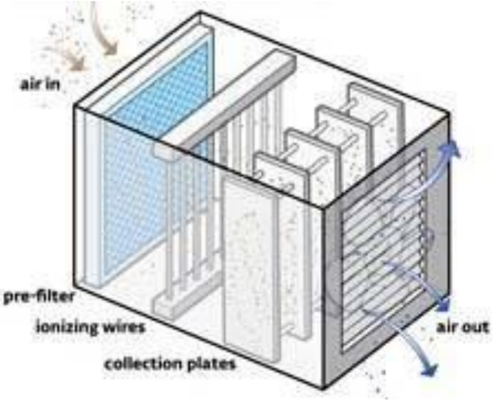


Figure: ESP Principle

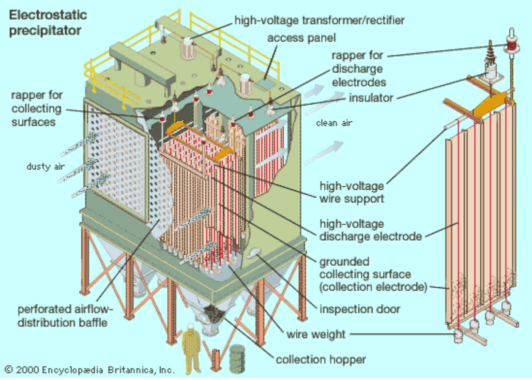


Figure: ESP Principle

A thermal power station or thermal power plant has ultimate target to make business profit. Hence for optimizing the profit, the location of the station is much important factor. Power generation plant location plays an optimizing part in the economy of the station.The most economical, location of power plant can be determined by graphical method as described below. The most economical and ideal power plant location is the center of gravity of the load because for such a power generation plant the length of the power transmission network will be minimum.

Let’s Q1(x1, y1), Q2(x2, y2), Q3(x3, y3), Q4(x4, y4) and Qn(xn, yn)
are n numbers of load centers. From the above graph we get, the coordinates of the center of gravity of the load, Q(x, y) where

$$x = \frac{x_1Q_1 + x_2Q_2 + x_3Q_3 + \cdots\cdots\cdots x_nQ_n}{Q_1 + Q_2 + Q_3 + \cdots\cdots\cdots Q_n} \; and \; y = \frac{y_1Q_1 + y_2Q_2 + y_3Q_3 + \cdots\cdots\cdots y_nQ_n}{Q_1 + Q_2 + Q_3 + \cdots\cdots\cdots Q_n}$$

Obviously the location of thermal power station is best at the center of gravity of the load, but many times it is not possible to establish a thermal power plant at the CG of the load. Since normally CG point of the load may be at the heart of the city. so other many points to be considered to decide the best optimized location of the power plant. The electric power generation plant must be constructed at such a place where the cost of land is quite reasonable. The land should be such that the acquisition of private property must be minimum.A large quantity of cooling water is required for the condensers etc of thermal power generation plant, hence the plant should preferably situated beside big source of natural water source such as big river.

Availability of huge amount of fuel at reasonable cost is one of the major criterion for choosing plant location. The plant should be established on plane land. The soil should be such that it should provide good and firm foundation of plant and buildings. The thermal power plant location should not be very nearer to dense locality as there are smoke, noise steam, water vapors etc. There must be ample scope of development of future demand. Place for ash handling plant for thermal power station should also be available very nearby Very tall chimney of power station should not obstruct the traffics of air ships.

Advantages & Disadvantages of Thermal Power Station Advantages:

Advantages:

- Economical for low initial cost other than any generating plant.
- Land required less than hydro power plant.
- Since coal is main fuel & its cost is quite cheap than petrol/diesel so generation cost is economical.
- There are easier maintenance.
- Thermal power plant can be installed in any location where transportation & bulk of water are available.

Disadvantages:

- The running cost for a thermal power station is comparatively high due to fuel, maintenance etc.
- Large amount of smoke causes air pollution. The thermal power station is responsible for Global warming.
- The heated water that comes from thermal power plant has an adverse effect on the lives in the water and disturbs the ecology.
- Overall efficiency of thermal power plant is low like less 30%.

OVERVIEW OF NUCLEAR REACTORS

Nuclear Reactions:

Basics:

- Atoms consist of nucleus and electrons.
- The nucleus is composed of protons and neutrons.
- Protons are positively charged whereas neutrons are electrically neutral.
- Atoms with nuclei having same number of protons but difference in their masses are called isotopes. They are identical in terms of their chemical properties but differ with respect to nuclear properties.
- Natural Uranium consists of $92U^{238}$ (99.282%), $92U^{235}$ (0.712%) and $92U^{234}$
- $92U^{235}$ is used as fuel in nuclear power plants.

Energy from Nuclear Reactions:

- The sum of masses of protons and neutrons exceeds the mass of the atomic nucleus and this difference is called mass defect Δm.
- In a nuclear reaction the mass defect is converted into energy known as binding energy according to Einstein's equation ($E=\Delta m\ c^2$).
- Fissioning one amu of mass results in release of 931 MeV of energy.
- It has been found that element having higher and lower mass numbers are unstable. Thus the lower mass numbers can be fused or the higher mass numbers can be fissioned to produce more stable elements.
- This results in two types of nuclear reactions known as fusion and fission.
- The total energy per fission reaction of U^{235} is about 200 MeV.
- Fuel burn-up rate is the amount of energy in MW/days produced by each metric ton of fuel.

Nuclear Fission:

Nuclear fission is the reaction by which a heavy nucleus (that is one with a high value of Z) is hit with a small particle, as a result of which it splits into two (occasionally more) smaller nuclei.

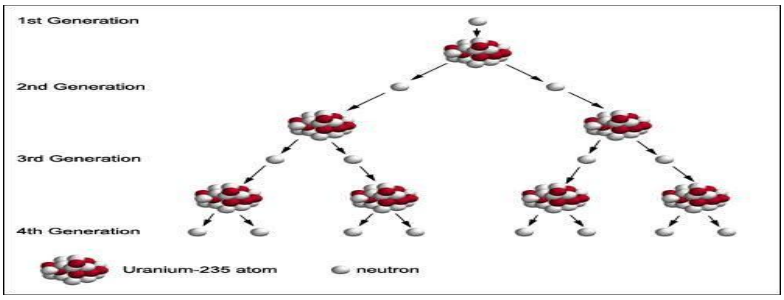


Figure: Nuclear Fission

Nuclear Fusion:

Fusion is the opposite of fission, it is the joining together of two light nuclei to form a heavier one (plus a small fragment). For example if two 2H nuclei (two deuterons) can be made to come together they can form He and a neutron.

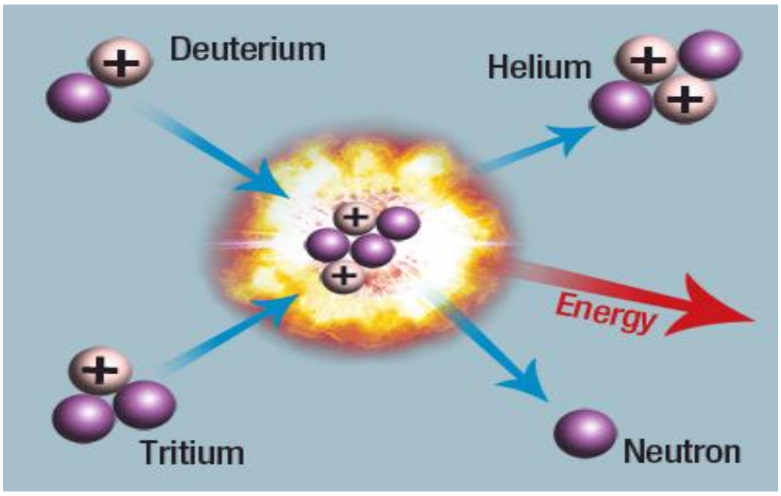


Figure: Nuclear Fusion

Nuclear Power Reactors:

Magnox Reactors:

- The six main commercial reactor types, two (Magnox and AGR) owe much to the very earliest reactor designs in that they are graphite moderated and gas cooled. Magnox reactors were built in the UK from 1956 to 1971 but have now been superseded.
- The Magnox reactor is named after the magnesium alloy used to encase the fuel, which is natural uranium metal. Fuel elements consisting of fuel rods encased in Magnox cans are loaded into vertical channels in a core constructed of graphite blocks.

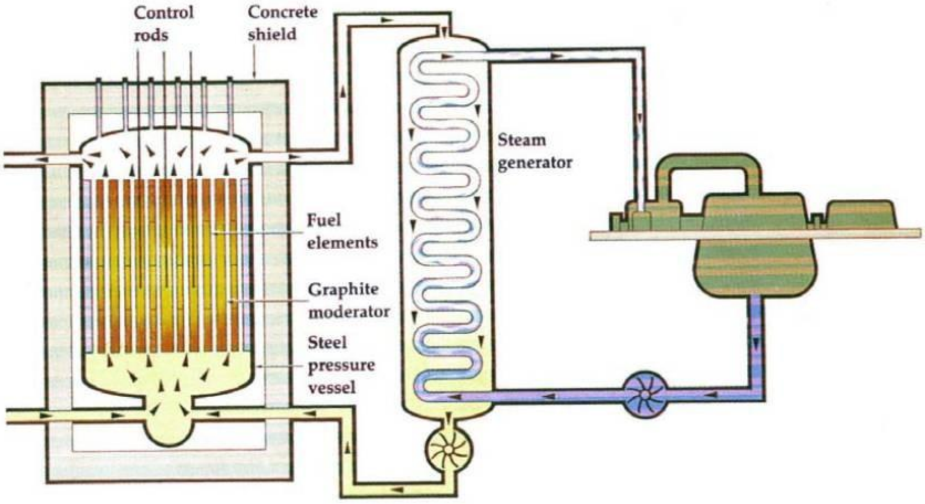


Figure: Magnox Reactor

Advanced Gas cooled Reactors:

- In order to improve the cost effectiveness of this type of reactor, it was necessary to go to higher temperatures to achieve higher thermal efficiencies and higher power densities to reduce capital costs.

- This entailed increases in cooling gas pressure and changing from Magnox to stainless steel cladding and from uranium metal to uranium dioxide fuel. This in turn led to the need for an increase in the proportion of U^{235} in the fuel. The resulting design, known as the **Advanced Gas-Cooled Reactor, Or AG.**

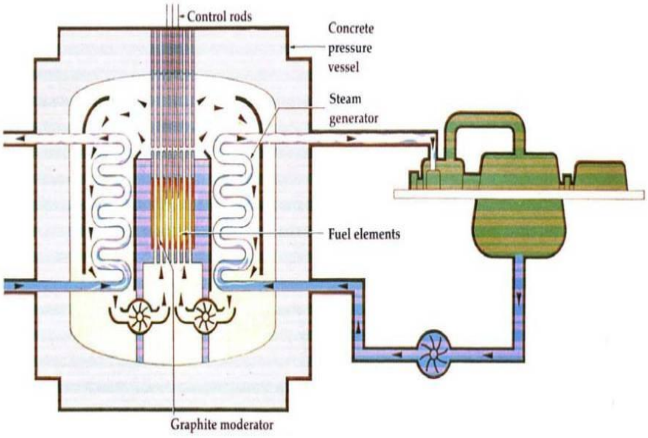


Figure: Advanced Gas cooled Reactors

Pressurized Water Reactor (PWR):

- The most widely used reactor type in the world is the Pressurized Water Reactor (PWR) which uses enriched (about 3.2% U235) uranium dioxide as a fuel in zirconium alloy cans.
- The fuel, which is arranged in arrays of fuel "pins" and interspersed with the movable control rods, is held in a steel vessel through which water at high pressure (to suppress boiling) is pumped to act as both a coolant and a moderator.

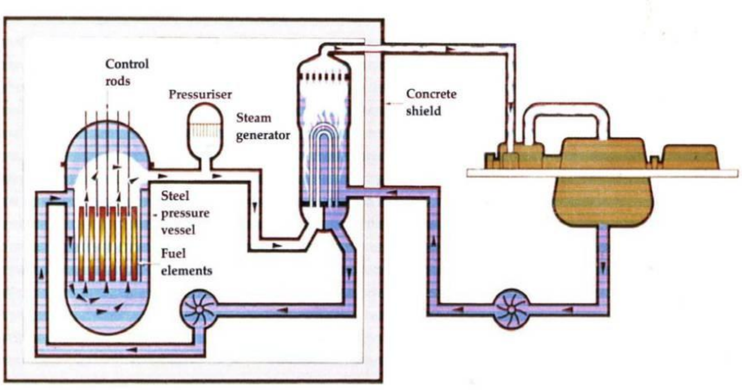


Figure: Pressurized Water Reactor

Boiling Water Reactors (BWR):

- The second type of water cooled and moderated reactor does away with the steam generator and, by allowing the water within the reactor circuit to boil, it raises steam directly for electrical power generation. Such reactors, known as Boiling Water Reactors (BWRs), throughout the world.
- The high-pressure water is then passed through a steam generator, which raises steam
- This, however, leads to some radioactive contamination of the steam circuit and turbine, which then requires shielding of these components in addition to that surrounding the reactor.

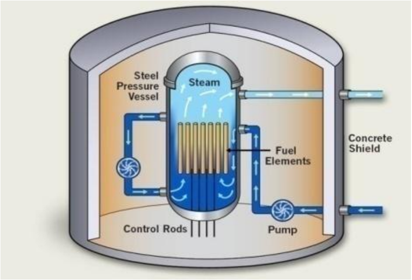


Figure: Boiling Water Reactor

Comparison of PWR and BWR:

Table: Comparison of PWR and BWR:

PWR	**BWR**
Advantages	**Advantages**
• Relatively compact in size • Possibility of breeding plutonium by providing a blanket of U-238 • High power density • Containment of fission products due to heat exchanger • Inexpensive ‘light water’ can be used as moderator, coolant and reflector • Positive power demand coefficient i.e. the reactor responds to load increase	• Elimination of heat exchanger circuit results in reduction in cost and gain in thermal efficiency (to about 30%) • Pressure inside in the reactor vessel is considerably lower resulting in lighter and less costly design • BWR cycle is more efficient than PWR as the outlet temperature of steam is much higher • Metal surface temperature is lower since boiling of water is inside the reactor • BWR is more stable than PWR and hence is commonly known as a self-controlled reactor
Disadvantages	Disadvantages
• Moderator remains under high pressure and hence a strong pressure vessel is required • Expensive cladding material is required to prevent corrosion • Heat loss occurs due to heat exchanger • Elaborate safety devices are required Lacks flexibility i.e. the reactor needs to be shut down for recharging and there is difficulty in fuel element design and fabrication • Thermal efficient is very low; around 20%	• Possibility of radio-active contamination in the turbine mechanism • Wastage of steam may result in lowering of thermal efficiency on part load operation • Power density of BWR is nearly half that of PWR resulting in large size vessel • Possibility of burn-out of fuel is more as water boiling is on the surface of fuel. • BWR cannot meet a sudden increase in load

Fast Breeder Reactors:

- All of today's commercially successful reactor systems are "thermal" reactors, using slow or thermal neutrons to maintain the fission chain reaction in the U235 fuel. Even with the enrichment levels used in the fuel for such reactors, however, by far the largest numbers of atoms present are U238, which are not fissile.
- Consequently, when these atoms absorb an extra neutron, their nuclei do not split but are converted into another element, Plutonium.
- Plutonium is fissile and some of it is consumed in situ, while some remains in the spent fuel together with unused U235. These fissile components can be separated from the fission product wastes and recycled to reduce the consumption of uranium in thermal reactors by up to 40%, although clearly thermal reactors still require a substantial net feed of natural uranium.
- It is possible, however, to design a reactor which overall produces more fissile material in the form of Plutonium than it consumes. This is the fast reactor in which the neutrons are unmoderated, hence the term "fast".
- The physics of this type of reactor dictates a core with a high fissile concentration, typically around 20%, and made of Plutonium. In order to make it breed, the active core is surrounded by material (largely U238) left over from the thermal reactor enrichment process. This material is referred to as fertile, because it converts to fissile material when irradiated during operation of the reactor.
- The successful development of fast reactors has considerable appeal in principle. This is because they have the potential to increase the energy available from a given quantity of uranium by a factor of fifty or more, and can utilize the existing stocks of depleted uranium, which would otherwise have no value.

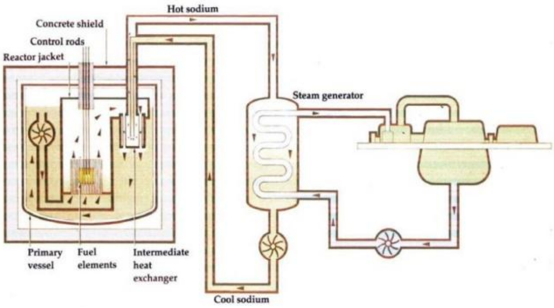


Figure: Fast Breeder Reactors

Schematic Arrangement of a BWR:

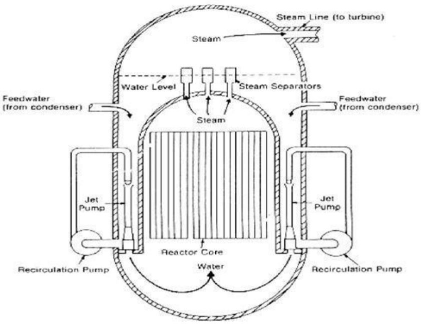


Figure: BWR Reactors

Pressurized Water Reactors:

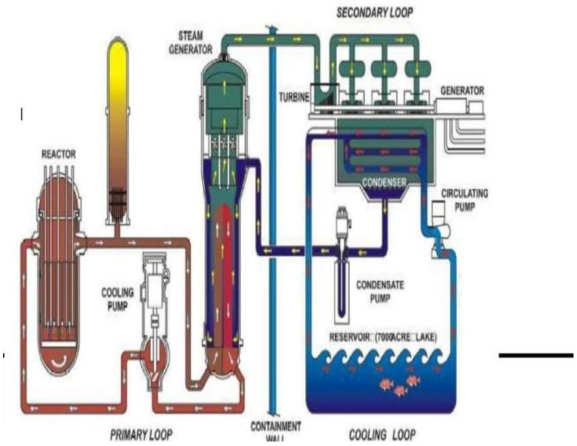


Figure: Pressurized Water Reactors

Power Cycle –Brayton:

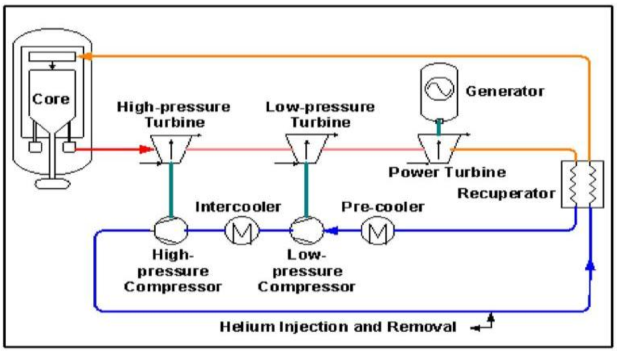


Figure: Power Cycle –Brayton

Factors for Site Selection of NPPs:

1. Availability of Water: working fluid
2. Distance from Populated Area: danger of radioactivity
3. Nearness to the load centre: reduction in transmission cost
4. Disposal of Waste: radioactive waste
5. Accessibility by Rail and Road: transport of heavy equipment

Advantages of NPPs:

1. Reduces demand for fossil fuels
2. Quantity of nuclear fuel is much less: thus reducing transport and resulting costs
3. Area of land required is less: compared to a conventional plant of similar capacity
4. Production of fissile material
5. Location independent of geographical factors: except water requirement

Disadvantages of NPPs:

1. Not available for variable loads (load factor-0.8): as the reactors cannot be controlled to respond quickly
2. Economical reason should be substantial
3. Risk of leakage of radioactive material
4. Further investigation on life cycle assessment and reliability needs to be done
5. Perception problems

Nuclear Power in India:
Plant Units Capacity Established

- Tarapur, Maharashtra
- Rawatbhata, Rajasthan
- Kalpakkam, Tamil Nadu
- Kakrapar, Gujarat
- Kaiga, Karnataka
- Kundankulam, Tamil Nadu

UNIT – II

HYDRO ELECTRIC POWER STATIONS

INTRODUCTION:

Hydroelectric power plants do not use up resources to create electricity nor do they pollute the air, land, or water, as other power plants may. Hydroelectric power has played an important part in the development of this Nation's electric power industry. Both small and large hydroelectric power developments were instrumental in the early expansion of the electric power industry. Hydroelectric power comes from flowing water winter and spring runoff from mountain streams and clear lakes. Water, when it is falling by the force of gravity, can be used to turn turbines and generators that produce electricity.

Hydroelectric power is important to our Nation. Growing populations and modern technologies require vast amounts of electricity for creating, building, and expanding. In the 1920's, hydroelectric plants supplied as much as 40 percent of the electric energy produced. Although the amount of energy produced by this means has steadily increased, the amount produced by other types of power plants has increased at a faster rate and hydroelectric power presently supplies about 10 percent of the electrical generating capacity of the United States.

Hydropower is an essential contributor in the national power grid because of its ability to respond quickly to rapidly varying loads or system disturbances, which base load plants with steam systems powered by combustion or nuclear processes cannot accommodate. Reclamation=s 58 power plants throughout the Western United States produce an average of 42 billion kWh (kilowatt-hours) per year, enough to meet the residential needs of more than 14 million people. This is the electrical energy equivalent of about 72 million barrels of oil.

Hydroelectric power plants are the most efficient means of producing electric energy. The efficiency of today's hydroelectric plant is about 90 percent. Hydroelectric plants do not create air pollution, the fuel--falling water--is not consumed, projects have long lives relative to other forms of energy generation, and hydroelectric generators respond quickly to changing system conditions. These favorable characteristics continue to make hydroelectric projects attractive sources of electric power.

How Hydropower Works:

Hydroelectric power comes from water at work, water in motion. It can be seen as a form of solar energy, as the sun powers the hydrologic cycle which gives the earth its water. In the hydrologic cycle, atmospheric water reaches the earth= s surface as precipitation. Some of this water evaporates, but much of it either percolates into the soil or becomes surface runoff. Water from rain and melting snow eventually reaches ponds, lakes, reservoirs, or oceans where evaporation is constantly occurring.

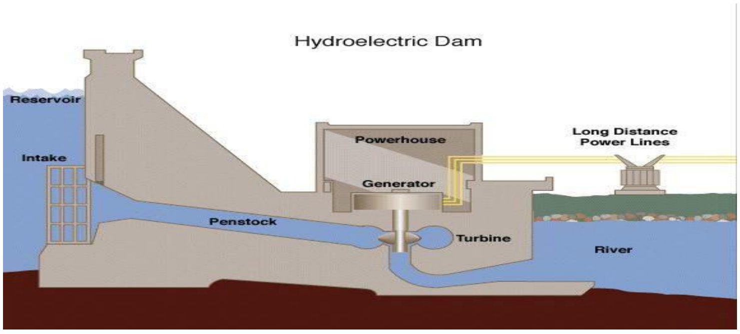


Figure: Schematic of a Hydropower Plant

Figure: Forebay

Figure: Surge Tank

Figure below: Tail race

Figure: Kaplan Turbine

Moisture percolating into the soil may become ground water (subsurface water), some of which also enters water bodies through springs or underground streams. Ground water may move upward through soil during dry periods and may return to the atmosphere by evaporation.Water vapor passes into the atmosphere by evaporation then circulates, condenses into clouds, and some returns to earth as precipitation. Thus, the water cycle is complete. Nature ensures that water is a renewable resource.

Generating Power:

In nature, energy cannot be created or destroyed, but its form can change. In generating electricity, no new energy is created. Actually one form of energy is converted to another form. To generate electricity, water must be in motion. This is kinetic (moving) energy. When flowing water turns blades in a turbine, the form is changed to mechanical (machine) energy. The turbine turns the generator rotor which then converts this mechanical energy into another energy form -- electricity. Since water is the initial source of energy, we call this hydroelectric power or hydropower for short.

At facilities called hydroelectric power plants, hydropower is generated. Some power plants are located on rivers, streams, and canals, but for a reliable water supply, dams are needed. Dams store water for later release for such purposes as irrigation, domestic and industrial use, and power generation. The reservoir acts much like a battery, storing water to be released as needed to generate power.

The dam creates a Ahead or height from which water flows. A pipe (penstock) carries the water from the reservoir to the turbine. The fast-moving water pushes the turbine blades, something like a pinwheel in the wind. The waters force on the turbine blades turns the rotor, the moving part of the electric generator. When coils of wire on the rotor sweep past the generator=s stationary coil (stator), electricity is produced.This concept was discovered by Michael Faraday in 1831 when he found that electricity could be generated by rotating magnets within copper coils. When the water has completed its task, it flows on unchanged to serve other needs.

Once the electricity is produced, it must be delivered to where it is needed -- our homes, schools, offices, factories, etc. Dams are often in remote locations and power must be transmitted over some distance to its users. Vast networks of transmission lines and facilities are used to bring electricity to us in a form we can use. All the electricity made at a power plant comes first through transformers which raise the voltage so it can travel long distances through power lines. (Voltage is the pressure that forces an electric current through a wire.) At local substations, transformers reduce the voltage so electricity can be divided up and directed throughout an area. Transformers on poles (or buried underground, in some neighborhoods) further reduce the electric power to the right voltage for appliances and use in the home. When electricity gets to our homes, we buy it by the kilowatt-hour, and a meter measures how much we use.

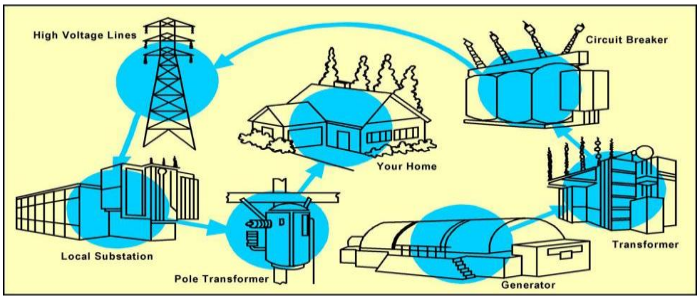


Figure: Electricity supply to Loads

While hydroelectric power plants are one source of electricity, other sources include power plants that burn fossil fuels or split atoms to create steam which in turn is used to generate power. Gas-turbine, solar, geothermal, and wind-powered systems are other sources. All these power plants may use the same system of transmission lines and stations in an area to bring power to you. By use of this power grid," electricity can be interchanged among several utility systems to meet varying demands. So the electricity lighting your reading lamp now may be from a hydroelectric power plant, a wind generator, a nuclear facility, or a coal, gas, or oil-fired power plant or a combination of these.

The area where you live and its energy resources are prime factors in determining what kind of power you use. For example, in Washington State hydroelectric power plants provided approximately 80 percent of the electrical power during 2002. In contrast, in Ohio during the same year, almost 87 percent of the electrical power came from coal-fired power plants due to the area=s ample supply of coal. Electrical utilities range from large systems serving broad regional areas to small power companies serving individual communities.

Most electric utilities are investor-owned (private) power companies. Others are owned by towns, cities, and rural electric associations. Surplus power produced at facilities owned by the Federal Government is marketed to preference power customers (A customer given preference by law in the purchase of federally generated electrical energy which is generally an entity which is nonprofit and publicly financed.) by the Department of Energy through its power marketing administrations.

How Power is Computed:

Before a hydroelectric power site is developed, engineers compute how much power can be produced when the facility is complete. The actual output of energy at a dam is determined by the volume of water released (discharge) and the vertical distance the water falls (head). So, a given amount of water falling a given distance will produce a certain amount of energy. The head and the discharge at the power site and the desired rotational speed of the generator determine the type of turbine to be used.

The head produces a pressure (water pressure), and the greater the head, the greater the pressure to drive turbines. This pressure is measured in pounds of force (pounds per square inch). More head or faster flowing water means more power.T o find the theoretical horsepower (the measure of mechanical energy) from a specific site, this formula is used:

$THP = (Q \times H)/8.8$

Where: THP = theoretical horsepower
Q = flow rate in cubic feet per second (cfs)
H = head in feet
8.8 = a constant

A more complicated formula is used to refine the calculations of this available power. The formula takes into account losses in the amount of head due to friction in the penstock and other variations due to the efficiency levels of mechanical devices used to harness the power.To find how much electrical power we can expect, we must convert the mechanical measure (horsepower) into electrical terms (watts). One horsepower is equal to 746 watts (U.S. measure).

Turbines:

While there are only two basic types of turbines (impulse and reaction), there are many variations. The specific type of turbine to be used in a power plant is not selected until all operational studies and cost estimates are complete. The turbine selected depends largely on the site conditions. A reaction turbine is a horizontal or vertical wheel that operates with the wheel completely submerged a feature which reduces turbulence. In theory, the reaction turbine works like a rotating lawn sprinkler where water at a central point is under pressure and escapes from the ends of the blades, causing rotation. Reaction turbines are the type most widely used.

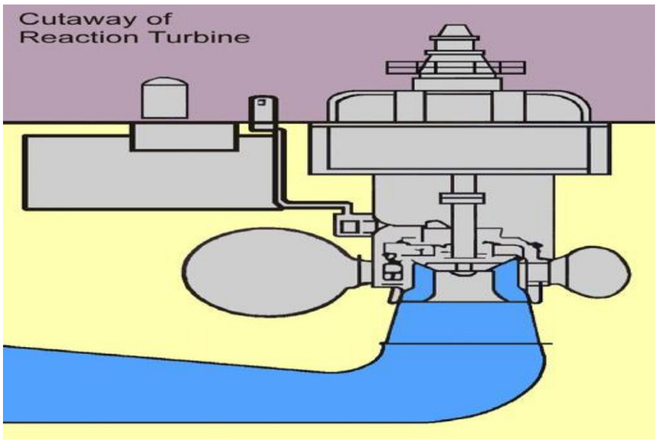


Figure: Reaction Turbine

An impulse turbine is a horizontal or vertical wheel that uses the kinetic energy of water striking its buckets or blades to cause rotation. The wheel is covered by a housing and the buckets or blades are shaped so they turn the flow of water about 170 degrees inside the housing. After turning the blades or buckets, the water falls to the bottom of the wheel housing and flows out.

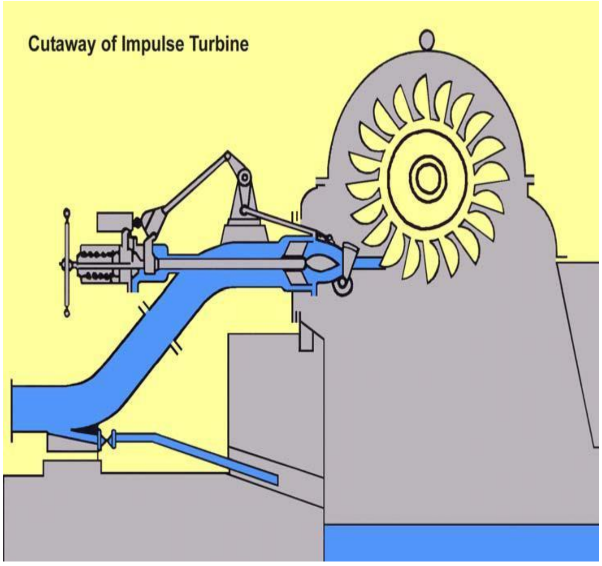


Figure: Impulse Turbine

Modern Concepts and Future Role:

Hydropower does not discharge pollutants into the environment; however, it is not free from adverse environmental effects. Considerable efforts have been made to reduce environmental problems associated with hydropower operations, such as providing safe fish passage and improved water quality in the past decade at both Federal facilities and non-Federal facilities licensed by the Federal Energy Regulatory Commission. Efforts to ensure the safety of dams and the use of newly available computer technologies to optimize operations have provided additional opportunities to improve the environment. Yet, many unanswered questions remain about how best to maintain the economic viability of hydropower in the face of increased demands to protect fish and other environmental resources. Reclamation actively pursues research and development (R&D) programs to improve the operating efficiency and the environmental performance of hydropower facilities.

Hydropower research and development today is primarily being conducted in the following areas:

- Fish Passage, Behavior, and Response
- Turbine-Related Projects
- Monitoring Tool Development
- Hydrology
- Water Quality
- Dam Safety
- Operations & Maintenance
- Water Resources Management

Reclamation continues to work to improve the reliability and efficiency of generating hydropower. Today, engineers want to make the most of new and existing facilities to increase production and efficiency.

Existing hydropower concepts and approaches include:

- Updating existing power plants
- Developing small plants (low-head hydropower)
- Peaking with hydropower
- Pumped storage
- Tying hydropower to other forms of energy

The updating of existing hydroelectric generator and turbine units at power plants is one of the most immediate, cost- effective and environmentally acceptable means of developing additional electric power. Since 1978, Reclamation has pursued an aggressive updating program which has added more than 1,600,000 kW to Reclamation's capacity at an average cost of $69 per kilowatt.

This compares to an average cost for providing new peaking capacity through oil-fired generators of more than $400 per kilowatt. Reclamation's updating program has essentially provided the equivalent of another major hydroelectric facility of the approximate magnitude of Hoover Dam and Power plant at a fraction of the cost and impact on the environment when compared to any other means of providing new generation capacity.

Low-head Hydropower:

A low- head dam is one with a water drop of less than 65 feet and a generating capacity less than 15,000 kW. Large, high-head dams can produce more power at lower costs than low-head dams, but construction of large dams may be limited by lack of suitable sites, by environmental considerations, or by economic conditions.

In contrast, there are many existing small dams and drops in elevation along canals where small generating plants could be installed. New low-head dams could be built to increase output as well. The key to the usefulness of such units is their ability to generate power near where it is needed, reducing the power inevitably lost during transmission.

Peaking with Hydropower:

Demands for power vary greatly during the day and night. These demands vary considerably from season to season, as well. For example, the highest peaks are usually found during summer daylight hours when air conditioners are running. Nuclear and fossil fuel plants are not efficient for producing power for the short periods of increased demand during peak periods. Their operational requirements and their long startup times make them more efficient for meeting base load needs.

Since hydroelectric generators can be started or stopped almost instantly, hydropower is more responsive than most other energy sources for meeting peak demands. Water can be stored overnight in a reservoir until needed during the day, and then released through turbines to generate power to help supply the peak load demand. This mixing of power sources offers a utility company the flexibility to operate steam plants most efficiently as base plants while meeting peak needs with the help of hydropower. This technique can help ensure reliable supplies and may help eliminate brownouts and blackouts caused by partial or total power failures.

Today, many of Reclamation’s 58 power plants are used to meet peak electrical energy demands, rather than operating around the clock to meet the total daily demand. Increasing use of other energy-producing power plants in the future will not make hydroelectric power plants obsolete or unnecessary. On the contrary, hydropower can be even more important. While nuclear or fossil-fuel power plants can provide base loads, hydroelectric power plants can deal more economically with varying peak load demands. This is a job they are well suited for.

Tying Hydropower to Other Energy Forms:

When we hear the term solar energy,” we usually think of heat from the sun’s rays which can be put to work. But there are other forms of solar energy. Just as hydropower is a form of solar energy, so too is wind power. In effect, the sun causes the wind to blow by heating air masses that rise, cool, and sink to earth again. Solar energy in some form is always at work in rays of sunlight, in air currents, and in the water cycle. Solar energy, in its various forms, has the potential of adding significant amounts of power for our use. The solar energy that reaches our planet in a single week is greater than that contained in all of the earth’s remaining coal, oil, and gas resources.

However, the best sites for collecting solar energy in various forms are often far removed from people, their homes, and work places. Building thousands of miles of new transmission lines would make development of the power too costly. Because of the seasonal, daily, and even hourly changes in the weather, energy flow from the wind and sun is neither constant nor reliable. Peak production times do not always coincide with high power demand times.

To depend on the variable wind and sun as main power sources would not be acceptable to most American lifestyles. Imagine having to wait for the wind to blow to cook a meal or for the sun to come out from behind a cloud to watch television. As intermittent energy sources, solar power and wind power must be tied to major hydroelectric power systems to be both economical and feasible. Hydropower can serve as an instant backup and to meet peak demands.

Linking wind power and hydropower can add to the Nation’s supply of electrical energy. Large wind machines can be tied to existing hydroelectric power plants. Wind power can be used, when the wind is blowing, to reduce demands on hydropower. That would allow dams to save their water for later release to generate power in peak periods. The benefits of solar power and wind power are many. The most valuable feature of all is the replenishing supply of these types of energy. As long as the sun shines and the wind blows, these resources are truly renewable.

Future Potential:

What is the full potential of hydropower to help meet the Nation's energy needs? The hydropower resource assessment by the Department of Energy's Hydropower Program has identified 5,677 sites in the United States with acceptable undeveloped hydropower potential. These sites have a modeled undeveloped capacity of about 30,000 MW. This represents about 40 percent of the existing conventional hydropower capacity.

A variety of restraints exist on this development, some natural and some imposed by our society. The natural restraints include such things as occasional unfavorable terrain for dams. Other restraints include disagreements about who should develop a resource or the resulting changes in environmental conditions. Often, other developments already exist where a hydro electric power facility would require a dam and reservoir to be built.

Finding solutions to the problems imposed by natural restraints demands extensive engineering efforts. Sometimes a solution is impossible, or so expensive that the entire project becomes impractical. Solution to the societal issues is frequently much more difficult and the costs are far greater than those imposed by nature. Developing the full potential of hydropower will require consideration and coordination of many varied needs.

Hydropower, the Environment, and Society:

- It is important to remember that people, and all their actions, are part of the natural world. The materials used for building, energy, clothing, food, and all the familiar parts of our day-to-day world come from natural resources.

- Our surroundings are composed largely of the built environment structures and facilities built by humans for comfort, security, and well-being. As our built environment grows, we grow more reliant on its offerings.

- To meet our needs and support our built environment, we need electricity which can be generated by using the resources of natural fuels. Most resources are not renewable; there is a limited supply. In obtaining resources, it is often necessary to drill oil wells, tap natural gas supplies, or mine coal and uranium. To put water to work on a large scale, storage dams are needed.

- We know that any innovation introduced by people has an impact on the natural environment. That impact may be desirable to some, and at the same time, unacceptable to others. Using any source of energy has some environmental cost. It is the degree of impact on the environment that is crucial.

Some human activities have more profound and lasting impacts than others. Techniques to mine resources from below the earth may leave long-lasting scars on the landscape. Oil wells may detract from the beauty of open, grassy fields. Reservoirs behind dams may cover picturesque valleys. Once available, use of energy sources can further impact the air, land, and water in varying degrees. People want clean air and water and a pleasing environment. We also want energy to heat and light our homes and run our machines.

What is the solution?

- The situation seems straightforward: The demand for electrical power must be curbed or more power must be produced in environmentally acceptable ways. The solution, however, is not so simple.
- Conservation can save electricity, but at the same time our population is growing steadily.
- Growth is inevitable, and with it the increased demand for electric power.
- Since natural resources will continue to be used, the wisest solution is a careful, planned approach to their future use. All alternatives must be examined, and the most efficient, acceptable methods must be pursued.
- Hydroelectric facilities have many characteristics that favor developing new projects and upgrading existing power plants.
- Hydroelectric power plants do not use up limited nonrenewable resources to make electricity.
- They do not cause pollution of air, land, or water.
- They have low failure rates, low operating costs, and are reliable.
- They can provide startup power in the event of a system wide power failure.

As an added benefit, reservoirs have scenic and recreation value for campers, fishermen, and water sports enthusiasts. The water is a home for fish and wildlife as well. Dams add to domestic water supplies, control water quality, provide irrigation for agriculture, and avert flooding. Dams can actually improve downstream conditions by allowing mud and other debris to settle out.

Existing power plants can be updated or new power plants added at current dam sites without a significant effect on the environment. New facilities can be constructed with consideration of the environment. For instance, dams can be built at remote locations, power plants can be placed underground, and selective withdrawal systems can be used to control the water temperature released from the dam. Facilities can incorporate features that aid fish and wildlife, such as salmon runs or resting places for migratory birds.

In reconciling our natural and our built environments there will be tradeoffs and compromises. As we learn to live in harmony as part of the environment, we must seek the best alternatives among all ecologic, economic, technological, and social perspectives. The value of water must be considered by all energy planners. Some water is now dammed and can be put to work to make hydroelectric power. Other water is presently going to waste. The fuel burned to replace this wasted energy is gone forever and, so, is a loss to our Nation. The longer we delay the balanced development of our potential for hydropower, the more we unnecessarily use up other vital resources.

UNIT - III

SOLAR ENERGY

Renewable energy is generally defined as energy that comes from resources which are naturally replenished on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat. Renewable energy replaces conventional fuels in four distinct areas: electricity generation, hot water/space heating, motor fuels, and rural (off-grid) energy services. Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and bio fuels and hydrogen derived from renewable resources

Introduction:

How Solar Power Plant works?

Figure: Solar Power Plant

The sun is the source of energy that drives the cycle of life and death on earth. It is also the energy source that gives us warmth and evaporates water and melts snow. The sun is about 150,000,000 km away from the Earth. Due to its immense, but finite size, it has an angular diameter of 0.5 degree (32 minutes), as viewed from Earth.

Sun burns continuously via thermonuclear reactions (fusion). Inside the sun, radioactive processes releases energy and convection transfers solar energy to its exterior surface. Despite the extremely high temperatures needed at the core of the sun, to sustain its thermonuclear reactions, the sun has a black body temperature of 5770 K. Consequently, we receive a relatively constant flux density of energy, defined as the Solar Constant. Its mean value is 1366 W m-2.

The earth receives 1.6 × 1018 units of energy from the Sun annually, which is 20,000 times the requirement of mankind on the earth. Some of the solar energy causes evaporation of water, leading to rains and creation of rivers etc.

Some of itis utilized in photosynthesis which is essential for sustenance of life on earth. Man has tried, from time immemorial, to harness this infinite source of energy, but has been able to tap only a negligibly small fraction of this energy.

When light travels from outer space to earth, solar energy is lost because of following reasons:

- Scattering: The rays collide with particles present in atmosphere
- Absorption: Because of water vapor there is absorption
- Cloud cover: The light rays are diffused because of clouds.
- Reflection: When the light rays hit the mountains present on the earth surface there is reflection.
- Climate: Latitude of the location, day (time in the year) also affects the amount of solar energy received by the place

Solar Radiation geometry:

In Solar Radiation geometry the following terms are important:

Horizon is the horizontal plane that extends from the point where the observer is standing, to infinity, straight through space. Since we're only working with relatively short distances (compared to the Universe), a line extending N-S will be quite sufficient. Altitude (A) is the angle of the sun over the horizon. In this problem, we will be working with the sun at noon, so it will either be over the N or S horizon.

- Zenith (Z) is the angle that the sun is from directly overhead, and it is equal to 90-A. It, too, can be over the S or N horizon, but there is little need to state it.
- Declination (D) is the latitude at which the sun is directly overhead. It is always between 23.5 N and 23.5 S latitude, those occurring on the Solstices.
- Latitude (L) is the location N or S of the equator at which the observer is located. (It is determined by radii from the center of Earth at different angles to the equator. If such an angle is swept along the surface of the planet, it draws a circle.)

Solar radiation data is necessary for calculating cooling load for buildings, prediction of local air temperature and for the estimating power that can be generated from photovoltaic cells. Solar radiation falling on the surface of the earth is measured by instruments called pyranometers. The weather service in most countries has many stations to measure solar radiation using pyranometers. In India pyranometers have been used for a long time.

Generally flat plate collectors are mounted on roofs or sloping walls. In most of these collectors, the absorber element is made of a metal such as galvanised iron, aluminium, copper etc. and the cover is usually of glass of 4 mm thickness. The back of the absorber is insulated with glass wool, asbestos wool or some other insulating material. The casing, enclosing all the components of the collector is either made of wood or some light metal like aluminium. The cost, with such meterials, is rather too high to be acceptable for common use. As the temperatures needed for space heating are rather low, plastics are being considered as potential material for fabrication of various components of the flat, plate collector. This would make solar energy systems comparable with other energy systems.

Solar Concentrators:

Solar concentrators are the collection devices which increase the flux on the absorber surface as compared to the flux impinging on the concentrator surface. Optical concentration is achieved by the use of reflecting refracting elements, positioned to concentrate the incident flux onto a suitable absorber. Due to the apparent motion of the Sun.

The concentrating surface, whether reflecting or refracting will not be in a position to redirect the sun rays onto the absorber, throughout the day if both the concentrator surface, and absorber are stationary. Ideally, the total system consisting of mirrors or lenses and the absorber should follow the Sun's apparent motion so that the Sun rays are always captured by the absorber. In general, a solar concentrator consists of the following a focusing device. A blackened metallic absorber provided with a transparent cover; and a tracking device for continuously following the Sun. Temperatures as high as 3000°C can be achieved with such devices and they find applications in both photo-thermal and photo-voltaic conversion of solar energy.

The use of solar concentrators has the following advantages:

- Increased energy delivery temperature, facilitating their dynamic match between temperature level and the task. Improved thermal efficiency due to reduced heat loss area.
- Reduced cost due to replacement of large quantities of expensive hardware material for constructing flat plate solar collector systems, by less expensive reflecting and/or refracting element and a smaller absorber tube.
- Increased number of thermal storage options at elevated temperatures, thereby reducing the storage cost. Parameters Characterizing Solar Concentrators
- The aperture area is that plane area through which the incident solar flux is accepted. It is defined by the physical extremities of the concentrator.
- The acceptance angle defines the limit to which the incident ray path may deviate, from the normal drawn to the aperture plane, and still reach the absorber.

The absorber area is the total area that receives the concentrated radiation. It is the area from which useful energy can be removed. Geometrical concentration ratio or the radiation balance concentration ratio is defined as the ratio of the aperture area to the absorber area. The optical efficiency is defined as the ratio of the energy, absorbed by the absorber, to the energy, incident on the aperture. The thermal efficiency is defined as the ratio of the useful energy delivered to the energy incident on the aperture.

Solar concentrators may be classified as point focus or line focus system. Point focus systems have circular symmetry and are generally used when high concentration is required as in the case of solar furnaces and central tower receiver systems. Line focus systems have cylindrical symmetry and generally used when medium concentration is sufficient to provide the desired operating temperature.

Solar Energy Storage and Applications:

Storage of Solar energy in a solar system may:

- Permit solar energy to be captured when insolation is high to be used when the need arises.
- Deliver electric load power demand during times when insolation is below normal or non-existent. Also caters to delivering short power-peaks
- Be located closed to the load

- Improve the reliability of solar thermal and solar PV systems
- Permit a better match between energy input and load demand output

Some of the important storage methods are:

- Mechanical Energy Storage – pumped storage, compressed air storage, flywheel storage
- Chemical Energy Storage – Batteries storage, Hydrogen storage and reversible chemical reactions storage
- Electromagnetic energy storage
- Electrostatic energy storage
- Thermal (heat) energy storage – Sensible heat storage and Latent heat storage
- Biological Storage
- Thermal (heat) energy storage

Energy storage may be in the form of sensible heat of solids or liquid medium, as heat of fusion in chemical systems or as chemical energy of products in the reversible chemical reaction. Mechanical energy could be converted to P.E. and stored in elevated fluids Energy can be stored by virtue of latent heat of change of phase of the storage medium. Phase-change materials like Glaubers salt have considerably higher thermal energy storage densities

Applications of Solar Energy:
Three broad categories of possible large scale applications of solar power are:

- The heating and cooling of residential and commercial buildings;
- The chemical and biological conversion of organic material to liquid, solid and gaseous fuels
- Conversion of solar energy to electricity.
- Solar distillation, pumping, solar cooking etc

The use of solar energy for generation of electricity is costly as compared to conventional methods. However, due to scarcity of fuel, solar energy will certainly find a place in planning the national energy resources.

Residential cooling and heating

- A flat plate collector is located on the roof of a house, which collects the solar energy. The cooling water is pumped through the tubes of the solar collector.
- The heat is transferred from the collector to the water and the hot water is stored in a storage tank which may be located at ground level or in the basement of the house. Hot water is then utilized to heat or cool the house by adjusting the automatic valve.
- A separate circuit is there to supply hot water. Thus all the three requirements i.e., space cooling, heating and water heating

Solar PV Cells:

The solar cells operate on the principle of photo electricity i.e., electrons are liberated from the surface of a body when light is incident on it. Backed by semi-conductor technology, it is now possible to utilize the phenomenon of photo-electricity. It is known that if an n-type semi-conductor is brought in contact with a p-type material, a contact potential difference is set-up at the junction (Schottky effect), due to diffusion of electrons. When the p-type material is exposed to light, its electrons get excited, by the photons of light, and pass into the n-type semi-conductor. Thus, an electric current is generated in a closed circuit. The pn junction silicon solar cells have emerged as the most important source of long duration power supply necessary for space vehicles. These cells are actuated by both, direct Sun rays and diffuse light.

The efficiency of silicon solar cells increases with decreasing temperature. In cold weather the decreased luminous flux is compensated for, by higher efficiency. The efficiency of these solar cells varies from 15 to 20%. Although the energy from the Sun is available free of cost, the cost of fabrication and installation of systems, for utilization of solar energy, is often too high to be economically viable. In order to make solar installations economically attractive, plastic materials are being increasingly used for the fabrication of various components of the system.

The efficiency of solar heating/cooling installation depends on the efficiency of collection of solar energy and its transfer to the working fluid (e.g. water, air etc.). There are two main classes of collectors. The flat plate collector is best suited for low and intermediate temperature applications (40°–60°, 80°–120°C) which include water heating for buildings, air heating and small industrial applications like agricultural drying etc. The concentrating collectors are usually employed for power generation and industrial process heating.

Working of Photovoltaic Plant :

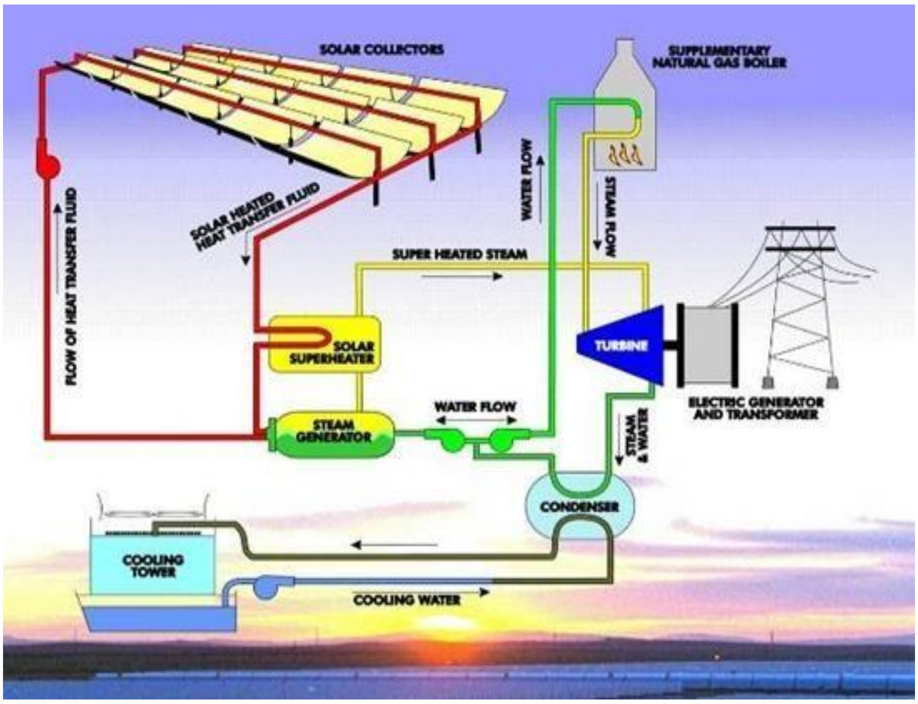


Figure: Photovoltaic Plant

UNIT – IV

WIND ENERGY

Introduction:

Wind is simple air in motion. It is caused by the uneven heating of the earth’s surface by the sun. Since the earth’s surface is made of very different types of land and water, it absorbs the sun’s heat at different rates. During the day, the air above the land heats up more quickly than the air over water. The warm air over the land expands and rises, and the heavier, cooler air rushes in to take its place, creating winds.

At night, the winds are reversed because the air cools more rapidly over land than over water. In the same way, the large atmospheric winds that circle the earth are created because the land near the earth's equator is heated more by the sun than the land near the North and South Poles. Today, wind energy is mainly used to generate electricity. Wind is called a renewable energy source because the wind will blow as long as the sun shines.

The History of Wind Since ancient times, people has harnessed the winds energy:

Over 5,000 years ago, the ancient Egyptians used wind to sail ships on the Nile River. Later, people built windmills to grind wheat and other grains. The earliest known windmills were in Persia (Iran). These early windmills looked like large paddle wheels. Centuries later, the people of Holland improved the basic design of the windmill. They gave it propeller-type blades, still made with sails. Holland is famous for its windmills.

The wind wheel, like the water wheel, has been used by man for a long time for grinding corn and pumping water. Ancient seamen used wind power to sail their ships. With the development of the fossil Characteristics of Wind Power Wind as a source of energy is plentiful, inexhaustible and pollution free but it has the disadvantage that the degree and period of its availability are uncertain. Also, movement of large volumes of air is required, to produce even a moderate amount of power.

As a result, the wind power must be used as and when it is available, in contrast to conventional methods where energy can be drawn upon when required. Wind power, therefore, is regarded as a means of saving fuel, by injection of power into an electrical grid, or run wind power plant in conjunction with a pumped storage plant. The power that can be theoretically obtained from the wind, is proportional to the cube of its velocity and thus high wind velocities are most important. The power developed using this law, in atmospheric condition

where
the density of air is 1.2014 kg/cu metre, is given as
Power developed = 13.14 × 10–6 A V 3 KW
where A is the swept area in sq. metre and V the wind velocity in Km/hr

A wind turbine is the popular name for a device that converts kinetic energy from the wind into electrical power.

Betz Law:

Betz's law calculates the maximum power that can be extracted from the wind, independent of the design of a wind turbine in open flow. It was published in 1919, by the German physicist Albert Betz. The law is derived from the principles of conservation of mass and momentum of the air stream flowing through an idealized actuator disk that extracts energy from the wind stream. According to Betz's law, no turbine can capture more than 16/27 (59.3%) of the kinetic energy in wind. The factor 16/27 (0.593) is known as Betz's coefficient. Practical utility-scale wind turbines achieve at peak 75% to 80% of the Betz limit

Speed and Power Relations:

The wind turbine captures the wind's kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical generator. The turbine is mounted on a tall tower to enhance the energy capture. Numerous wind turbines are installed at one site to build a wind farm of the desired power generation capacity. Obviously, sites with steady high wind produce more energy over the year. Two distinctly different configurations are available for turbine design, the horizontalaxis configuration (Figure) and the vertical-axis configuration. The horizontal-axis machine has been the standard in Denmark from the beginning of the wind power industry. Therefore, it is often called the Danish wind turbine. The vertical-axis machine has the shape of an egg beater and is often called the Darrieus rotor after its inventor. It has been used in the past because of its specific structural advantage. However, most modern wind turbines use a horizontal axis design. Except for the rotor, most other components are the same in both designs, with some differences in their placements.

The kinetic energy in air of mass m moving with speed V is given by the following in joules:

$$\text{kinetic energy} = \frac{1}{2} m V^2$$

The power in moving air is the flow rate of kinetic energy per second in watts:

$$\text{power} = \frac{1}{2} (\text{mass flow per second}) V^2$$

If

P= mechanical power in the moving air (watts),

ρ = air density (kg/m3),

A= area swept by the rotor blades (m2), and

V= velocity of the air (m/sec),

then the volumetric flow rate is AV, the mass flow rate of the air in kilograms per second is ρAV, and the mechanical power coming in the upstream wind is given by the following in watts:

$$P = \frac{1}{2} (\rho A V) V^2 = \frac{1}{2} \rho A V^3$$

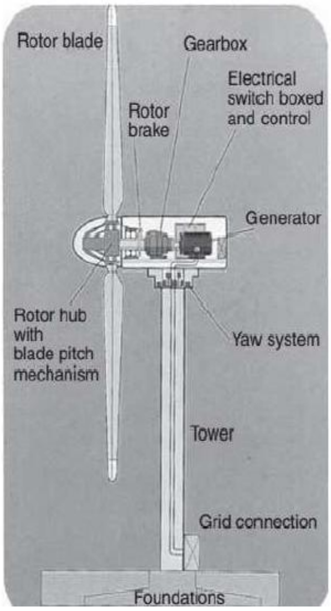


Figure: Horizontal-axis wind turbine showing major components.

Two potential wind sites are compared in terms of the specific wind power expressed in watts per square meter of area swept by the rotating blades. It is also referred to as the power density of the site, and is given by the following expression in watts per square meter of the rotor-swept area

$$\text{specific power of the site} = \frac{1}{2}\rho V^3$$

This is the power in the upstream wind. It varies linearly with the density of the air sweeping the blades and with the cube of the wind speed. The blades cannot extract all of the upstream wind power, as some power is left in the downstream air that continues to move with reduced speed. This is the power in the upstream wind. It varies linearly with the density of the air sweeping the blades and with the cube of the wind speed. The blades cannot extract all of the upstream wind power, as some power is left in the downstream air that continues to move with reduced speed.

Power Extracted From The Wind:

The actual power extracted by the rotor blades is the difference between the upstream and downstream wind powers. Using Equation 3.2, this is given by the following equation in units of watts:

$$P_o = \frac{1}{2}(\text{mass flow per second})\left\{V^2 - V_o{}^2\right\}$$

where
Po= mechanical power extracted by the rotor, i.e., the turbine output power,
V= upstream wind velocity at the entrance of the rotor blades, and
Vo= downstream wind velocity at the exit of the rotor blades

Let us leave the aerodynamics of the blades to the many excellent books available on the subject, and take a macroscopic view of the airflow around the blades. Macroscopically, the air velocity is discontinuous from V to Vo at the “plane” of the rotor blades, with an “average” of .(V + Vo). Multiplying the air density by the average velocity, therefore, gives the mass flow rate of air through the rotating blades, which is as follows:

$$\text{mass flow rate} = \rho A \frac{V + V_o}{2}$$

The mechanical power extracted by the rotor, which drives the electrical generator, is Therefore

$$P_o = \frac{1}{2}\left[\rho A \frac{(V + V_o)}{2}\right](V^2 - V_o^2)$$

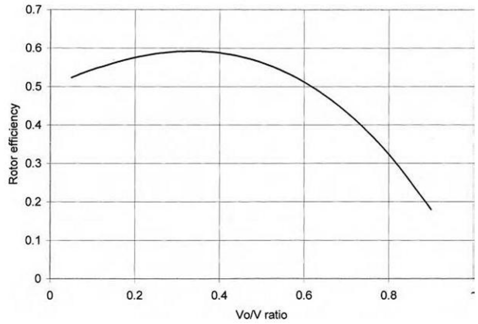


Figure: Rotor efficiency vs. Vo/V ratio has a single maximum.

The preceding expression is algebraically rearranged in the following form:

$$P_o = \frac{1}{2}\rho A V^3 \frac{\left(1 + \frac{V_o}{V}\right)\left[1 - \left(\frac{V_o}{V}\right)^2\right]}{2}$$

Wind Speed Distribution:

Having a cubic relation with power, wind speed is the most critical data needed to appraise the power potential of a candidate site. The wind is never steady at any site. It is influenced by the weather system, the local land terrain, and its height above the ground surface. Wind speed varies by the minute, hour, day, season, and even by the year. Therefore, the annual mean speed needs to be averaged over 10 yr or more.

Such a long term average gives a greater confidence in assessing the energy-capture potential of a site. However, long-term measurements are expensive and most projects cannot wait that long. In such situations, the short-term data, for example, over 1 yr, is compared with long-term data from a nearby site to predict the long-term annual wind speed at the site under consideration.

This is known as the measure, correlate, and predict (mcp) technique. Because wind is driven by the sun and the seasons, the wind pattern generally repeats over a period of 1 yr. The wind site is usually described by the speed data averaged over calendar months. Sometimes, the monthly data is aggregated over the year for brevity in reporting the overall “windiness” of various sites. Wind speed variations over the period can be described by a probability distribution function.

Energy Distribution:

If we define the energy distribution function

$$e = \frac{\text{kWh contribution in the year by the wind between } v \text{ and } (v + \Delta v)}{\Delta v}$$

then, for the Rayleigh speed distribution (k = 2), the energy distribution would look like the shaded curve in Figure. The wind speed curve has the mode at 5.5m/sec and the mean at 6.35 m/sec. However, because of the cubic relation with speed, the maximum energy contribution comes from the wind speed at 9.45 m/sec. Above this speed, although V3 continues to increase in a cubic manner, the number of hours at those speeds decreases faster than V3. The result is an overall decrease in the yearly energy contribution reason, it is advantageous to design the wind power system to operate at variable speeds in order to capture the maximum energy available during high-wind periods.

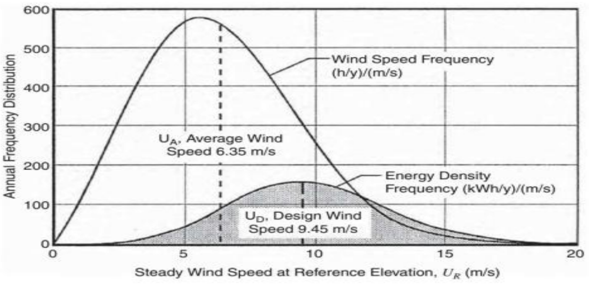


Figure: Annual frequency distributions of hours vs. wind speed and energy density per year

Wind Speed Prediction:

Because the available wind energy at any time depends on the wind speed at that time, which is a random variable, knowing the average annual energy potential of a site is one thing and the ability to accurately predict when the wind will blow is quite another thing. For the wind farm operator, this poses difficulties in system scheduling and energy dispatching as the schedule of wind power availability is not known in advance.

However, a reliable forecast of wind speed several hours in advance can give the following benefits:

- Generating schedule can efficiently accommodate wind generation in a timely manner
- Allows the grid-connected wind farm to commit to power purchase contracts in advance for a better price
- Allows investors to proceed with new wind farms and avoid the penalties they must pay if they do not meet their hourly generation targets

Wind Power System Components:

The wind power system comprises one or more wind turbine units operating electrically in parallel. Each turbine is made of the following basic components:

- Tower structure
- Rotor with two or three blades attached to the hub
- Shaft with mechanical gear
- Electrical generator
- Yaw mechanism, such as the tail vane
- Sensors and control

Because of the large moment of inertia of the rotor, design challenges include starting, speed control during the power-producing operation, and stopping the turbine when required. The eddy current or another type of brake is used to halt the turbine when needed for emergency or for routine maintenance. In a modern wind farm, each turbine must have its own control system to provide operational and safety functions from a remote location.

It also must have one or more of the following additional components:

- Anemometers, which measure the wind speed and transmit the data to the controller.
- Numerous sensors to monitor and regulate various mechanical and electrical parameters. A 1-MW turbine may have several hundred sensors.
- Stall controller, which starts the machine at set wind speeds of 8 to 15 mph and shuts off at 50 to 70 mph to protect the blades from overstressing and the generator from overheating.
- Power electronics to convert and condition power to the required standards.

- Control electronics, usually incorporating a computer.
- Battery for improving load availability in a stand-alone plant.
- Transmission link for connecting the plant to the area grid.

The following are commonly used terms and terminology in the wind power industry:
Low-speed shaft: The rotor turns the low-speed shaft at 30 to 60 rotations per minute (rpm).

High-speed shaft:
It drives the generator via a speed step-up gear.

Brake:
A disc brake, which stops the rotor in emergencies. It can be applied mechanically, electrically, or hydraulically.

Gearbox:
Gears connect the low-speed shaft to the high-speed shaft and increase the turbine speed from 30 to 60 rpm to the 1200 to 1800 rpm required by most generators to produce electricity in an efficient manner. Because the gearbox is a costly and heavy part, design engineers are exploring slow speed, direct-drive generators that need no gearbox.

Generator:
It is usually an off-the-shelf induction generator that produces 50- or 60-Hz AC power.

Nacelle:
The rotor attaches to the nacelle, which sits atop the tower and includes a gearbox, low- and high-speed shafts, generator, controller, and a brake. A cover protects the components inside the nacelle. Some nacelles are large enough for technicians to stand inside while working.

Pitch:
Blades are turned, or pitched, out of the wind to keep the rotor from turning in winds that have speeds too high or too low to produce electricity.

Upwind and downwind:
The upwind turbine operates facing into the wind in front of the tower, whereas the downwind runs facing away from the wind after the tower.

Vane:
It measures the wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

Yaw drive:
It keeps the upwind turbine facing into the wind as the wind direction changes. A yaw motor powers the yaw drive. Downwind turbines do not require a yaw drive, as the wind blows the rotor downwind. The design and operating features of various system components are described in the following subsections.

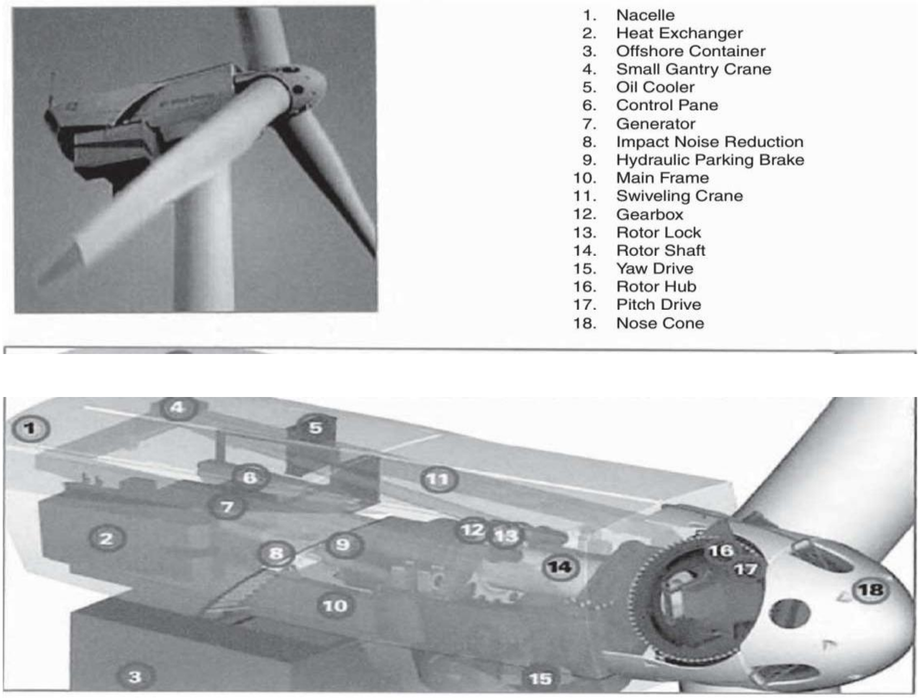


Figure: Horizontal-axis wind turbine showing major components.

The design and operating features of various system components are described in the following subsections:

A. Tower:

The wind tower supports the rotor and the nacelle containing the mechanical gear, the electrical generator, the yaw mechanism, and the stall control. Figure depicts the component details and layout in a large nacelle, and Figure shows the installation on the tower. The height of the tower in the past has been in the 20 to 50 m range. For medium and large-sized turbines, the tower height is approximately equal to the rotor diameter, as seen in the dimension drawing of a 600-kW wind turbine Small turbines are generally mounted on the tower a few rotor diameters high. Otherwise, they would suffer fatigue due to the poor wind speed found near the ground surface. Figure 4.5 shows tower heights of various-sized wind turbines relative to some known structures. Both steel and concrete towers are available and are being used. The construction can be tubular or lattice. Towers must be at least 25 to 30 m high to avoid turbulence caused by trees and buildings. Utility-scale towers are typically twice as high to take advantage of the swifter winds at those heights.

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B. Turbine:

Wind turbines are manufactured in sizes ranging from a few kW for stand-alone remote applications to a few MW each for utility-scale power generation. The turbine size has been steadily increasing. The average size of the turbine installed worldwide in 2002 was over 1 MW. By the end of 2003, about 1200 1.5-MW turbines made by GE Wind Energy alone were installed and in operation. Today, even larger machines are being routinely installed on a large commercial scale, such as GE’s new 3.6-MW turbines for offshore wind farms both in Europe and in the U.S. It offers lighter variable-speed, pitchcontrolled blades on a softer support structure, resulting in a cost-effective foundation. Its rated wind speed is 14 m/sec with cut in speed at 3.5 m/sec and the cutout at 25 m/sec. The blade diameter is 104 m with

C. Blades:

Modern wind turbines have two or three blades, which are carefully constructed airfoils that utilize aerodynamic principles to capture as much power as possible. The airfoil design uses a longer upper-side surface whereas the bottom surface remains somewhat uniform. By the Bernoulli principle, a “lift” is created on the airfoil by the pressure difference in the wind flowing over the top and bottom surfaces of the foil. This aerodynamic lift force flies the plane high, but rotates the wind turbine blades about the hub. In addition to the lift force on the blades, a drag force is created, which acts Department of Electrical Engineering, Veer Surendra Sai University of Technology Burla Page 90 perpendicular to the blades, impeding the lift effect and slowing the rotor down. The design objective is to get the highest lift-to-drag ratio that can be varied along the length of the blade to optimize the turbine’s power output at various speeds. The rotor blades are the foremost visible part of the wind turbine, and represent the forefront of aerodynamic engineering. The steady mechanical stress due to centrifugal forces and fatigue under continuous vibrations make the blade design the weakest mechanical link in the system.

Extensive design effort is needed to avoid premature fatigue failure of the blades. A swift increase in turbine size has been recently made possible by the rapid progress in rotor blade technology, including emergence of the Carbon- and glass-fiber-based epoxy composites. The turbine blades are made of high-density wood or glass fiber and epoxy composites. The high pitch angle used for stall control also produces a high force. The resulting load on the blade can cause a high level of vibration and fatigue, possibly leading to a mechanical failure.

Regardless of the fixed- or variable-speed design, the engineer must deal with the stall forces. Researchers are moving from the 2-D to 3-D stress analyses to better understand and design for such forces. As a result, the blade design is continually changing, particularly at the blade root where the loading is maximum due to the cantilever effect. The aerodynamic design of the blade is important, as it determines the energy capture potential. The large and small machine blades have significantly different design philosophies. The small machine sitting on a tower relatively taller than the blade diameter, and generally unattended, requires a low-maintenance design. On the other hand, a large machine tends to optimize aerodynamic performance for the maximum possible energy capture. In either case, the blade cost is generally kept below 10% of the total installed cost.

D. Speed Control:

The wind turbine technology has changed significantly in the last 25 yr.1 Large wind turbines being installed today tend to be of variable-speed design, incorporating pitch control and power electronics. Small machines, on the other hand, must have simple, low cost power and speed control.

The speed control methods fall into the following categories:

No speed control whatsoever:

In this method, the turbine, the electrical generator, and the entire system are designed to withstand the extreme speed under gusty winds.

Yaw and tilt control:

The yaw control continuously orients the rotor in the direction of the wind. It can be as simple as the tail vane or more complex on modern towers. Theoretical considerations dictate free yaw as much as possible. However, rotating blades with large moments of inertia produce high gyroscopic torque during yaw, often resulting in loud noise. A rapid yaw may generate noise exceeding the local ordinance limit. Hence, a controlled yaw is often required and used, in which the rotor axis is shifted out of the wind direction when the wind speed exceeds the design limit.

Pitch control:

This changes the pitch of the blade with changing wind speed to regulate the rotor speed. Large-scale power generation is moving towards variable-speed rotors with power electronics incorporating a pitch control.

Stall control:

Yaw and tilt control gradually shifts the rotor axis in and out of the wind direction. But, in gusty winds above a certain speed, blades are shifted (profiled) into a position such that they stall and do not produce a lift force. At stall, the wind flow ceases to be smooth around the blade contour, but separates before reaching the trailing edge. This always happens at a high pitch angle. The blades experience a high drag, thus lowering the rotor power output. This way, the blades are kept under the allowable speed limit in gusty winds. This not only protects the blades from mechanical overstress, but also protects the electrical generator from overloading and overheating. Once stalled, the turbine has to be restarted after the gust has subsided.

Turbine Rating:

The method of assessing the nominal rating of a wind turbine has no globally accepted standard. The difficulty arises because the power output of the turbine depends on the square of the rotor diameter and the cube of the wind speed. The rotor of a given diameter, therefore, would generate different power at different wind speeds. A turbine that can generate 300 kW at 7 m/sec would produce 450 kW at 8 m/sec wind speed. What rating should then be assigned to this turbine? Should we also specify the rated speed? Early wind turbine designers created a rating system that specified the power output at some arbitrary wind speed. This method did not work well because everyone could not agree on one speed for specifying the power rating. The “rated” wind speeds varied from 10 to 15 m/sec under this practice. Manufacturers quoted on the higher side to claim a greater output from the same design. Such confusion in quoting the rating was avoided by some European manufacturers who quoted only the rotor diameter. But the confusion continued as to the maximum power the machine can generate under the highest wind speed in which the turbine can continuously and safely operate. Many manufacturers have, therefore, adopted the combined rating designations x/y, the generator’s peak electrical capacity followed by the wind turbine diameter. For example, a 300/30-kW/m wind system means a 300-kW electrical generator and a 30-m diameter turbine.

Classification of WEC system:

Several types of wind wheels have been used but the advantage of propeller rotating about a horizontal shaft, in a plane perpendicular to the direction of the wind make it the most likely type to realise economic generation on a large scale. A propeller consisting of two or three blades (with an aerofoil section) and capable of running at the high speeds is likely to be the most efficient. Present technology has been able to build systems with 60 m long blades, on towers as high as 305 m. A large tower system, to support many small rotor-generator units, can also be built.

Horizontal-axis wind turbines (HAWT) 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. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator.

Vertical-axis wind turbines (VAWTs) are a type of wind turbine where the main rotor shaft is set traverse, not necessarily vertical, to the wind and the main components are located at the base of the turbine. This arrangement allows the generator and gearbox to be located close to the ground, facilitating service and repa Wind pressure rotates the wind vanes or propellers attached to a shaft.

The revolving shaft rotates the rotor of a generator, through a mechanism of gears couplings etc. Thus, electricity is generated. The wind power plants can be operated in combination with steam or hydro power station, which will lead to saving in fuel and increase in firm capacity, respectively of these plants. Wind energy can prove to be a potential source of energy for solving the energy problem. It can certainly go a long way to supply pollution-free energy to millions of people, living in the villages all over the world. The economic viability of wind mills is better in situations where conventional transmission costs are extremely high (because of in accessibility and small load) or where continuous availability of supply is not essential so that only a limited amount of storage on standby power need be provided.

UNIT – V

ECONOMIC ASPECTS OF POWER GENERATION

TERMS USED IN POWER SYSTEM

Automatic Generation Control Equipment operated by System Management, which sends signals to Generating facilities participating in the AGC scheme to automatically adjust their output so as to maintain frequency or restore frequency within the Normal Operating Frequency Band.

Ancillary Service Provider Is a Rule Participant that is not a Market Participant or Network Operator, that has contracted or intends to contract with System Management for the supply of an Ancillary Service.

Continuous maximum generation output: means the maximum output generated at the generator terminals less the station load and auxiliary loads that are consumed by the generating unit (and power station) in generating that output.

Commissioning Test means a test specified under section 6 of the Power System Operation Procedure – Commissioning and Testing, for the purpose of testing the ability of a generating system to operate reliably at different levels of output.

Curtailment Alert Notice is a notice sent out by System Management to a Demand Customer alerting the Demand Customer that System Management expects to issue a Demand Instruction to the Demand Customer requiring a particular Curtailable Load to be activated within the next few hours.

Direction means an instruction given to a Market Participant or Network Operator consequent upon a Dispatch Advisory or other power specified in the Market Rules or the Power System Operation Procedures, which is not a Dispatch Instruction or Dispatch Order, and requires a specific action by a Participant or Network Operator.

Dispatch Merit Order is the merit order list provided by IMO to System Management setting out the combined price ranking for Curtailable Loads and non-EGC generating facilities, for increasing system load and decreasing system load.

Dispatch Instruction means an instruction issued by System Management to a Market Participant other than EGC directing that Participant to vary the MW output or consumption of one of Facilities from the level it otherwise would have operated at**.**

Dispatch Order An instruction issued by System Management to an EGC generating facility

Dispatch Plan A plan prepared by System Management setting out for a Trading Day, the estimated output expected for each generating facility and Curtailable Load.

EGC means Electricity Generation Corporation

EGC Dispatch Plan means the Dispatch Plan produced by System Management for each Trading Interval in a Trading Day and showing the order in which System Management expect to dispatch EGC Generation Facilities.

Equipment: means one or more items of equipment owned by a Market Generator, Network Operator or Market Customer that forms part of a registered facility.

Equipment Limit: Any (technical) limit on the operation of a Facility's equipment that is provided as Standing Data for the Facility to System Management by the IMO in accordance with Market Rule.

Equipment Test means a test or programme of tests, as specified within section 8 of the Power System Operation Procedure –Commissioning and Testing, of either generating systems, Curtailable Loads or Interruptible loads that form part of whole of a Facility.

Facility: For the purpose of the Power System Operating Procedures, having the meaning of a grouping of either generating, transmission, Curtailable Load or Interruptible Load equipment at a specified site.

Financial Year means the 12 month financial period beginning the 1 July of each year.

Fuel determination is a Declaration made by a Market Generator relating to a particular Generation Facility, and stipulates whether the supply fuel to be used at the at the Facility is a Liquid fuel or a Non-Liquid Fuel.

Generator: An item of equipment whose purpose is the generation of electricity.

Intermittent Generator is a Non-Scheduled Generator that cannot be scheduled because its output level is dependent upon factors beyond the control of its operator (eg wind), but the operator can be instructed to reduce output from the generating system.

Minimum Frequency Keeping Capacity is the minimum quantity of Frequency Keeping Capacity to meet the Load Following Service standard.

MT PASA is the Medium Term Projected Assessment of System Adequacy.

MT PASA Capacity Planning Margin is the spare generation capacity available over the MT PASA planning period, after the forecast SWIS peak system load has been met, all planned outages and forced outage allowance been taken into account, demand management capability has been utilised, and all security standards and ancillary service requirements have been satisfied.

Non–scheduled generator: means a generator system that can be self scheduled by its operator (with the exception that System Management can require it to decrease its output subject to its physical capability).

Normal operating frequency band is the normal operating frequency band of 49.8 to 50.2 Hertz specified in the Technical Rules for the SWIS system.

Normal operating frequency excursion band. is the maximum frequency excursion band specified in the Technical Rules for the SWIS system of 48.75 to 51 Hertz that applies in the event of a single contingency event.

Opportunistic Maintenance means an equipment outage arranged within finally two days of when the outage is to take place, which meets the conditions in the Outage Procedure for Opportunistic Maintenance.

Outage the state of an item of equipment when it is not available to perform its intended function.

Outage Plan: has the meaning given to it in Market Rule and for the purpose of the Power System Operating Procedure – Facility Outages, is a plan submitted by a Market Participant or Network Owner to System Management containing the details of a proposed equipment outage.

Outage schedule means a schedule prepared and managed by System Management containing all Outage Plans accepted by System Management.

Participant means either a Market Participant or Network Operator.

Planned Outage is an outage that formerly was a Scheduled Outage, but has been approved by System Management in the final 2 days prior to outage commencement, and is now planned to proceed, subject to final power system conditions.

Rule Participant means a Market Participant, Network Operator, System Management or the IMO.

Scheduled Generator means a generating system whose MW output can be controlled by its operator to increase or decrease the quantity of energy it generates.

Scheduled Outage: means an outage that has been accepted by System Management for inclusion in System Management's Outage Schedule.

Security Limit: means any technical limit on the operation of the SWIS as a whole, or a region of the SWIS, necessary to maintain the Power System Security, including both static and dynamic limits.

ST PASA is the Short Term Projected Assessment of System Adequacy.

SMMITS System Management Market Information Technology System—System Management's data storage and retrieval system that links the systems operated by System Management, including its EMS system, with the IMO and Market Participants.

SWIS Dispatch Plan means the Dispatch Plan produced by System Management for each Trading Interval in a Trading Day and showing the order that System Management expect to schedule EGC and non-EGC Generation and Demand Management facilities over the Trading Day.

SWIS Merit Order means the combined merit order list prepared by System Management for all EGC and Non-EGC facilities for increasing and decreasing system load.

SWIS Operating Standards refers to frequency, frequency time error and voltage standards in the SWIS Technical Rules.

SWIS Security Criteria refers to the security guidelines that apply to the SWIS.

SWIS System Load means the total SWIS load as measured at the Generation Facility connection points to the SWIS transmission network.

SWIS System Load Forecast is the forecast of total SWIS load measured at generation Facility connection points on the transmission network.

Switching programme: a technical plan agreed by System Management and a Network Operator or Generator to confirm the switching, isolating and earthing steps needed to make the equipment safe to work.

System Load is the demand in MW or MWh placed on the total SWIS generation system, and is equal to the demand created by SWIS connected consumers on the SWIS plus distribution and transmission losses.

Technical Rules means the technical Rules made under chapter 12 of the Electricity Networks Access Code 2004 (Access Code).

Voltage Order means a direction given by System Management to an EGC or NonEGC Generation Facility requiring a specific action of that Generating Facility relating to the reactive output or voltage control of the Facility.

WEMS is the IMO’s Wholesale Electricity Market System.

various factors affecting cost of generations

The distinct ways of electricity generation can incur significantly different costs. Calculations of these costs can be made at the point of connection to a load or to the electricity grid. The cost is typically given per kilowatt-hour or megawatt-hour. It includes the initial capital, discount rate, as well as the costs of continuous operation, fuel, and maintenance. This type of calculation assists policymakers, researchers and others to guide discussions and decision making.

The levelized cost of energy (LCOE) is a measure of a power source that allows comparison of different methods of electricity generation on a consistent basis. It is an economic assessment of the average total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime. The LCOE can also be regarded as the average minimum price at which electricity must be sold in order to break even over the lifetime of the project.

Cost Factors

While calculating costs, several internal cost factors have to be considered. Note the use of "costs," which is not the actual selling price, since this can be affected by a variety of factors such as subsidies and taxes:

- Capital costs (including waste disposal and decommissioning costs for nuclear energy) – tend to be low for gas and oil power stations; moderate for onshore wind turbines and solar PV (photovoltaics); higher for coal plants and higher still for waste to energy, wave and tidal, solar thermal, offshore wind and nuclear.
- Fuel costs – high for fossil fuel and biomass sources, low for nuclear, and zero for many renewables. Fuel costs can vary somewhat unpredictably over the life of the generating equipment, due to political and other factors.
- Factors such as the costs of waste (and associated issues) and different insurance costs are not included in the following: Works power, own use or parasitic load – that is, the portion of generated power actually used to run the station's pumps and fans has to be allowed for.

To evaluate the total cost of production of electricity, the streams of costs are converted to a net present value using the time value of money. These costs are all brought together using discounted cash flow.

Capital costs

For power generation capacity capital costs are often expressed as overnight cost per watt. Estimated costs are:

- gas/oil combined cycle power plant - $1000/kW (2019)
- onshore wind - $1600/kW (2019)
- offshore wind - $6500/kW (2019)
- solar PV (fixed) - $1060/kW (utility),$1800/kW (2019)
- solar PV (tracking)- $1130/kW (utility)' $2000/kW (2019)
- battery storage power - $2000/kW (2019)
- conventional hydropower - $2680/kW (2019)
- geothermal - $2800/kW (2019)
- coal (with SO2 and NOx controls)- $3500–3800/kW
- advanced nuclear - $6000/kW (2019)
- fuel cells - $7200/kW (2019)

Running costs

Running costs include the cost of any fuel, maintenance costs, repair costs, wages, handling any wastes etc.

Fuel costs can be given per kWh and tend to be highest for oil fired generation, with coal being second and gas being cheaper. Nuclear fuel is much cheaper per kWh.

Levelized cost of electricity

The levelized cost of electricity (LCOE), also known as Levelized Energy Cost (LEC), is the net present value of the unit-cost of electrical energy over the lifetime of a generating asset. It is often taken as a proxy for the average price that the generating asset must receive in a market to break even over its lifetime. It is a first-order economic assessment of the cost competitiveness of an electricity-generating system that incorporates all costs over its lifetime: initial investment, operations and maintenance, cost of fuel, and cost of capital.

The levelized cost is that value for which an equal-valued fixed revenue delivered over the life of the asset's generating profile would cause the project to break even. This can be roughly calculated as the net present value of all costs over the lifetime of the asset divided by the total electrical energy output of the asset.

The levelized cost of electricity (LCOE) is given by:

$$\mathrm{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

I_t : investment expenditures in the year t

M_t : operations and maintenance expenditures in the year t

F_t : fuel expenditures in the year t

E_t : electrical energy generated in the year t

r : discount rate

n : expected lifetime of system or power station

Note: Some caution must be taken when using formulas for the levelized cost, as they often embody unseen assumptions, neglect effects like taxes, and may be specified in real or nominal levelized cost. For example, other versions of the above formula do not discount the electricity stream.

Typically the LCOE is calculated over the design lifetime of a plant, which is usually 20 to 40 years, and given in the units of currency per kilowatt-hour or megawatt-day, for example AUD/kWh or EUR/kWh or per megawatt-hour, for example AUD/MWh (as tabulated below). However, care should be taken in comparing different LCOE studies and the sources of the information as the LCOE for a given energy source is highly dependent on the assumptions, financing terms and technological deployment analyzed. In particular, assumption of capacity factor has significant impact on the calculation of LCOE. Thus, a key requirement for the analysis is a clear statement of the applicability of the analysis based on justified assumptions.

Many scholars,[*specify*] such as Paul Joskow, have described limits to the "levelized cost of electricity" metric for comparing new generating sources. In particular, LCOE ignores time effects associated with matching production to demand. This happens at two levels:

- Dispatchability, the ability of a generating system to come online, go offline, or ramp up or down, quickly as demand swings.
- The extent to which the availability profile matches or conflicts with the market demand profile.

Thermally lethargic technologies like coal and solid-fuel nuclear are physically incapable of fast ramping. However, many designs of Generation 4 molten fuel nuclear reactors will be capable of fast ramping because (A) the neutron poison xenon-135 can be removed from the reactor while it runs leaving no need to compensate for xenon-135 concentrations and (B) the large negative thermal and void coefficients of reactivity automatically reduce or increase fission output as the molten fuel heats or cools, respectively. Nevertheless, capital intensive technologies such as wind, solar, and nuclear are economically disadvantaged unless generating at maximum availability since the LCOE is nearly all sunk-cost capital investment. Intermittent power sources, such as wind and solar, may incur extra costs associated with needing to have storage or backup generation available. At the same time, intermittent sources can be even more competitive if they are available to produce when demand and prices are highest, such as solar during summertime mid-day peaks seen in hot countries where air conditioning is a major consumer. Despite these time limitations, leveling costs is often a necessary prerequisite for making comparisons on an equal footing before demand profiles are considered, and the levelized-cost metric is widely used for comparing technologies at the margin, where grid implications of new generation can be neglected.

Another limitation of the LCOE metric is the influence of energy efficiency and conservation (EEC). EEC has caused the electricity demand of many countries to remain flat or decline. Considering only the LCOE for utility scale plants will tend to maximise generation and risks overestimating required generation due to efficiency, thus "lowballing" their LCOE. For solar systems installed at the point of end use, it is more economical to invest in EEC first, then solar. This results in a smaller required solar system than what would be needed without the EEC measures. However, designing a solar system on the basis of LCOE would cause the smaller system LCOE to increase, as the energy generation drops faster than the system cost. The whole of system life cycle cost should be considered, not just the LCOE of the energy source.LCOE is not as relevant to end-users than other financial considerations such as income, cashflow, mortgage, leases, rent, and electricity bills. Comparing solar investments in relation to these can make it easier for end-users to make a decision, or using cost-benefit calculations "and/or an asset’s capacity value or contribution to peak on a system or circuit level".

Chronological Curve

There is an average load on the power station in a given time period which could be set depending on the load variation. If this load on the power supply station is plotted against the time periods in which these loads occur, it gives rise to what is known as the chronological curve because of the chronological appearance of the power demand along the time sequence. You can take a look at one such curve in the adjacent diagram which shows such a curve where the average load is plotted along the y-axis while the time frame of that average load comes in the x-axis. So as you can see in the diagram the load is maximum between the time periods of 5pm to 12 midnight, while it is lowest in the time period of 1pm to 5pm. This is just an imaginary graph to give you an idea about the load curve and does not represent any actual data. Needless to say this data representation is extremely important for the power generation company as it helps to forecast the size of the generation equipment as well as to understand the load variations during the day.

Load Duration Curve

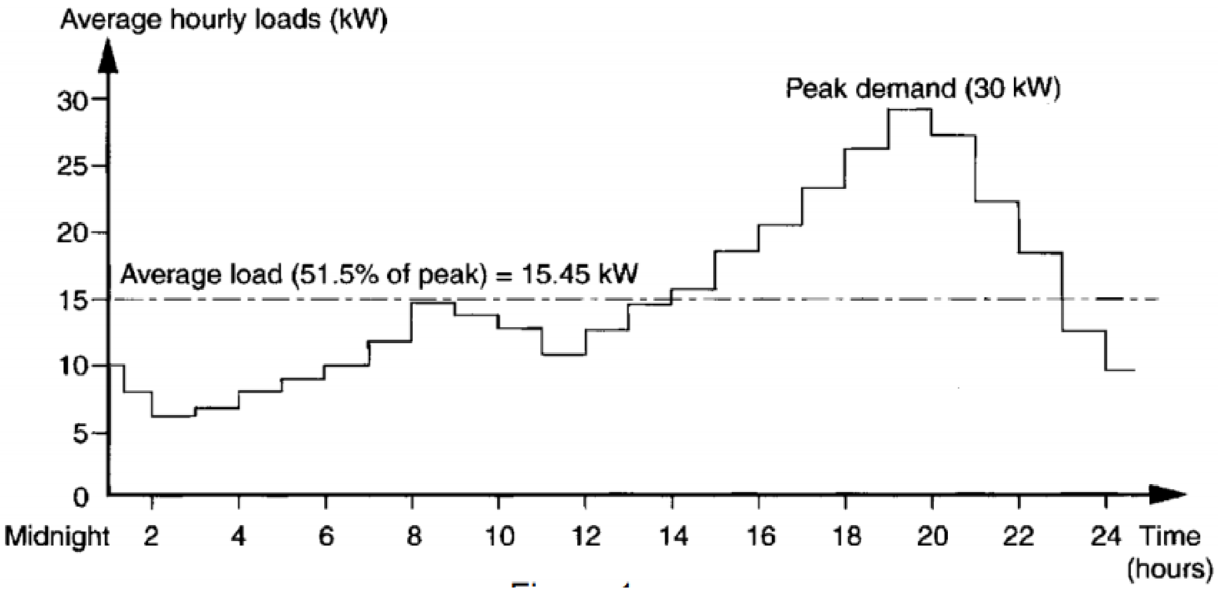
If the above variation given in chronological order is given in order of the size or magnitude of power consumption, the curve in such a case is known as load duration curve. For example if we simply rearrange the bars of the above bar graph in such an order that the highest demand comes first, and so on; we get what is known as the load duration curve. Also note that instead of specific time periods like load curve, the load duration curve gives total time period. This means to say that for example instead of 5pm to midnight now we put simply 7 hours which is just the same though. This curve immediately gives an idea about the number units of power consumed during the day as well as their consumption during various time periods.

Load Energy Curve

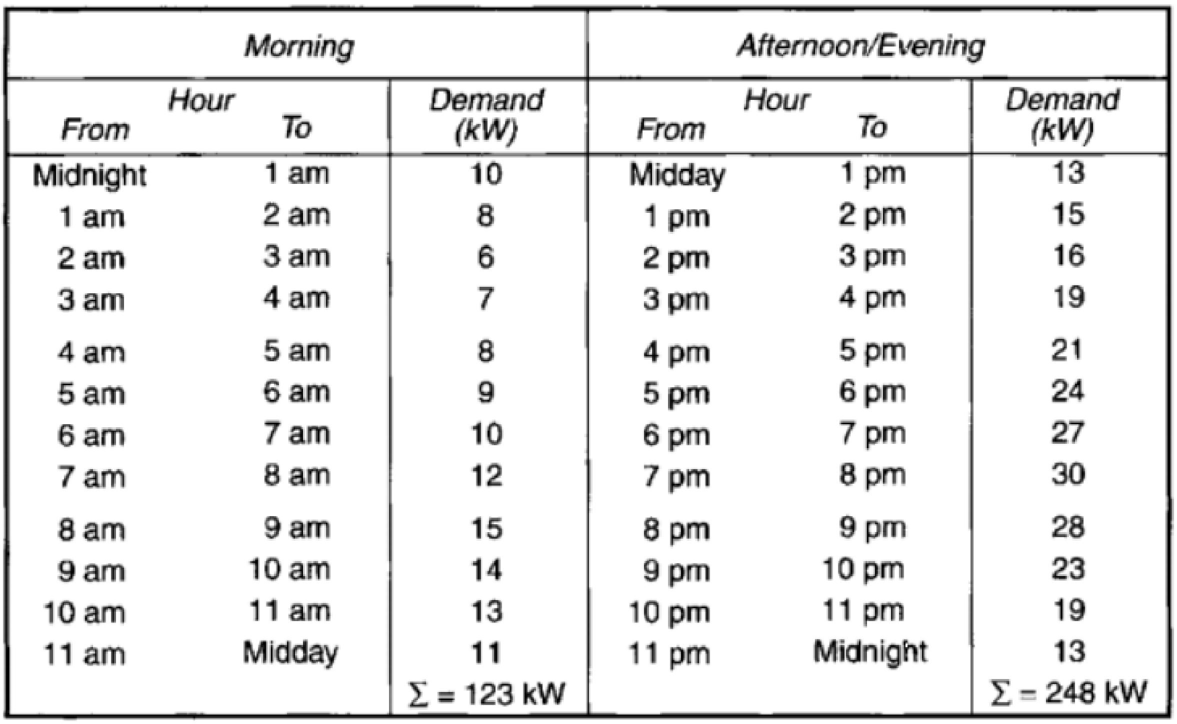
As the name itself suggests, the load energy curve is a graph between the load that is on the power plant vs. the energy that is produced at or below that load for a given power generation plant both being taken in the same units of kW. Usually the load is plotted along the vertical axis whilst the energy goes along the horizontal or the x-axis. The method of drawing this graph is to the use the previously discussed bar chart namely the load duration curve. Let us understand this in the following manner There are four points on the curve represented by u, v, x and y respectively. For the point “u” we have lowest average power from the load duration curve and multiplied by the number of hours against it which means 24. Similarly we go on taking the next higher load and the lesser number of hours that it corresponds to. These points are then joined together by a straight line to get the graph as shown in the adjacent sketch.

Demand or average demand:

The demand of system is the load at the receiving terminals averaged over a specified interval of time'. The load may be expressed as active power (kW) or reactive power (kvar). The period over which the demand is averaged is known as the demand interval ,the next figure load curve illustrates average hourly loads (kW) over a 24-hour period.



Average hourly loads (kW)
Example peak day



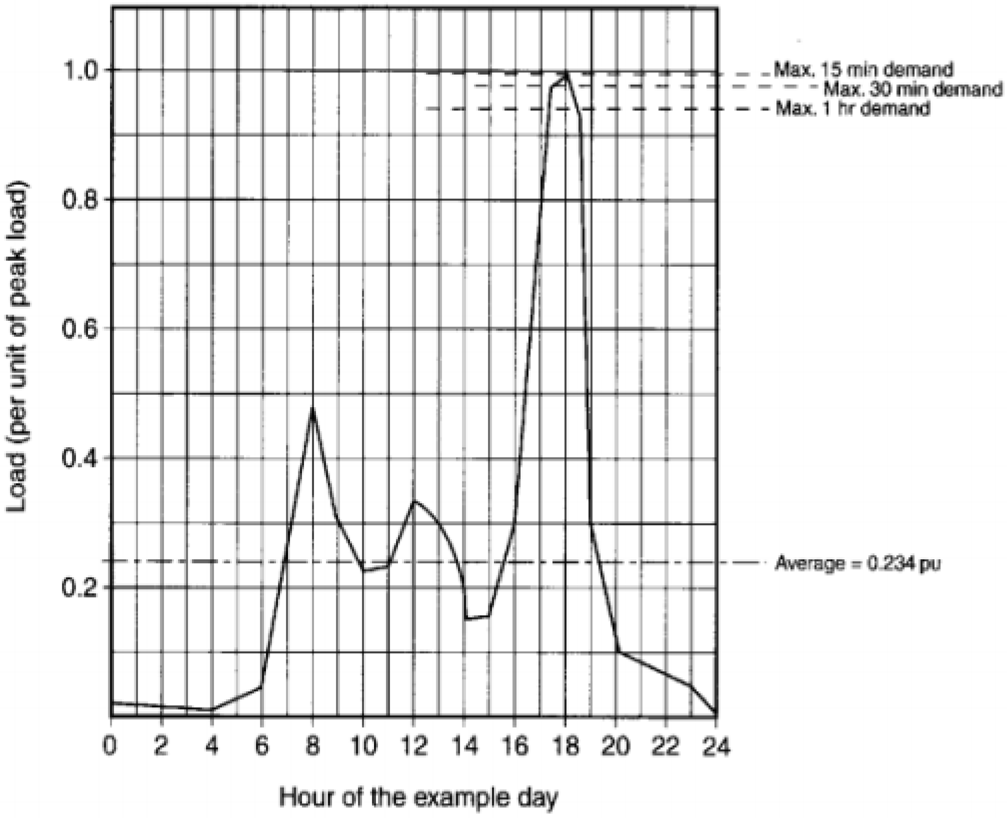
Morning			Afternoon/Evening		
Hour From	Hour To	Demand (kW)	Hour From	Hour To	Demand (kW)
Midnight	1 am	10	Midday	1 pm	13
1 am	2 am	8	1 pm	2 pm	15
2 am	3 am	6	2 pm	3 pm	16
3 am	4 am	7	3 pm	4 pm	19
4 am	5 am	8	4 pm	5 pm	21
5 am	6 am	9	5 pm	6 pm	24
6 am	7 am	10	6 pm	7 pm	27
7 am	8 am	12	7 pm	8 pm	30
8 am	9 am	15	8 pm	9 pm	28
9 am	10 am	14	9 pm	10 pm	23
10 am	11 am	13	10 pm	11 pm	19
11 am	Midday	11	11 pm	Midnight	13
		Σ = 123 kW			Σ = 248 kW

Total = 371 kWh

$$\text{Average demand} = \frac{\text{Total energy (kWh)}}{\text{Total Period (hours)}} = \frac{371\ \text{kWh}}{24\ \text{hours}} = 15.45\ \text{kW (based upon average hourly demands over a 24-hour period)}$$

Maximum demand (MD):

MD: Is the greatest of all demands which have occurred during the specified period of time, the maximum demand may be expressed in kW, kvar, etc.



Demand factor

DF : Is the ratio of the maximum demand of a system to the total connected load of the system

$$\text{Demand factor} = \frac{\text{Maximum demand of the system}}{\text{Total connected load}} \quad (\text{normally} \leq 1)$$

Utilization factor (UF)

The utilization factor is the ratio of the maximum demand of a system to the rated capacity of the system, UF indicates the degree to which the system is being loaded during peak load periods with respect to its capacity.

$$\text{Utilization factor, UF} = \frac{\text{Maximum demand of the system}}{\text{Rated capacity of the system}} (\text{normally} \leq 1)$$

Load factor (LDF)

LDF: is the ratio of the average load over a designated period of time to the peak load occurring in that period.

$$\text{Load factor, LDF} = \frac{\text{Average demand over designated period of time}}{\text{Peak load occurring in that period}} \quad (\text{normally} \leq 100\% \text{ or } \leq 1)$$

Diversity factor (DF)

DF: Is the ratio of the sum of the individual maximum demands of the various subdivisions of a system to the maximum demand of the whole system.

$$\text{Diversity factor, DF} = \frac{\sum(\text{individual maximum demands})}{\text{Maximum demand of the system}} \quad (\text{normally} \geq 1)$$

Coincident factor
Is the reciprocal of the diversity factor.

Load diversity
Is the difference between the sum of the peaks of two or more individual loads and the peak of the combined load.

$$\text{Load diversity} = \{\Sigma\ (\text{individual maximum demands})\} - (\text{maximum demand of the system})$$

Loss factor (LSF)
Is the ratio of the average power loss to the peak load loss, during a specified period of time. Since power losses are proportional to the square of the load current:

$$\text{Loss factor, LSF} = \frac{\text{Average (load)}^2}{\text{Maximum (load)}^2} \quad \text{or} \quad \frac{\text{Average loss}}{\text{Peak loss}}$$

Load duration
Is the relationship of demands and the duration of the demands over a specified time period.

Loss equivalent hours

Loss equivalent hours are the number of hours of peak loads which will produce the same total losses as is produced by the actual loads over a specified period of time. Both the actual and peak demand values must be chosen from the associated load duration:

$$\text{Loss equivalent hours} = \frac{\text{Square of all actual demands}}{\text{Square of peak demand}}$$

Peak responsibility factor (PRF)
The peak responsibility factor represents the contribution a component makes to the system demand losses at the time of system peak demand.