RAMAIAH INSTITUTE OF TECHNOLOGY

DEPARTMENT OF ELECTRICAL &ELECTRONICS ENGINEERING

BASIC ELECTRICAL ENGINEERING, EE15

UNIT -1

ELECTRIC POWER SYSTEM:

The complete network from a power station to consumer premises is known as electric power system.

The **electric power system** consists of three principal components.

i) **Power generation in Power station:** electric power is generated at the power stations which are located at favorable places.

ii) **Transmission lines:** power is transmitted over large distances to load centers with the help of conductors known as transmission lines.

iii) **Distribution network:** power is distributed to a large number of small and bulk consumers through a distribution network.

GENERATION OF ELECTRIC POWER:

Electricity for commercial use is generated in power stations by converting primary sources of energy to electricity. These energy resources fall into two main categories, often called renewable and non-renewable energy resources. Some examples of non-renewable sources of energy include coal, Oil and natural gas**,** nuclear fuel etc. while renewable sources include solar, hydro, wind, biomass, tidal, geothermal, ocean thermal etc.

A.C power can be generated as a single phase or as a balanced poly-phase system. However, it was found that 3-phase power generation at 50 Hz will be economical and most suitable. Present day three phase generators, used to generate 3-phase power are called alternators (synchronous generators). A turbine is used to rotate these generators. Turbine may be of two types, namely steam turbine and water turbine.

In this section we briefly outline the basics of some of the widely found generating stations –

Thermal plant

Coal is first powdered and burnt in a furnace and the heat energy is used to boil water in the boiler to produce steam. The steam from the boiler is passed through a steam turbine to produce rotational motion. The generator, mechanically coupled to the turbine, thus rotates producing electricity. The chemical energy in coal is first converted to heat energy, then to mechanical energy and finally to electrical energy. The steam after passing Through the turbine goes to a condenser where it is condensed into water. This water if again fed to the boiler and the process repeats. In our country coal is available in abundance and naturally thermal power plants are most popular. However, these plants pollute the atmosphere because of burning of coals. A large amount of ash is produced every day in a thermal plant and effective handling of the ash adds to the running cost of the plant. Nonetheless 78% of the generation in our country is from thermal plants.

In the figure 1, the elementary features of a thermal power plant is shown.

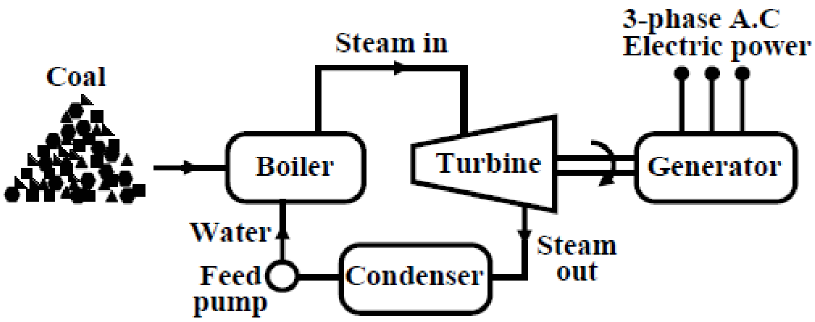

Fig 1. Thermal power plant (image courtesy: NPTEL)

Hydro Electric Power (Hydel Power)

Most hydroelectric power comes from the potential energy of water stored water reservoir at the hill tops. The potential energy of water stored is proportional to the volume of water stored and the head(difference in height between the reservoir surface and the outflow to the turbine). Water head may also be created artificially by constructing dams on a suitable river. Figure 2 depicts a typical hydro electric power plant.

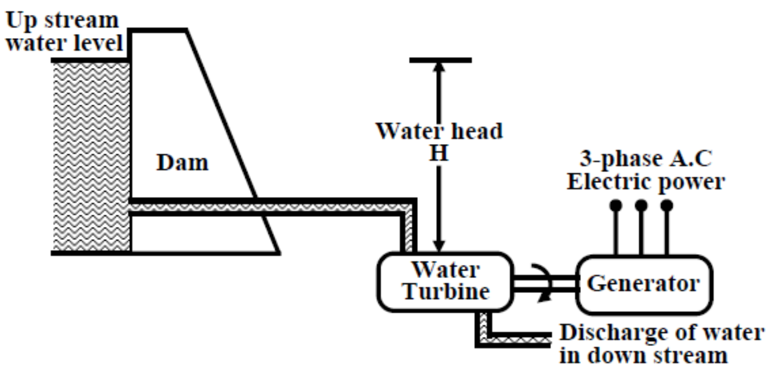

Fig 2. Hydro electric power plant (image courtesy: NPTEL)

Water is released through the penstock driving the water turbine and the generator. Hydel power plants are eco-friendly, neat and clean as no fuel is to be burnt to produce electricity. While running cost of such plants are low, the initial installation cost is rather high due to massive civil construction necessary. Also sites to be selected for such plants depend upon natural availability of water reservoirs at hill tops or availability of suitable rivers for constructing dams. 12% of the generation in our country is from hydroelectric power plants.

Nuclear plants

The present day nuclear power plants work on the principle of nuclear fission of ^{235}U. When ^{235}U is bombarded by neutrons a lot of heat energy along with additional neutrons are produced. These new neutrons further bombard 235U producing more heat and more neutrons. Thus a chain reaction sets up. However this reaction is allowed to take place in a controlled manner inside a closed chamber called nuclear reactor. To ensure sustainable chain reaction, moderator and control rods are used.

Moderators such as heavy water (deuterium) or very pure carbon ^{12}C are used to reduce the speed of neutrons. To control the number neutrons, control rods made of cadmium or boron steel are inserted inside the reactor. The control rods can absorb neutrons. If we want to decrease the number neutrons, the control rods are lowered down further and vice versa. The heat generated inside the reactor is taken out of the chamber with the help of a coolant such as liquid sodium or some gaseous fluids. The coolant gives up the heat to water in heat exchanger to convert it to steam as shown in figure 3 .The steam then drives the turbo set and the exhaust steam from the turbine is cooled and fed back to the heat exchanger with the help of water feed pump.

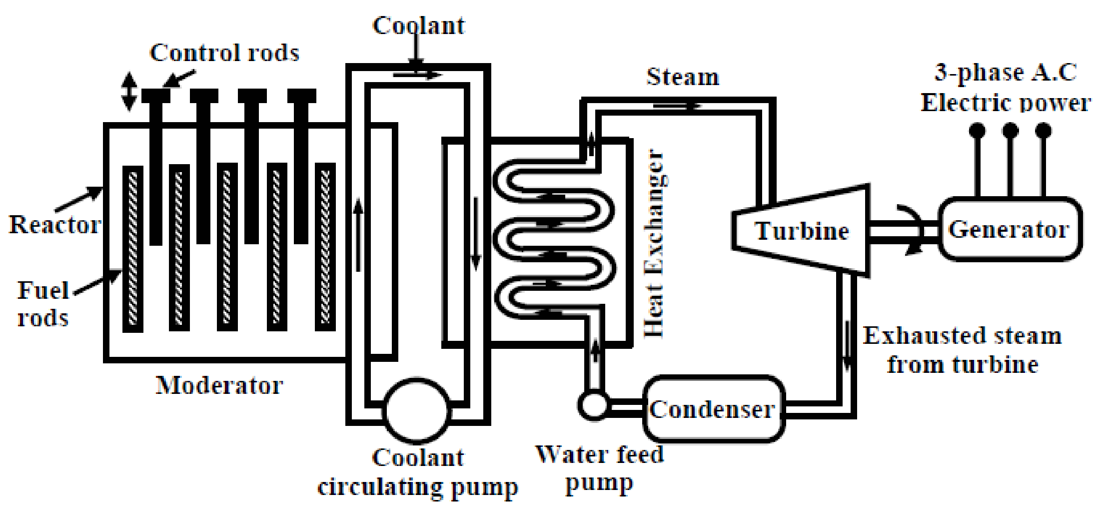

Fig 3. Nuclear Power Generation (image courtesy :NPTEL)

NON- CONVENTIONAL / ALTERNATIVE METHODS OF GENERATION

The bulk generation of power by thermal, hydel and nuclear plants are called conventional methods for producing electricity. Search for newer avenues for harnessing eco friendly electrical power has already begun to meet the future challenges of meeting growing power demand. Compared to conventional methods, the capacity in terms of MW of each non-conventional plant is rather low, but most of them are eco friendly and self sustainable. Some of them are discussed below:

Wind energy: Wind results from temperature gradients between the equator and the poles and between land and sea. Wind energy system converts the kinetic energy of wind into electricity by using wind turbines combined with a generator. The wind velocity of a particular location depends of the height and nature of the terrain. Nearly 4% of the generation in our country is from wind energy. Fig 4 shows a typical wind energy conversion system.

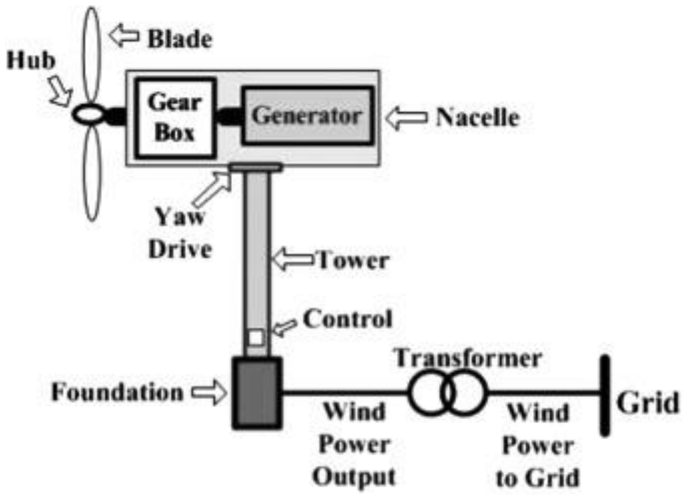

Fig 4. Typical wind energy conversion system (image courtesy: Science Direct)

Solar energy: Energy from the Sun can be used for heating water, cooking food, pumping water and generating electricity. For generation of electricity, solar photovoltaic cells are used. A solar PV cell is made up of silicon which releases electrons when exposed to light. Individual solar cells are connected together to form a panel or module which in turn can be connected in series and parallel to produce large amount of electricity. Fig. 5 shows a solar PV system which can be set up at homes.

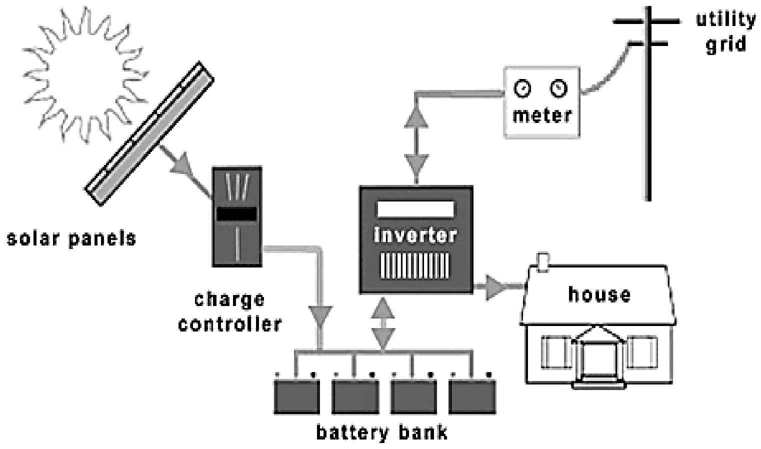

Fig 5. Residential Solar PV system block diagram
(image courtesy: energy informative)

Biomass energy: The decay of biomass produces methane which produces steam is produced on burning. The steam drives the steam turbine which rotates the generator coupled with it to produce electricity.

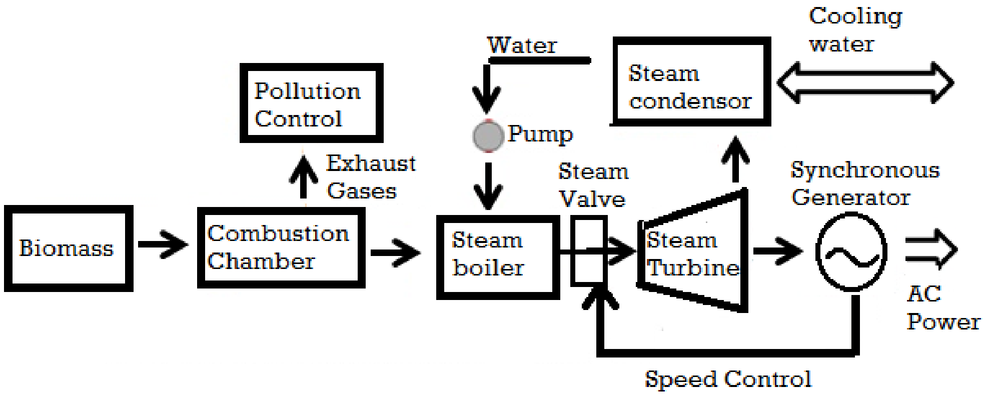

Fig6 Block diagram of a biomass power plant
(image courtesy: Electropaedia)

Tidal Energy: Tides are created due to the gravitation effects of the moon. Sufficient head of water can be captured by constructing barrages along the sea shore. A tidal wave of at least 7m is required for economical generation of electricity using water turbines. Fig. 7 shows a typical tidal power setup.

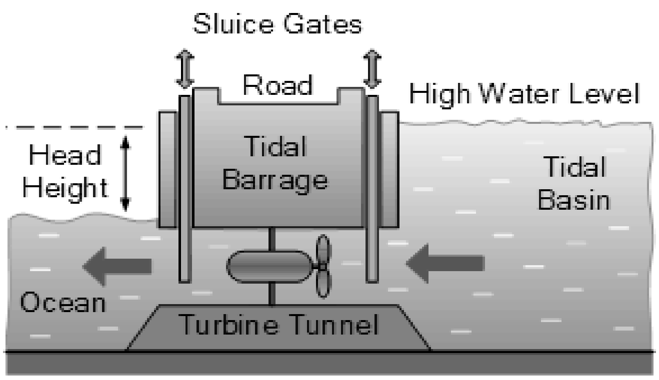

Fig 7 Typical tidal power system (image courtesy: alternative energy tutorials)

Ocean thermal Energy: The surface of water in the Ocean gets heated up due to sun's energy and can act as a solar collector. The warm water can be used to vaporize a working liquid of low boiling point. The vapour will expand and run a gas turbine which will drive a generator.

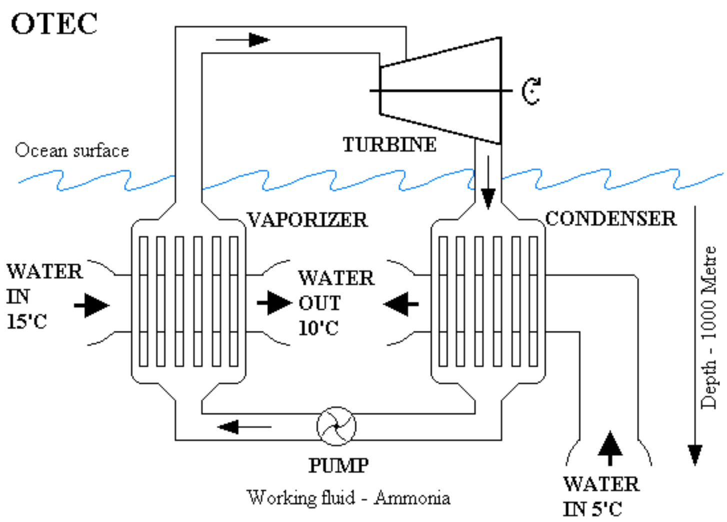

Fig 8 Typical OTEC system
(image courtesy: alternative energy tutorials)

Introduction to Transmission and Distribution

The electrical energy produced at the power stations has to be supplied to the consumers. Typical Power flow from generating station to consumers is shown below:

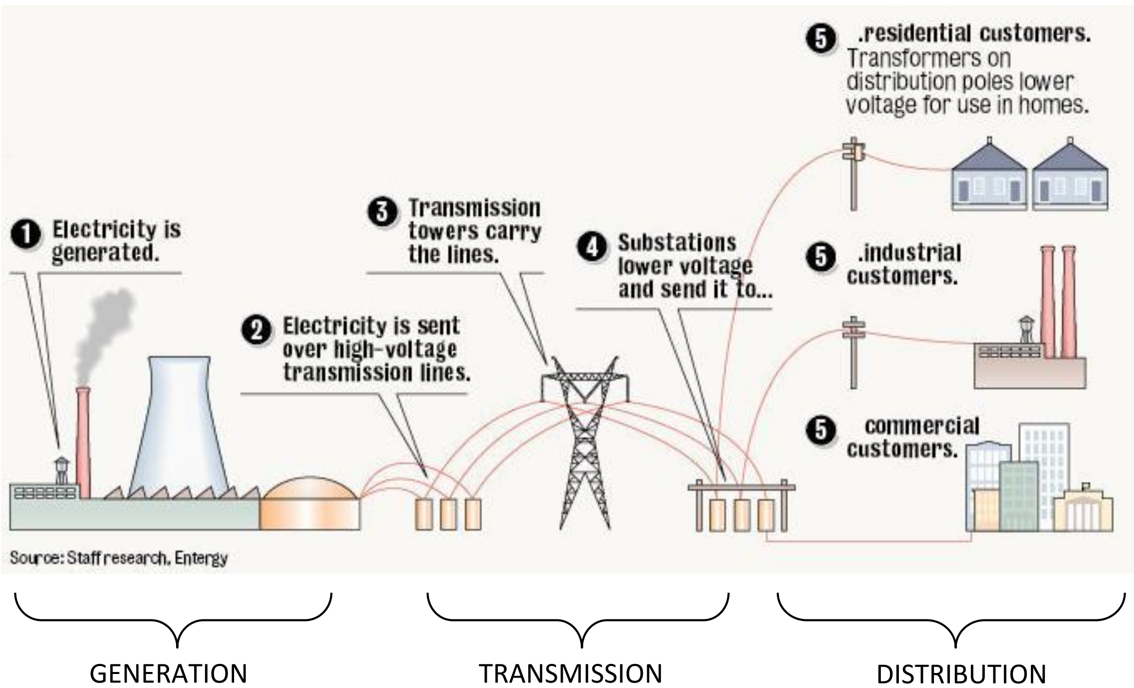

Fig 9. AC Power flow in a power system (image courtesy: staff research, entergy)

Transmission system:

Huge amount of power generated in a power station (hundreds of MW) is to be transported over a long distance (hundreds of kilometers) to load centers to cater power to consumers with the help of transmission line and transmission towers

The transmission of electric power is carried at high voltages due to the following reasons:

1. It reduces the volume of conductor material
2. It reduces the I^2R losses and hence increases the transmission efficiency
3. It decreases the percentage line drop

However high voltage transmission results in

1. Increased cost of insulating the conductors
2. Increased cost of transformers, switchgear and other terminal equipment.

Therefore, there is a limit to the higher transmission voltage which can be economically employed in any case.

At the load centers voltage level should be brought down at suitable values for supplying different types of consumers. Consumers may be (1) big industries, such as steel plants, (2) medium and small industries and (3) offices and domestic consumers. Electricity is purchased by different consumers at different voltage level. For example big industries may purchase power at 132 kV, medium and big industries purchase power at 33 kV or 11 kV and domestic consumers also called Low Tension(LT) consumers at rather low voltage of 230V, single phase. Thus we see that 400 kV transmission voltage is to be brought down to different voltage levels before finally delivering power to different consumers. To do this we require step down transformers.

Substations: The function of a substation is to receive power at some voltage through incoming lines and transmit it at some other voltage through outgoing lines. So the most important equipment in a substation is transformer(s). However, for flexibility of operation and protection transformer and lines additional equipments are necessary.

Single line representation of power system

Trying to represent a practical power system where a lot of interconnections between several generating stations involving a large number of transformers using three lines corresponding to R, Y and B phase will become unnecessary clumsy and complicated. To avoid this, a single line along with some symbolical representations for generator, transformers substation buses are used to represent a power system rather neatly.

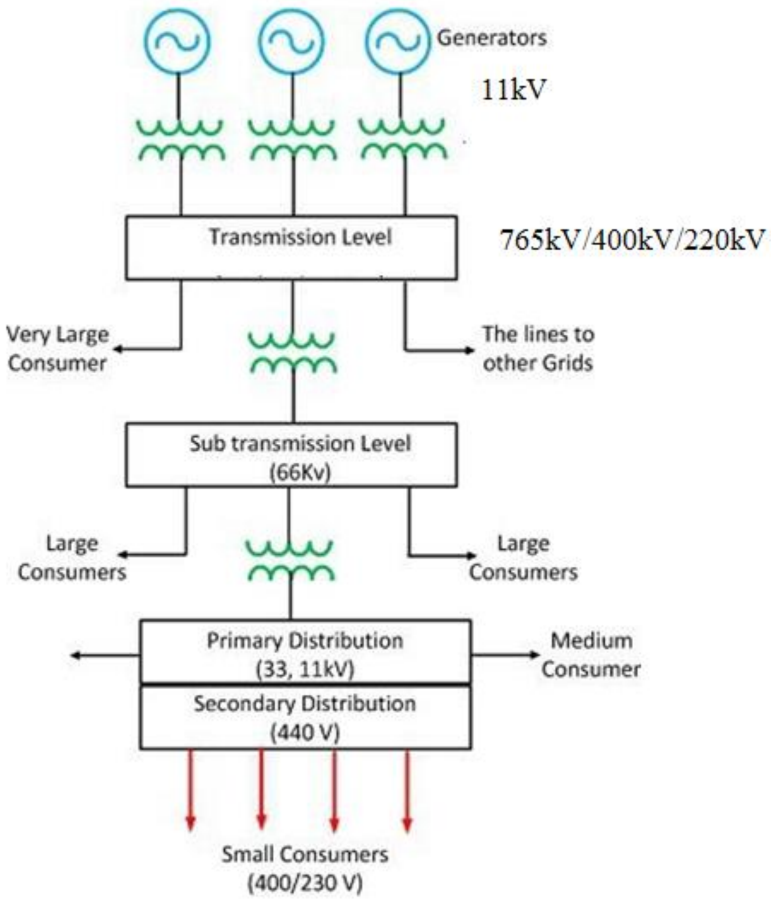

Fig 10. Single line representation of power system showing some typical voltage levels

Distribution system:

Power received at a 33 kV substation is first stepped down to 6 kV and with the help of underground cables (called feeder lines), power flow is directed to different directions of the city. At the last level, step down transformers are used to step down the voltage form 6 kV to 400 V. These transformers are called distribution transformers. From the secondary of these transformers 4 terminals (R, Y, B and N) come out. N is called the neutral and taken out from the common point of star connected secondary. Voltage between any two phases i.e R-Y, Y-B and B-R is 400 V and between any phase and neutral is 230 V (=400/√3). Residential buildings are supplied with single phase 230V, 50Hz. So individual are to be supplied with any one of the phases and neutral. Supply authority tries to see that the loads remain evenly balanced among the phases as far as possible. Which means roughly one third of the consumers will be supplied from R-N, next one third from Y-N and the remaining one third from B-N. The distribution of power from the pole mounted substation can be done either by (1) overhead lines (bare conductors) or by (2) underground cables. Use of overhead lines although cheap, is often accident prone and also theft of power by hooking from the lines take place. Although costly, in big cities and thickly populated areas underground cables for distribution of power, are used.

Electrical Grid

Electrical grid or power grid is defined as the network which interconnects the generation, transmission and distribution unit. It supplies the electrical power from generating unit to the distribution unit.

It consists of,

- Generating stations that produce electrical power
- high voltage transmission lines that carry power from distant sources to demand centers
- Distribution lines that connect individual customers

The electrical grid is mainly classified into two types. They are

1. **Regional Grid** – The Regional grid is formed by interconnecting the different transmission system of a particular area through the transmission line.
2. **National Grid** – It is formed by interconnecting the different regional grid.

Necessity for interconnection of grid

- ***Improving reliability and pooling reserves***: The amount of reserve capacity that must be built by individual networks to ensure reliable operation when supplies are short can be reduced by sharing reserves within an interconnected network.

- ***Reduced investment in generating capacity***: Individual systems can reduce their generating capacity requirement, or postpone the need to add new capacity, if they are able to share the generating resources of an interconnected system.

- ***Improving load factor and increasing load diversity***: Systems operate most economically when the level of power demand is steady over time, as opposed to having high peaks. Poor load factors (the ratio of average to peak power demand) mean that utilities must construct generation capacity to meet peak requirements, but that this capacity sits idle much of the time. Systems can improve poor load factors by interconnecting to other systems with different types of loads, or loads with different daily or seasonal patterns that complement their own.

- ***Economies of scale in new construction***: Unit costs of new generation and transmission capacity generally decline with increasing scale, up to a point. Sharing resources in an interconnected system can allow the construction of larger facilities with lower unit costs.

- ***Diversity of generation mix and supply security***: Interconnections between systems that use different technologies and/or fuels to generate electricity provide greater security in the event that one kind of generation becomes limited (e.g., hydroelectricity in a year with little rainfall). Historically, this complementarity has been a strong incentive for interconnection between hydro-dominated systems and thermal-dominated systems. A larger and more diverse generation mix also implies more diversity in the types of forced outages that occur, improving reliability.

- ***Economic exchange***: Interconnection allows the dispatch of the least costly generating units within the interconnected area, providing an overall cost savings that can be divided among the component systems. Alternatively, it allows inexpensive power from one system to be sold to systems with more expensive power.

- ***Environmental dispatch and new plant siting***: Interconnections can allow generating units with lower environmental impacts to be used more, and units with higher impacts to be used less. In areas where environmental and land use constraints limit the siting of power plants, interconnections can allow new plant construction in less sensitive areas.

- ***Coordination of maintenance schedules***: Interconnections permit planned outages of generating and transmission facilities for maintenance to be coordinated so that overall cost and reliability for the interconnected network is optimized.

Conditions for Interconnection of Grids

- There are five conditions that must be met before the synchronization process takes place.

- The source (generator or sub-network) must have equal **line voltage, frequency, phase sequence, phase angle, and waveform** to that of the system to which it is being synchronized.

- Waveform and phase sequence are fixed by the construction of the generator and its connections to the system.

- During installation of a generator, careful checks are made to ensure the generator terminals and all control wiring is correct so that the order of phases (phase sequence) matches the system.

- Connecting a generator with the wrong phase sequence will result in a circulating current as the system voltages are opposite to those of the generator terminal voltages.

- The voltage, frequency and phase angle must be controlled each time a generator is to be connected to a grid.

Renewable Energy Sources

Renewable energy comes from a source that will not deplete. Two common examples of this type of energy are solar power and wind power. Geothermal power, hydropower, biomass, and tidal power are additional forms of renewable energy that produce power.

Advantages of Renewable Energy

- It is sustainable and will never run out.
- They provide clean energy because they are non-pollutant and non-contributor to greenhouse effects and global warming.
- Renewable energy facilities generally require less maintenance than traditional generators.
- Their fuel being derived from natural and available resources reduces the costs of operation.

- Renewable energy produces little or no waste products such as carbon dioxide or other chemical pollutants, so have a minimal impact on the environment.
- Renewable energy projects can also bring economic benefits to many regional areas, as most projects are located away from large urban centres and suburbs of the capital cities.

Disadvantages of Renewable Energy

- It unpredictable and inconsistent.
- Not every form of renewable energy is commercially viable.
- Many forms of renewable energy are location-specific.

Benefits of grid integration of RESs

Renewable energy source (RES) integrated at distribution level is termed as distributed generation (DG). The benefits of RES based DGs are highly dependent on the characteristics of each installation and the characteristics of the local power system.

Benefits with integrating RES based DG to grid are given below:

Reliability and Security Benefits	• Increased security for critical loads • Relieved transmission and distribution congestion • Reduced impacts from physical or cyber attack Increased generation diversity
Economic Benefits	• Reduced costs associated with power losses • Deferred investments for generation, transmission, or distribution upgrades • Lower operating costs due to peak shaving • Reduced fuel costs due to increased overall efficiency • Reduced land use for generation
Emission Benefits	• Reduced line losses • Reduced pollutant emission

Conditions for grid interconnection of RESs

Solar PV:

When driving power to the grid, grid-tied inverters must provide a stable, sinusoidal AC waveform that matches grid voltage and frequency according to utility standards. Poor synchronization can lead to load imbalances, damage to connected equipment, instability in the grid, and even power outages in the grid itself.

Wind Energy:

The generator of wind turbine must have equal **line voltage, frequency, phase sequence, phase angle, and waveform** to that of the grid to which it is being synchronized.

Definition of Load

An electrical load is an electrical component/device or portion of a circuit that consumes electric power.

Types of Load

Based on Nature of load

1. *Resistive Load* - The resistive load obstructs the flow of electrical energy in the circuit and converts it into thermal energy, due to which the energy dropout occurs in the circuit. The resistive loads take power in such a way so that the current and the voltage wave remain in the same phase. Thus the power factor of the resistive load is unity. Loads consisting of any heating element are classified as resistive loads. These include incandescent lights, toasters, ovens, space heaters, coffee makers, geyser etc.,

2. *Inductive Load* - The inductive loads use the magnetic field for doing the work. The inductive load has a coil which stores magnetic energy when the current pass through it. The current wave of the inductive load is lagging behind the voltage wave, and the power factor of the inductive load is also lagging. Electrical motors can be classified as inductive loads. Electrical motors are found in a variety of household appliances such as fans, vacuum cleaners, dishwashers, washing machines, compressors, refrigerators and air conditioners

3. *Capacitive load* - Reactive/capacitive load banks are used in a variety of industries and applications. Some examples include telecommunications, IT, manufacturing and mining. Some of the examples for Capacitive loads are Radio Circuits, Synchronous Motor, Capacitor Bank, TV picture tubes, Buried cables, Motor starter circuit etc.,. The current wave of the capacitive load is leading behind the voltage wave, and the power factor of the capacitive load is also leading.

Based on type of Utility -

1. *Domestic Load* - The domestic load is defined as the energy consumed by the electrical appliances in the household work. The domestic loads mainly consist of lights, fan, refrigerator, air conditioners, mixer, grinder, heater, ovens, small pumping motor, etc. The domestic load consumes very little power. This load largely consists of lighting, cooling or heating.

2. *Commercial Load* - The energy consumed by the commercial establishments such as market, office, amusement parks, malls, cinema theatre, restaurants, etc. are considered as a commercial load. This load largely consists of fans, Heaters, air conditioners and many other

electrical appliances used in these establishments

3. *Industrial Load* - The energy consumed by cottage, small, medium and heavy industries are classified as Industrial load. The induction motor forms a high proportion of the composite load.

4. *Agricultural load* - The energy consumed in farming activities is termed as agricultural load. This type of load mainly consists of submersible motor for irrigation purposes

Definition of Power Factor

Power factor is defined as the cosine of the phase angle between voltage and current. It can also be defined as the ratio of active power to apparent power. Power factor is unit-less and it ranges from zero to one

Power and Energy

Electrical Power - The rate at which work is done in an electric circuit is called electrical power. The unit of power is watts or kilo-watts. 1 kW = 1000 W

Electrical Energy - The total amount of work done in an electric circuit is called electrical energy. It is the product of electrical power and time. The unit of electrical energy is Watt-Hour (Wh) or KiloWatt-hour (kWh).

1 KWh = 1000 Wh. One unit of electrical energy consumed by an electrical appliance means 1 kWh of electrical energy consumed.

Tariff Structure for Electrical Energy Consumption

Definition of Tariff

It is the rate at which the electric energy is supplied to the consumer. It depends upon the magnitude of electric energy & load conditions. It will be different for different customers such as domestic, agricultural, commercial & industrial consumers.

Objectives of tariff

1. It should include the recovery of cost of producing electric energy at power station.
2. It should include the recovery of capital investment in transmission & distribution.
3. It should include recovery of cost of operation & maintain of supply of electrical energy such as metering, billing etc.

Desirable characteristics

1. Proper return - It should give proper return with a profit.
2. Fairness - It should be fair such that different set of consumers should receive different tariffs according to their demand.

3. Simplicity - It should be simple so that ordinary lay man should understand.
4. Attractive - It should be attractive to large number of consumers.

Types of tariff

1. Simple tariff - Fixed rate per unit charge of energy consumed. The disadvantage is that it should not discriminate between different types of consumers.
2. Flat rate tariff - Different set of consumers are charged at different uniform per unit rates. The disadvantage is that it is expensive regardless of what load is used.
3. Block rate tariff - Each block of energy will be charged at specific rates and as consumers consume more energy charges will reduced. The advantage of such tariffs is that consumer gets incentive to consume more electricity.
4. Power factor tariff - It is the tariff where power factor of the consumer is taken into consideration. If the power factor of the consumer is less, he will be penalized.
5. Two part tariff - It has fixed charges and running charges. The fixed charges depends upon the maximum demand of the consumer and running charges on the amount of kwh consumed.

   Total charges=Rs(axkw+bxkwh)

   a - Charges per kW of maximum demand

   b - Charges per kWh of energy consumed

   The consumer has to pay fixed charges irrespective of the consumer uses his load or not.
6. Three part tariff -IT has fixed, semi fixed and running charges

   Total charge=Rs(a+bxkW+cxkWh)

   a -Fixed charges made during each billing period. It includes interest and depreciation on the cost of the secondary distribution and labour costs of collecting revenues

   b - Charge per kW of maximum demand

   c - Charge per kWh of energy consumed