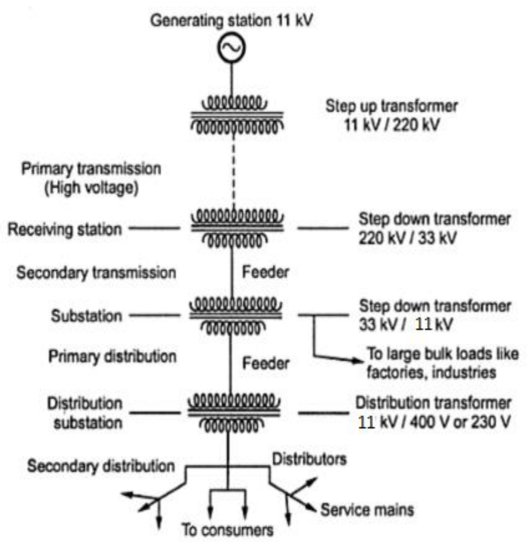
Module I

Syllabus

Power System evolution–Load curve -Load factor, diversity factor, Load curve (brief description only) - Numerical Problems.

Generation-conventional (block schematic details, special features, environmental and ethical factors, advantages, disadvantages) -hydro, thermal, nuclear –renewable energy(block schematic details, special features, environmental factors, regulations, advantages, disadvantages) –solar and wind –Design of a rooftop/ground mounted solar farm (concepts only) – Energy storage systems as alternative energy sources- grid storage systems- bulk power grids –smart grids – micro grids.

Structure of Power System



Variable Load on Power Station

The load on a power station varies from time to time due to uncertain demands of the consumers and is known as variable load on the station.

Effects of variable load

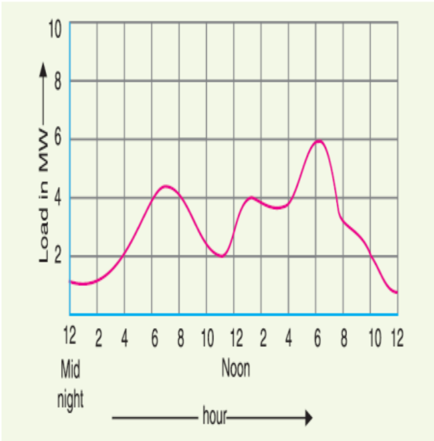
(*i*) **Need of additional equipment**

The variable load on a power station necessitates to have additional equipment.

(ii) **Increase in production cost.**

The variable load on the plant increases the cost of the production of electrical energy.

Load Curves



The curve showing the variation of load on the power station with respect to (w.r.t) time is known as a **load curve.** The load on a power station is never constant; it varies from time to time. These load variations during the whole day (i.e., 24 hours) are recorded half-hourly or hourly and are plotted against time on the graph. The curve thus obtained is known as daily load curve as it shows the variations of load w.r.t. time during the day.

The daily load curves give us the following information:

(*i*) The daily load curve shows the variations of load on the power station during different hours of the day.

(*ii*) The area under the daily load curve gives the number of units generated in the day.

Units generated/day = Area (in kwh) under daily load curve.

(*iii*) The highest point on the daily load curve represents the maximum demand on the station on that day.

(*iv*) The area under the daily load curve divided by the total number of hours gives the average load on the station in the day.

$$\text{Average load} = \frac{\text{Area (in kWh) under daily load curve}}{\text{24 hours}}$$

(*vi*) The load curve helps in selecting the size and number of generating units.

(*vii*) The load curve helps in preparing the operation schedule of the station.

The **monthly load curve** can be obtained from the daily load curves of that month. For this purpose, average values of power over a month at different times of the day are calculated and then plotted on the graph. The monthly load curve is generally used to **fix the rates of energy.** The **yearly load curve** is obtained by considering the monthly load curves of that particular year. The yearly load curve is generally used to determine **the annual load factor.**

Connected load. It is the sum of continuous ratings of all the equipments connected to supply system.

Maximum demand: It is the greatest demand of load on the power station during a given period.

Demand factor. It is the ratio of maximum demand on the power station to its connected load.

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}$$

The value of demand factor is usually less than 1. The knowledge of demand factor is vital in determining the capacity of the plant equipment.

Average load: -The average of loads occurring on the power station in a given period (day or month or year) is known as **average load** or **average demand.**

$$\text{Daily average load} = \frac{\text{No. of units (kWh) generated in a day}}{24 \text{ hours}}$$

$$\text{Monthly average load} = \frac{\text{No. of units (kWh) generated in a month}}{\text{Number of hours in a month}}$$

$$\text{Yearly average load} = \frac{\text{No. of units (kWh) generated in a year}}{8760 \text{ hours}}$$

Load factor: - The ratio of average load to the maximum demand during a given period is known as **load factor** i.e.,

$$\text{Load factor} = \frac{\text{Average load}}{\text{Max. demand}}$$

If the plant is in operation for T hours,

$$\text{Load factor} = \frac{\text{Average load} \times T}{\text{Max. demand} \times T}$$

$$= \frac{\text{Units generated in T hours}}{\text{Max. demand} \times \text{T hours}}$$

Load factor is always less than 1 because average load is smaller than the maximum demand.

The load factor plays key role in determining the overall cost per unit generated. Higher the load factor of the power station, lesser will be the cost per unit generated because a higher load factor means lesser maximum demand. The station capacity is so selected that it must meet the maximum demand.

Diversity factor: -The ratio of the sum of individual maximum demands to the maximum demand on power station is known as diversity factor i.e.,

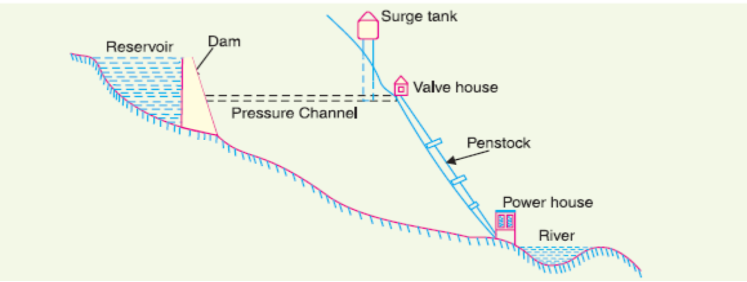
$$\text{Diversity factor} = \frac{\text{Sum of individual max. demands}}{\text{Max. demand on power station}}$$

Diversity factor will always be greater than 1. The greater the diversity factor, the lesser is the cost of generation of power. Greater diversity factor means lesser maximum demand, this in turn means that lesser plant capacity is required. Thus, the capital investment on the plant is reduced.

Hydroelectric Power Plant

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

Schematic arrangement of Hydroelectric power plant



Dam is constructed across the river. Pressure tunnel connects dam and the valve house. The valve house contains main sluice valve and automatic isolating valves. Sluice valve control water flow to the power house and the automatic valve cuts off supply of water when the penstock bursts. From the valve house water is taken to turbine through huge pipes called penstocks. Turbine drives the alternator where the mechanical energy is converted into electrical energy. A surge tank is built before valve house and it protects the penstock from bursting in case turbine gates suddenly close due to electrical load being thrown off.

Advantages

i) No fuel charges.
ii) Highly reliable.
iii) Maintenance and operation charges are less.
iv) Running cost is low.
v) It takes a few minutes to run and synchronize the plant.
vi) Plant has comparatively long life.
vii) Less supervising staff is required.
viii) No pollution problem.
ix) They can be also used for flood control and irrigation purpose.

Disadvantages

1) Environmental Consequences: -The environmental consequences of hydropower are related to interventions in nature due to damming of water, changed water flow and the construction of roads and power lines.
2) Expensive: -Building power plants in general is expensive.
3) Electricity generation and energy prices are directly related to how much water is available
4) Environmental Consequences: -The environmental consequences of hydropower are related to interventions in nature due to damming of water, changed water flow and the construction of roads and power lines.
5) Expensive: -Building power plants in general is expensive.
6) Electricity generation and energy prices are directly related to how much water is available

Choice of site

Availability of water
Storage of water
Cost and type of land
Transportation facilities

Main components of Hydro-Electric Plant

(i) **Hydraulic structures**: - It includes dam, spillway, headworks, surge tank, penstock etc.
(ii) **Dam**: - stores water and creates waterhead.
(iii) **Spillway**: - A spillway is a structure constructed in a hydroelectric dam to provide a safe path for floodwaters to escape to some downstream area. Generally, the area that the spillway is released to is the river on which the hydroelectric dam was constructed.
(iv) **Headworks**:-It consists of diversion structures at the head of intake. They include frameworks for diverting floating debris, sluices for bypassing debris and sediments and valves for controlling the flow of water to the turbine.

(v) **Surge tank**:-It is a small reservoir tank in which water level rises or falls to reduce the pressure swings in the penstock.

(vi) **Penstocks**: - A penstock is a sluice or gate or intake structure that controls water flow, or an enclosed pipe that delivers water to hydro turbines. It is a closed or open conduit which carry water to the turbines. They are made up of reinforced concrete or steel.

(vii) **Water turbines**: -

Two types.

I)Impulse Turbine

Ii) Reaction turbine

Impulse turbines are used for high heads. Ex: -Pelton turbine

Reaction turbines are used for low and medium heads. Important types of reaction turbines are i) Francis turbine ii) Kaplan turbine.

(viii) **Electrical Equipments**: -

It includes transformers, alternators, circuit breakers and other switching devices.

Types of Hydro-Power Plants

(i) **Conventional Plants: -**Conventional plants use potential energy from dammed water.

(ii) **Pumped Storage Plant:-**In pumped storage plant, a second reservoir is constructed near the water outflow from the turbine. When the demand of electricity is low, the water from lower reservoir is pumped into the upper (main) reservoir. This is to ensure sufficient amount of water available in the main reservoir to meet the peak loads.

(iii) **Run-Of-River Plant: -** In this type power plant, no dam is constructed and, hence, reservoir is absent. A portion of river is diverted through a penstock or canal to the turbine. Thus, only the water flowing from the river is available for the generation.

Thermal power station.

A generating station which converts heat energy of coal combustion into electrical energy is known as a **thermal power station**.

Advantages

i) The fuel used is cheap
ii) Initial cost is less compared to other generating stations
iii) Plant can be installed at any place.
iv) Space required is less.
v) Cost of generation is less compared to diesel power plants.

Disadvantages

i) It pollutes the atmosphere.
ii) Running cost is higher than hydroelectric power plant.

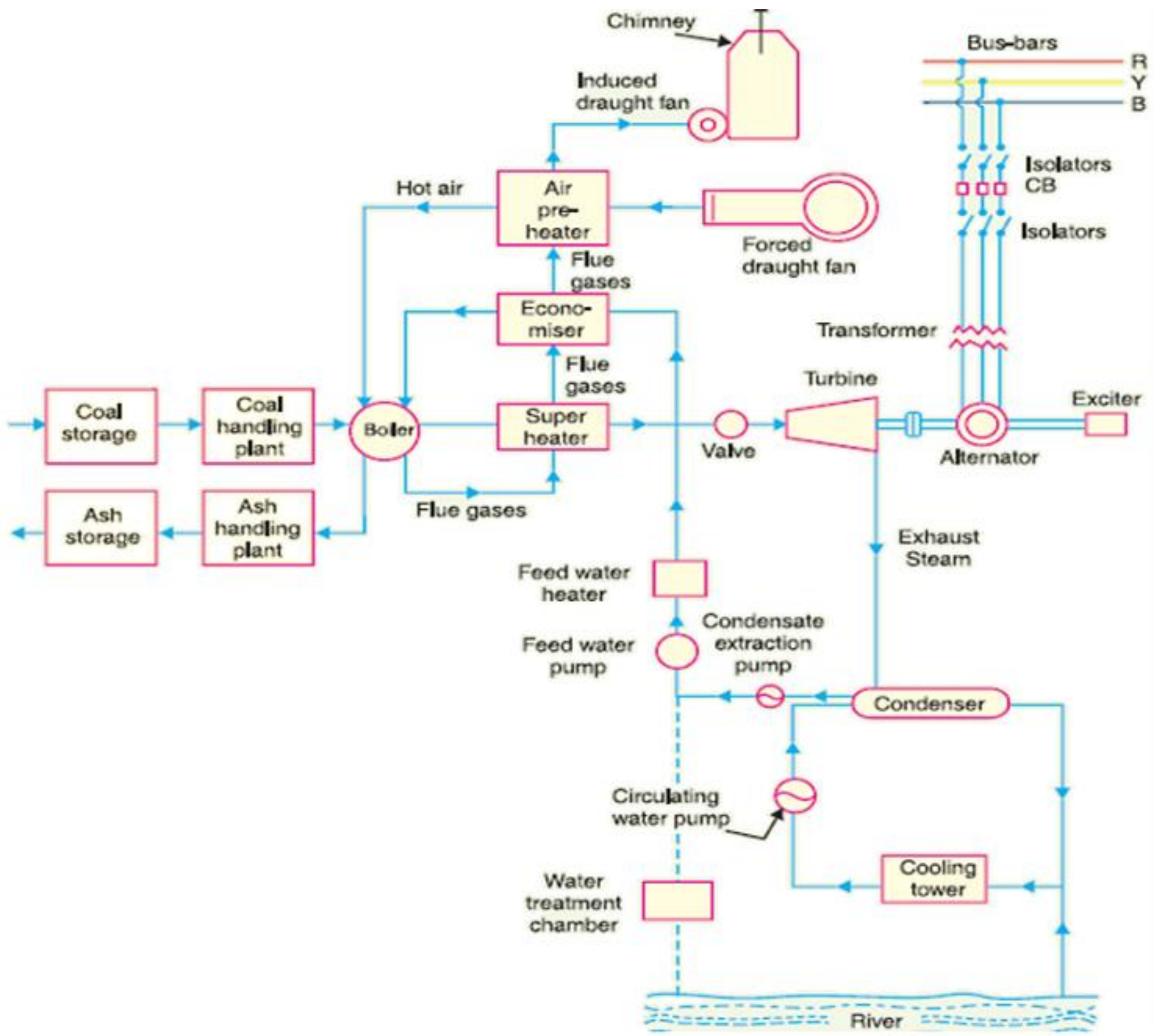
Main parts and Working

It works on Rankine cycle. Steam is produced in a boiler. It is then expanded in the prime mover and is condensed in a condenser and again fed into the boiler.

Main parts are

i) Fuel and ash handling arrangement
ii) Air and gas circuit
iii) Steam generating plant
iv) Feedwater
v) Cooling arrangement

Schematic arrangement of thermal power plant



Fuel and ash handling arrangement

Coal from the storage is fed to the boiler through coal handling plant. Ash produced during combustion of coal is removed to ash storage through ash handling equipment.

Air and gas circuit

Air from the atmosphere is supplied to the combustion chamber of the boiler through the action of a forced draught fan. Before passing to the boiler air is heated by heat of flue gases in the air pre-heater.

Steam generating plant

Steam generating plant consist of boiler and other equipments.

Boiler:-It is used to convert water into steam at high temperature and pressure. The flue gases from the boiler passes through superheater, economiser, air pre-heater and finally exhausted to atmosphere through chimney.
Super heater: -Steam is dried in the super heater by the flue gases.
Economiser:-It is a feed water heater and derives heat from flue gases.
Air preheater:-It extracts heat from flue gases and increases the temperature of air supplied for coal burning
Steam turbine: -The dry and superheated steam from the superheater is fed to the steam turbine through main valve. Heat energy will be converted into mechanical energy at the turbine. Steam is exhausted to the condenser which condenses the steam.
Alternator: -Steam turbine is coupled to the alternator. Alternator converts mechanical energy into electrical energy.
Feedwater: -The condensate from the condenser is used as feedwater to the boiler. Feedwater to the boiler is heated by water heaters and economizer.
Cooling Arrangement: -Water supply to the condenser helps in maintaining a low pressure in it. Water may be taken from natural resources such as river, lake or sea.

The overall efficiency of steam power plant is about **29%**.

Selection of site

i) Availability of raw materials
ii) Nature of land
iii) Cost of land
iv) Availability of water
v) Transport facilities
vi) Ash disposal facilities
vii) Size of the plant
viii) Load centre
ix) Public problems
x) Future extensions

<u>Nuclear Power Plant</u>

A generating station in which nuclear energy is converted into electrical energy is called a nuclear power station. In this power station Uranium235 or Thorium232 are subjected to nuclear fission in a reactor. The heat energy released is utilized in raising steam at high temperature and pressure. Steam runs steam turbine which converts steam energy into mechanical energy. Turbine runs the alternator.

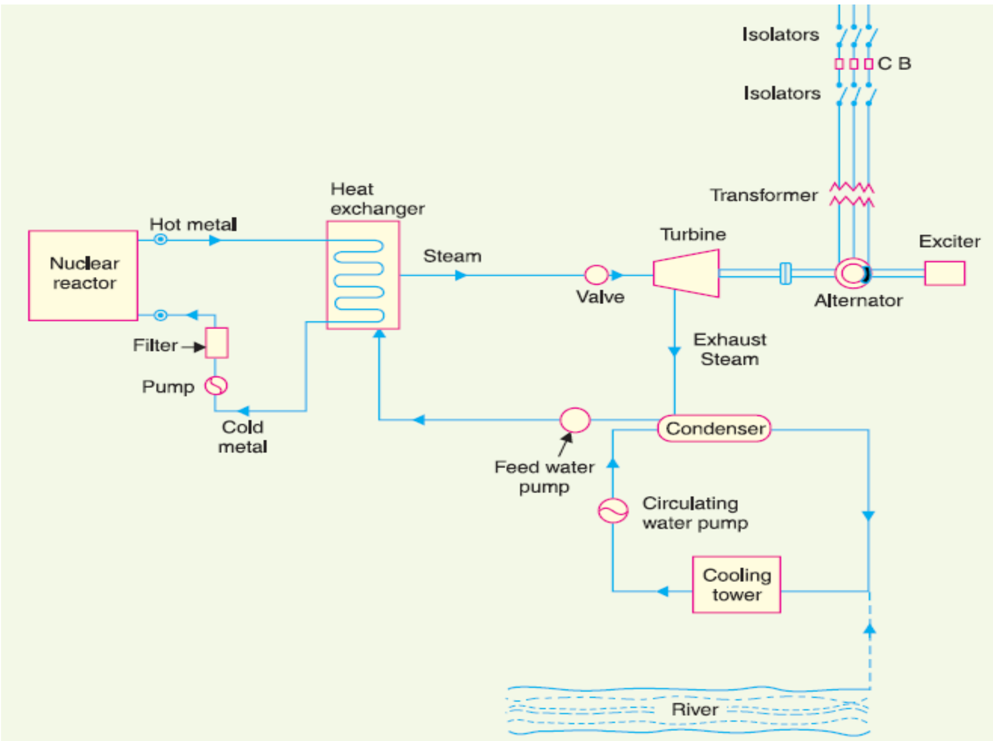
Advantages

(i) Cost of fuel transportation is less.
(ii) Requires only less space.
(iii) Running charges are less.
(iv) They are suitable for bulk production of electric power.
(v) Continuity of supply
(vi) Reliable

Disadvantages

(i) Capital cost is high
(ii) Fission byproducts are radioactive.
(iii) Maintenance charges are high.
(iv) Not suitable for varying loads.
(v) Erection and commissioning requires greater technical knowledge.

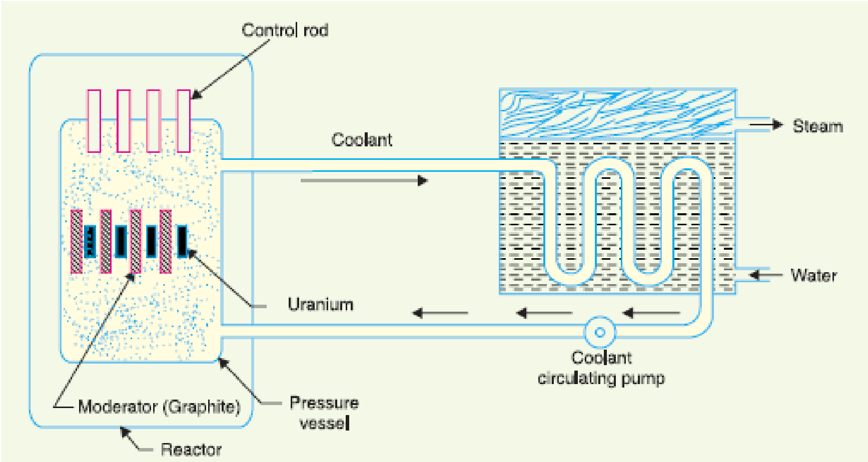
Schematic arrangement of nuclear power plant



Main parts are

(i) **Nuclear reactor**:-It is an apparatus in which nuclear fuel U235 is subjected to nuclear fission. It is a cylindrical stout pressure vessel and houses fuel rods of Uranium, moderator and control rods. Fuel rods contain fission material and release huge amount of energy when bombarded with slow moving neutrons. Moderator slows down the neutrons before they bombard the fuel rods. Graphite is generally used as moderator. Control rods are made up of cadmium and are inserted into the reactor. Cadmium is a strong neutron absorber and regulate the supply of neutrons for fission.Heat produced in the reactor is removed by the coolant, generally a sodium metal. Coolant carries heat to the heat exchanger.

Nuclear reactor and heat exchanger



(ii) **Heat exchanger**: -Coolant gives up heat to the heat exchanger which is used to produce steam. Coolant is again fed to the reactor.

(iii) **Steam turbine**: -Steam produced in the heat exchanger is fed to the steam turbine through a valve. After passing through the turbine, it is exhausted to the condenser.

(iv) **Alternator:** -Converts mechanical energy into electrical energy.

Selection of Site

i) Availability of water
ii) Disposal of waste
iii) Distance from populated areas.
iv) Transportation facilities

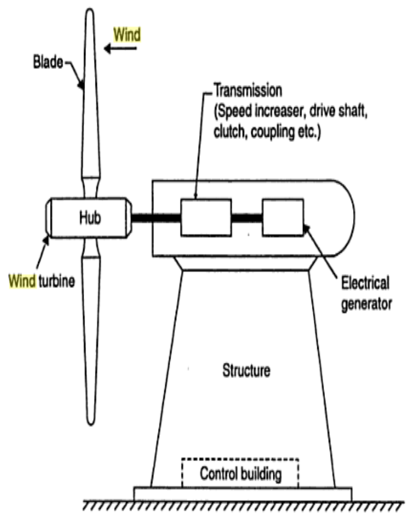
Non-conventional sources

Natural resources like wind, tides, solar, biomass, etc. generate energy which is known as **Non-conventional resources**. These are also called renewable sources of energy.

Advantages

(i) They are practically inexhaustible sources of energy
(ii) Their exploitation/utilisation is widely accepted by the general public, due to their environment- and human-friendly nature.
(iii) They constitute (together with energy conservation) the most ecologically sound solution for the effective reduction of carbon dioxide emissions
(iv) They usually have low operating costs

Wind Power Plant



A wind power plant consists of a **wind turbine** usually rotated in a horizontal axis, a **generator**, a speed changing **gear system** which couples the turbine with generator and the **control equipment**. The turbine and generator assembly is mounted at a height of 20-25m. Regions were steady wind in the range of 5 to 30 m/sec are considered suitable for grid connected wind generators. The turbine blades normally run at a lower speed and therefore a gear box is used to increase the speed to match the required generator speed.

Advantages

i) It does not pollute the atmosphere.
ii) Fuel provision and transport are not required.
iii) It is renewable source of energy.
iv) Production cost is cheap.

Disadvantages

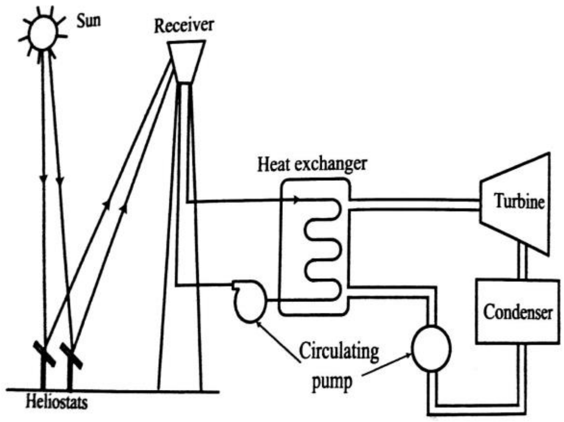
i) It is fluctuating in nature.
ii) Due to its irregularity it needs storage devices.
iii) This system produces ample noise

Solar Power Plant

Solar power plant can be of two types

1) Solar thermal systems
2) Solar photovoltaic systems

Solar thermal system



The basic principle of solar thermal system is to concentrate the solar radiation to a receiver using mirror reflectors and the resulting heat is used to produce steam. This steam is used to run steam turbine which in turn runs the alternator. The main parts are

1) **Receiver**
2) **Heat exchanger**
3) **Turbine**
4) **Alternator**

In this system, there is a central tower receiver surrounded by a large number of mirrors(heliostat). The mirrors reflect sunlight to the receiver on the top of the tower. Very high temperature is produced at the receiver. The receiver collects the heat of sunrays in a heat transfer fluid (normally molten salt), which is circulated through a heat exchanger. Water is pumped into heat exchanger. Steam is produced in the heat exchanger. This steam drives the turbine which is coupled to the generator.

Advantages

- No fuel is required
- No atmospheric pollution

Disadvantages

- Energy generation is possible only when there is sunlight
- Position of sun changes and therefore a tracking system is required to ensure that sunlight is always reflected to the receiver

Solar Photovoltaic (SPV)System

In this system solar energy is directly converted into electrical energy by solar cells usually made of silicon. A solar cell is basically a PN junction diode, which generates electron flow when visible light falls on it. Voltage produced by each cell is almost 0.5V, so large no. of cells are connected in series to get required voltage. Electricity can be used directly or can be stored in batteries/fed to grid Most suitable for homes with a flat roof or with slanting roof facing south

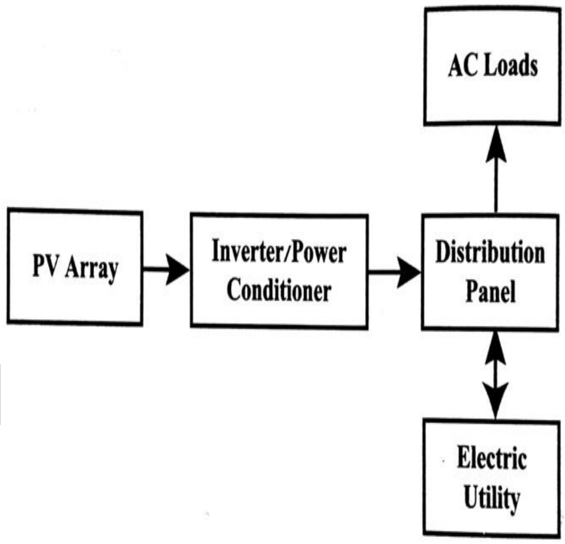
Types of PV electrical systems

There are two general types of design for PV power systems are

- Grid connected or utility interactive systems
- Stand-alone or off grid PV systems

Grid connected system

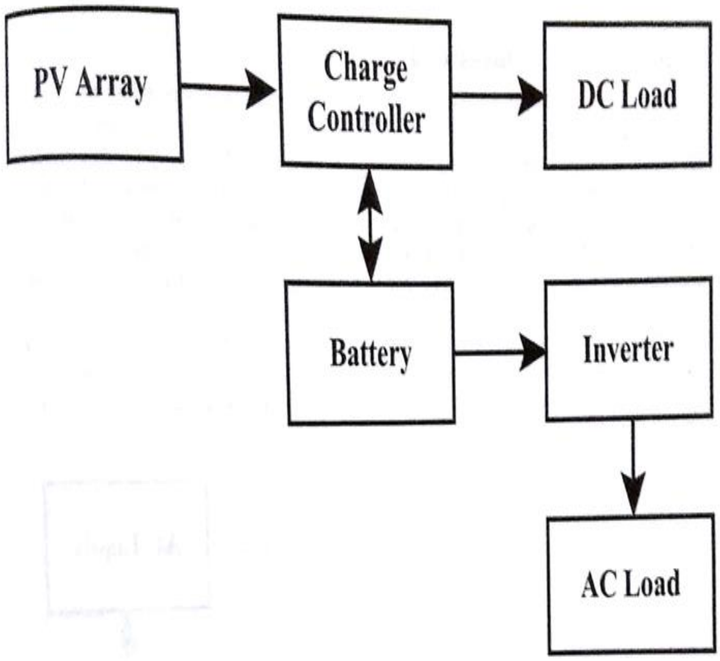
Designed to operate in parallel with and interconnected with the utility grid. Primary component is the inverter or power conditioning unit (PCU). Inverter converts DC power produced by the PV array into AC power consistent with the voltage and power quality required by the utility grid. Bidirectional interface is made between PV system AC output circuits and the electric utility network.



When the PV output is greater than the on site load demand, PV system feed the grid When electrical demand is greater than the PV system output, the balance of power required is drawn from the electric utility. Main Safety issue is PV system should not feed to utility grid when grid is down for service or repair.

Stand-alone system

It is designed to operate independent of the electric utility grid. Supply DC/AC loads. Most suited for remote locations where there is no utility supply. Drawbacks are 1) batteries won't last forever 2) wastage of surplus energy3) Need replacement every 5-6 years



Typical design for home application

Design steps

Step 1) Determine the load to be served in watt-hours/day

Step 2) Determine the average solar energy available on at least a month by month basis

Step 3) Calculate the size of solar panel that is required to meet the load demand under the worst month conditions

Step 4) Calculate the size and type of battery that is needed to provide the required reliability of power

Step 5) Determine the type of charge controller

Step 6) Determine the inverter capacity

Energy storage systems (ESS)

Energy storage is the capture of energy produced at one time for use at a later time to reduce imbalances between energy demand and energy production. A device that stores energy is generally called an accumulator or battery. Energy comes in multiple forms including radiation, chemical, gravitational potential, electrical potential, electricity, elevated temperature, latent heat and kinetic. Energy storage involves converting energy from forms that are difficult to store to more conveniently or economically storable forms. Bulk energy storage is currently dominated by hydroelectric dams, both conventional as well as pumped.

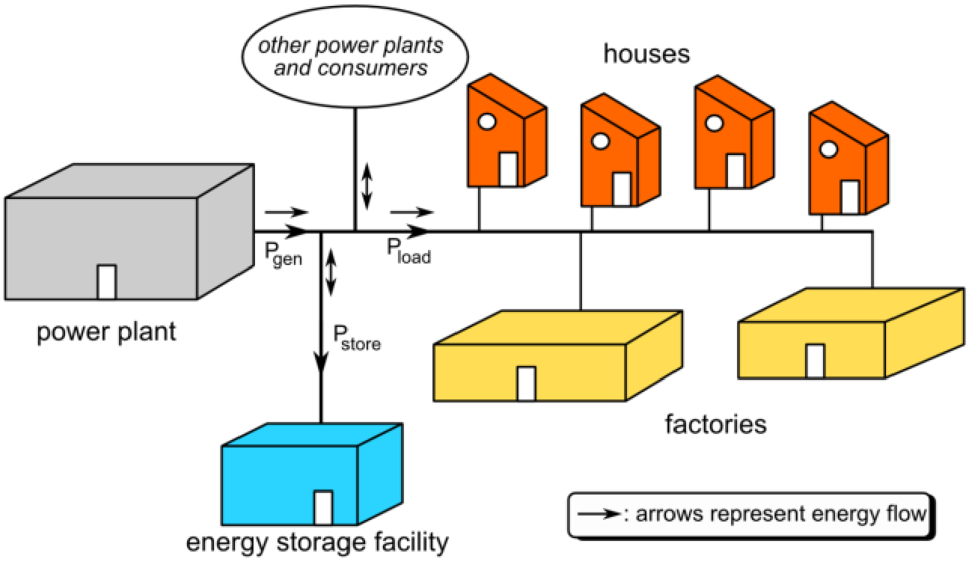
Grid energy storage is a collection of methods used for energy storage on a large scale within an electrical power grid. Common examples of energy storage are

The rechargeable battery, which stores chemical energy readily convertible to electricity to operate a mobile phone; the hydroelectric dam, which stores energy in a reservoir as gravitational potential energy and ice storage tanks, which store ice frozen by cheaper energy at night to meet peak daytime demand for cooling

Types of energy storage systems

- Electrochemical (Batteries)
- Mechanical (Flywheels)
- Electrical (Capacitors)
- Thermal (hot water storage)

Grid energy storage



Simplified electrical grid with energy storage

Grid energy storage (also called large-scale energy storage) is a collection of methods used for energy storage on a large scale within an electrical power grid. Electrical energy is stored during times when electricity is plentiful and inexpensive (especially from intermittent power sources such as renewable electricity from wind power, tidal power and solar power) or when demand is low, and later returned to the grid when demand is high, and electricity prices tend to be higher. Developments in battery storage have enabled commercially viable projects to store energy during peak production and release during peak demand, and for use when production unexpectedly falls. Two alternatives to grid storage are the use of peaking power plants to fill in supply gaps and demand response to shift load to other times.

Distributed Generation

Conventional power system is facing the problems like depletion of fossil fuel resources, poor energy efficiency and environmental pollution. This has led to a new trend of generating power locally at distribution voltage level by using non-conventional/renewable energy sources like natural gas, biogas, wind power, solar photovoltaic cells, fuel cells, combined heat and power (CHP) systems and their integration into the utility distribution network.

Microgrid

Micro grids are small-scale supply networks designed to supply electrical and heat loads for a small community, such as a housing estate or a suburban locality, or an academic or public community such as a university or school, a commercial area, an industrial site etc. Micro grid is essentially an active distribution network because it is the association of DG systems and different loads at distribution voltage level. The generators or microsources employed in a Microgrid are usually renewable/non-conventional integrated together to generate power at distribution voltage.

Differences between a Microgrid and a Conventional power plant

	Microgrid	Conventional power plant
1	Microsources are of much smaller capacity .	In conventional power plants the generators are large .
2	Power generated at distribution voltage.	Power is generated at generation voltage of 11kv.
3	Power generated is directly fed to the utility distribution network.	Power generated is fed to the utility transmission network.
4	Microsources are close to the customers' premises. So electrical/heat loads are supplied with satisfactory voltage and frequency profile and the line losses are negligible.	The sources are far away from load centres and the transmission losses are substantial.

What is smart grid

Definition by National Institute of Standards and Technology (NIST), USA:

A modernized grid that enables bidirectional flows of energy and uses two-way communication and control capabilities that will lead to an array of new functionalities and applications.

IEEE:

- Smart grid is a large 'System of Systems', where each functional domain consists of three layers: (i) the power and energy layer, (ii) the communication layer, and (iii) the IT/computer layer.
- Layers (ii) and (iii) above are the enabling infrastructure that makes the existing power and energy infrastructure 'smarter'.

Opportunities

Smart grid technology opens up opportunities in many areas

1) Upgrading and expanding infrastructure.

2) It leads to building smart tools and technologies to exploit DR, for demand load control and to provide better efficiency.

Challenges

Smart grid technology challenges as below

1) Strengthening Utility Grid: -The utility grid should have sufficient transmission capacity to accommodate more energy resources.
2) Developing decentralized architectures: -This is to enable harmonious operation of small scale electricity supply systems with the main system.
3) Communication: -Communication architecture which allows operation and trade of millions of parties in a single market has to be developed.

Sample Questions

1. What is Load curve. Explain the significance of Load curve.
2. Define the term Diversity factor and prove that the load factor of the supply is improved by an increase in the diversity factor.
3. Explain the significance of load factor and diversity factor.
4. A power station has a maximum demand of 15000kW.The annual load factor is 50% and capacity factor is 40%. Determine the reserve capacity of the plant.
5. Suppose a power station has to meet the following demands:

Group A : 200 kW between l0 AM and 8 PM
Group B : 100 kW between 6 AM and l0 AM
Group C : 50 kW between 7 AM and I I AM
Group D : 100 kW between 8 AM and 4 PM and then between 6 PM and 6 AM
Plot the daily load curve and hence determine the number of units generated per day.

6. With the help of a block diagram, explain the working of a wind energy conversion system. Discuss about any four disadvantages of wind power.
7. What are the limiting factors in tapping the wind and solar potential.
8. Explain the arrangement and operation of hydroelectric power plant.
9. With the help of a block diagram, explain the working of a thermal power plant.
10. A power station is to supply four regions of loads whose peak values are 10,000 kW, 5000 kW, 3000 kW and 7000 kW. The diversity factor of the load at the station is 1.5 and the average annual load factor is 60%. Calculate the maximum demand on the station and annual energy supplied from the station.
11. List the ethical and environmental factors associated with a nuclear power plant.
12. Explain utility scale battery energy storage system.
13. A diesel station supplies the following loads to various consumers:
    Industrial consumer = 1500 kW; Commercial establishment = 750 kW
    Domestic power = 100 kW; Domestic light = 450 kW.
    If the maximum demand on the station is 2500 kW and the number of kWh generated per year is 45×10^6 , determine (i) the diversity factor and (ii) annual load factor.
14. Differentiate between rooftop and ground mounted solar power plants.
15. A generating station has the following daily load cycle:

Time (Hours)	0—6	6—10	10—12	12—16	16—20	20—24
Load (MW)	40	50	60	50	70	40

Draw the load curve and find (i) maximum demand (ii) units generated per day (iii) average load and (iv) load factor.

16. Explain the functions of the following. (i) Super heater (ii) Economiser (iii) air pre heater.

14. With a neat schematic diagram explain the working of a nuclear power plant.

17. A generating station has a connected load of 23MW and a maximum demand of 20MW, the unit generated being 61.5×10^6 per annum, calculate (a) demand factor (b) average demand (c) load factor.
18. Explain the design steps of a ground mounted solar farm.
19. What is meant by smart grid and microgrid.