

#### NRI INSTITUTE OF TECHNOLOGY

## (Approved by AICTE - New Delhi, Affiliated to JNTUK, Kakinada)

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# DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING



## POWER SYSTEMS-I

# **Syllabus**

#### UNIT-I THERMAL POWER STATIONS

Selection of site, general layout of a thermal power plant showing paths of coal, steam, water, air, ash and flue gasses, ash handling system, Brief description of components: Boilers, Super heaters, Economizers, electrostatic precipitators steam Turbines: Impulse and reaction turbines, Condensers, feed water circuit, Cooling towers and Chimney.

#### **UNIT-II NUCLEAR POWER STATIONS**

Location of nuclear power plant, working principle, Nuclear fission, Nuclear fuels, Nuclear chain reaction, nuclear reactor Components, Moderators, Control rods, reflectors and coolants . Types of Nuclear reactors and brief description of PWR, BWR and FBR. Radiation:

Radiation hazards and Shielding, nuclear waste disposal.

## **UNIT-III SUBSTATIONS**

Classification of substations:

**Air Insulated Substations -** Indoor & Outdoor substations, Substations layouts of 33/11 kV showing the location of all the substation equipment. Bus bar arrangements in the Sub-Stations: Simple arrangements like single bus bar, sectionalized single bus bar, double bus bar with one and two circuit breakers, main and transfer bus bar system with relevant diagrams.

Gas Insulated Substations (GIS) – Advantages of Gas insulated substations, different types of gas insulated substations, single line diagram of gas insulated substations, constructional aspects of GIS, Installation and maintenance of GIS, Comparison of Air insulated substations and Gas insulated substations.

## **UNIT-IV UNDERGROUND CABLES**

Types of Cables, Construction, Types of insulating materials, Calculation of insulation resistance, stress in insulation and power factor of cable. Capacitance of single and 3-Core belted Cables: Grading of Cables-Capacitance grading and Inter sheath grading.

#### UNIT-V ECONOMIC ASPECTS OF POWER GENERATION & TARIFF

**Economic Aspects -** Load curve, load duration and integrated load duration curves, discussion on economic aspects: connected load, maximum demand, demand factor, load factor, diversity factor, power capacity factor and plant use factor, Base and peak load plants.

**Tariff Methods**- Costs of Generation and their division into Fixed, Semi-fixed and Running costs, Desirable Characteristics of a Tariff Method, Tariff Methods: Simple rate, Flat Rate, Block-Rate, two-part, three–part, and power factor tariff methods.

## **Text Books:**

- 1. A Text Book on Power System Engineering by M.L.Soni, P.V.Gupta, U.S.Bhatnagarand A. Chakrabarti, Dhanpat Rai & Co. Pvt. Ltd.
- 2. Generation, Distribution and Utilization of Electric Energy by C.L. Wadhawa New age International (P) Limited, Publishers.

## **Reference Books:**

- 1. Electrical Power Distribution Systems by V. Kamaraju, Tata McGraw Hill, New Delhi.
- 2. Elements of Electrical Power Station Design by M V Deshpande, PHI, New Delhi.

# **Learning Outcomes:**

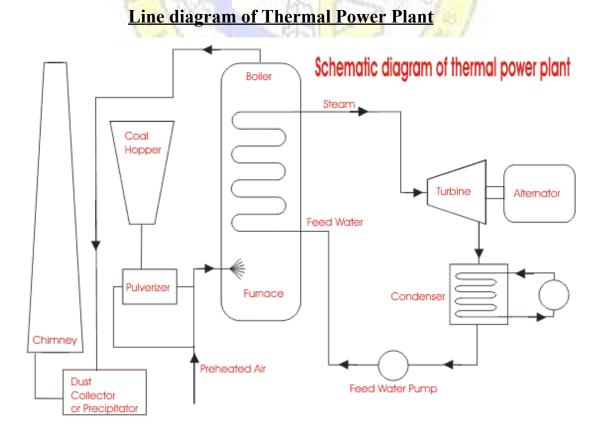
- Students are able to identify the different components of thermal power plants.
- Students are able to identify the different components of nuclear Power plants.
- Students are able to distinguish between AC/DC distribution systems and also estimate voltage drops of distribution systems.
- Students are able to identify the different components of air and gas insulated Substations.
- Students are able to identify single core and multi core cables with different insulating materials.
- Students are able to analyze the different economic factors of power generation and tariffs.

# <u>UNIT-1</u> 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,

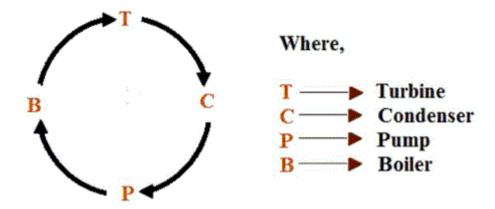
- 1) First the pulverized coal is burnt into the furnace of steam boiler.
- 2) High pressure steam is produced in the boiler.
- 3) This steam is then passed through the super heater, where it further heated up.

- 4) This supper heated steam is then entered into a turbine at high speed.
- 5) In turbine this steam force rotates the turbine blades that means here in the turbine the stored potential energy of the high pressured steam is converted into mechanical energy.
- 6) After rotating the turbine blades, the steam has lost its high pressure, passes out of turbine blades and enters into a condenser.
- 7) In the condenser the cold water is circulated with help of pump which condenses the low pressure wet steam.
- 8) 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.
- 9) The turbine in thermal power station acts as a prime mover of the alternator



# **Overview of Thermal Power Plant:**

A typical Thermal Power Station Operates on a Cycle which is shown below.



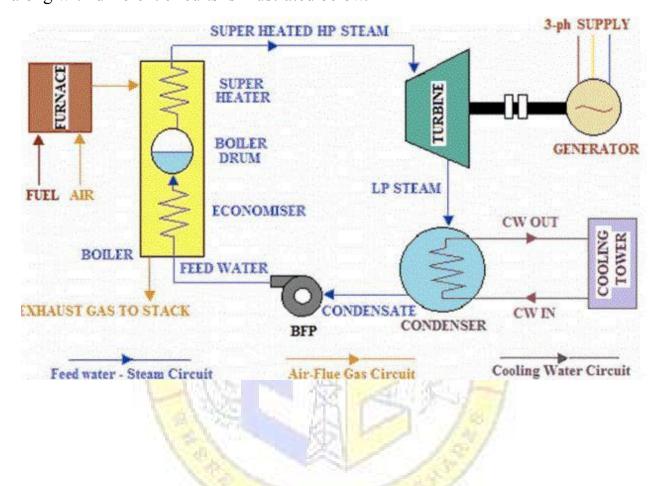
The working fluid is water and steam. This is called feed water and steam cycle. The ideal Thermodynamic Cycle to which the operation of a Thermal Power Station closely resembles is the RANKINE CYCLE.

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.



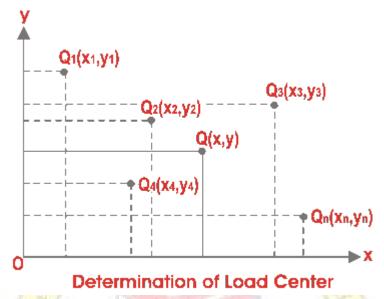
Inside the boiler there are various heat exchangers, viz.' **Economizer**', '**Evaporator**' (not shown in the fig above, it is basically the water tubes, i.e. down comer riser circuit), '**Super Heater**' (sometimes '**Reheater**', 'air preheater' are also present). In Economizer the feed water is heated 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.

## **Thermal Power Plant Location:**



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, thus the capital cost to the system is reduced. Let's explain the graphical method, say, X and Y be two reference axes.

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

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

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.

- 1) The **electric power generation plant** must be constructed at such a place where the cost of land is quite reasonable.
- 2) The land should be such that the acquisition of private property must be minimum.
- 3) 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.
- 4) Availability of huge amount of fuel at reasonable cost is one of the major criterion for choosing plant location.
- 5) The plant should be established on plane land.
- 6) The soil should be such that it should provide good and firm foundation of plant and buildings.
- 7) The **thermal power plant** location should not be very nearer to dense locality as there are smoke, noise steam, water vapors etc.
- 8) There must be ample scope of development of future demand.
- 9) Place for ash handling plant for thermal power station should also be available very nearby.
- 10) Very tall chimney of power station should not obstruct the traffics of air ships.

# **Advantages & Disadvantages of Thermal Power Station**

# **Advantages:**

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

# **Disadvantages:**

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

# UNIT-II NUCLEAR POWER STATIONS

## **Nuclear Power Plant**

□ A nuclear power plant is a thermal power station in which the heat source is one or more nuclear reactors. As in a conventional thermal power station the heat is used to generate steam which drives a steam turbine connected to a generator which produces electricity.

□ Nuclear power plants are usually considered to be base load stations, which are best suited to constant power output.

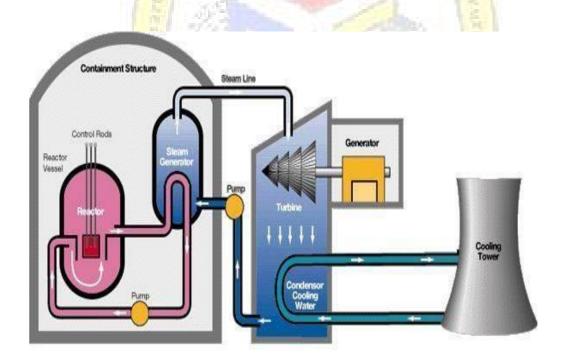


Figure 73: Schematic of a Nuclear Power Plant

## **Nuclear Power Reactors**

## **Magnox Reactors**

- ☐ Of 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.

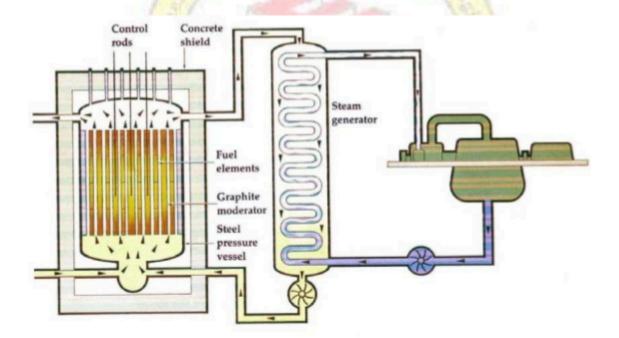


Figure 74: Magnox Reactor

#### **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.
- $\Box$  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 AGR

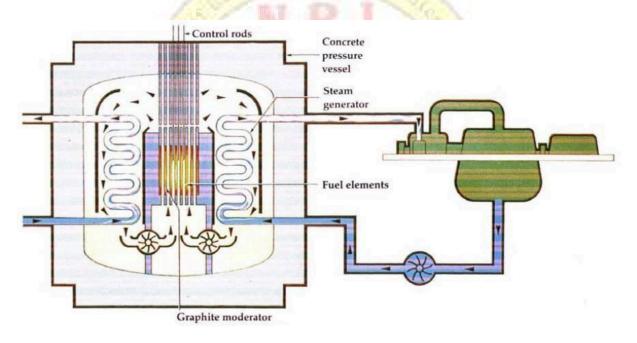


Figure 75: Advanced Gas Cooled Reactor

## **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.
- ☐ The high-pressure water is then passed through a steam generator, which raises steam in the usual way.

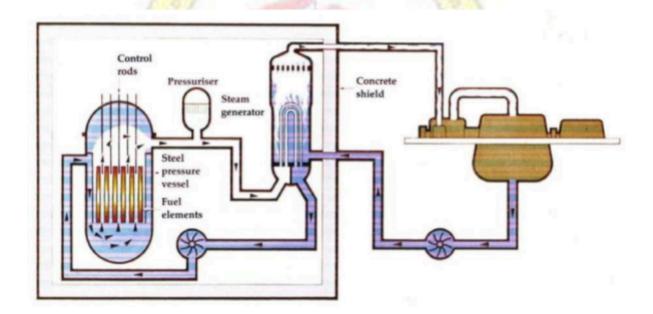


Figure 76: Pressurized Water Reactor

## **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.
- ☐ 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.

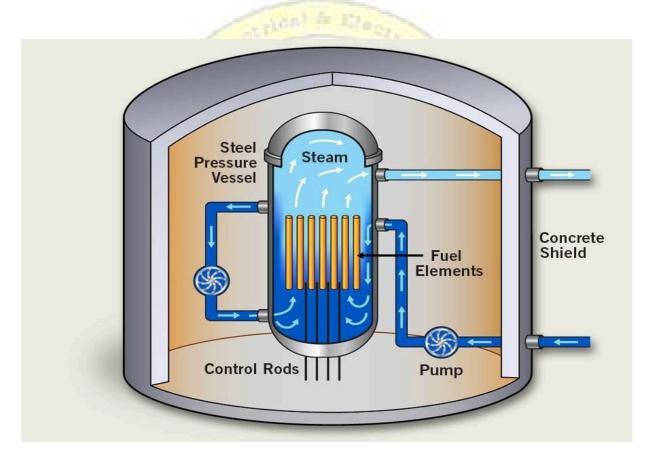


Figure 77: Boiling Water Reactor

# **Comparison of PWR and BWR**

Table 6: Comparison of PWR and BWR

PWR	BWR
Advantages	Advantages
<ul> <li>Relatively compact in size</li> <li>Possibility of breeding plutonium by providing a blanket of U-238</li> <li>High power density</li> <li>Containment of fission products due to heat exchanger</li> <li>Inexpensive 'light water' can be used as moderator, coolant and reflector</li> <li>Positive power demand coefficient i.e. the reactor responds to load increase</li> </ul>	<ul> <li>Elimination of heat exchanger circuit results in reduction in cost and gain in thermal efficiency (to about 30%)</li> <li>Pressure inside in the reactor vessel is considerably lower resulting in lighter and less costly design</li> <li>BWR cycle is more efficient than PWR as the outlet temperature of steam is much higher</li> <li>Metal surface temperature is lower since boiling of water is inside the reactor</li> <li>BWR is more stable than PWR and hence is commonly known as a self-controlled reactor</li> </ul>
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**

1 6	ist 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 $U^{235}$ fuel. Even with the
	enrichment levels used in the fuel for such reactors, however, by far the largest numbers of
	atoms present are $U^{238}$ , 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 $U^{235}$ . 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 utilise the existing stocks of depleted uranium, which would otherwise have no value.

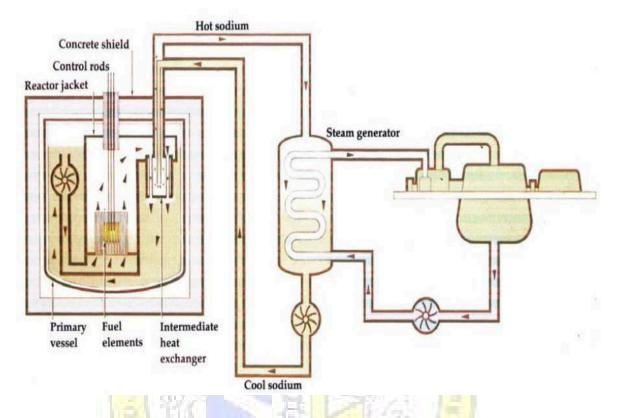


Figure 78: Fast Breeder Reactors

# **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
Tarap <mark>ur, Ma</mark> harashtra	BWR	160x2,	196 <mark>9, 20</mark> 05,
5 14		540x2	2006
Rawatb <mark>hata,</mark>	PHWR	110x1,	19 <mark>73, 19</mark> 81,
Rajastha <mark>n</mark>		200x1,	2000, 2010
100		220x4	37
Kalpakkam, Tamil	PHWR	220x2	1984, 1986
Nadu			
Narora, UP	PHWR	220x2	1991, 1992
Volumen	PHWR	220x2	1002 1005
Kakrapar, Gujarat	PHWK	220X2	1993, 1995
Kaiga,	PHWR	220x4	2000, 2007,
Karga, Karnataka	1 11 W IX	22084	
Turriuuru			2011
Kundankulam, Tamil	VVER- 1000	1000x1	2013
Nadu			

# **Nuclear Power in World**

Sl No	Country	Capacity (MW)	% Share in Electricity production
1	United States	102136	19 %
2	France	63130	75 %
3	Japan	44215	18 %
4	Russia	23643	18 %
5	South Korea	20739	30 %
6	Canada	14135	15 %

7	Ukraine	13107	46 %
8	China	12086	2 %
9	Germany	12068	16 %
10	UK	9938	18 %

## **Numerical Problems on Nuclear Power Plant**

1. Calculate the amount of coal containing the same energy as in 1 kg of Natural Uranium under the following assumptions. Also calculate the number of fissions per second to produce 1 watt power.

 $\Box$  Energy release from one fission of  $U^{235} = 200 \text{ MeV}$ 

 $\Box$  Atoms in one gram pure  $U^{235} = 25.64 \times 10^{20}$ 

 $\Box$  Calorific value of coal = 6000 kcal/kg

□  $U^{235}$  content in Natural Uranium = 0.7 %

□ Fission efficiency = 50 %

 $\Box$  One Joule = 0.239 cal

- 2. Find the power produced by fissioning 5 grams of U235 per day. Number of atoms in one gram of U235 =  $2.563 \times 1021$
- 3. Find the U235 fuel used in one year in a 235 MW pressurized water reactor. Assume overall plant efficiency of 33 % and 100% load factor throughout the year. Number of fissions required for 1 watt-sec= 3.1x1010. Number of atoms in one gram of U235 = 2.563 x 1021

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# **Types of Alternators**

**Table 7: Hydro and Turbo generators** 

Hydrogenerator	Turbogenerator
Low speed (50-500 RPM)	High speed (1500/3000 RPM)
Arrangement: Impulse: Horizontal; Reaction:	Always horizontal
Vertical	
Salient pole construction	Cylindrical construction
Damper windings provided	No damper windings needed
Direct axis and quadrature axis reactances	Synchronous reactances
Air cooled	Hydrogen cooled

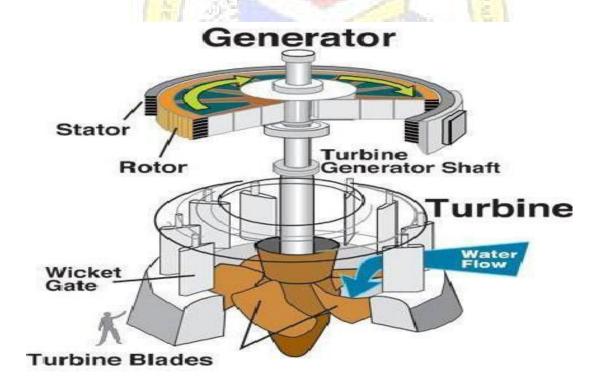




Figure 80: Hydrogenerator under construction





Figure 82: Turbogenerator



# **Generator Cooling Arrangements**

## Cooling is basically of two types:

- 1) Open circuit cooling
- 2) Closed circuit cooling

## **Open circuit cooling**

- Air is drawn into the generator by means of fans and is circulated inside.
- The air is later released into the atomosphere
- Suitable for small generators

# Closed circuit cooling

- Hydrogen is used as cooling medium
- Circulated by pumps and then drawn back into a chamber
- Used for large sized generators

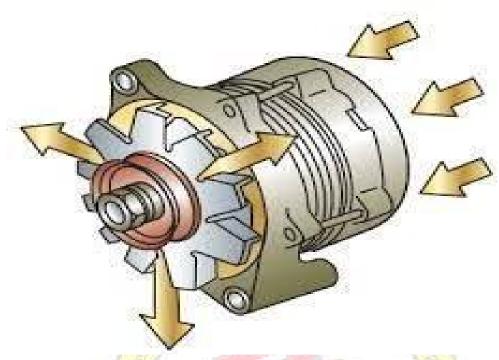
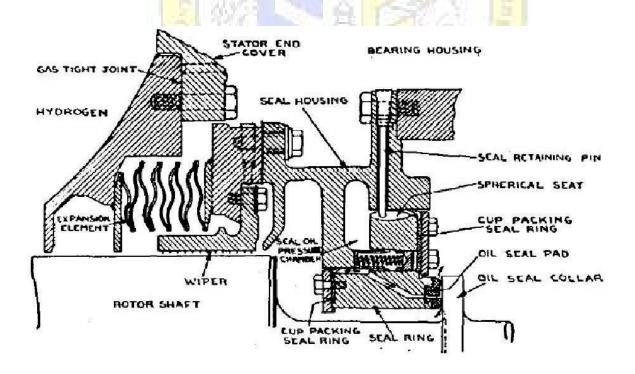


Figure 84: Air cooling of generators



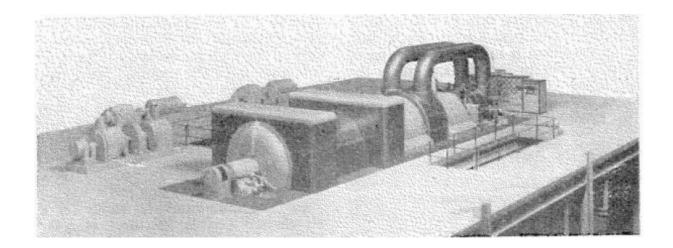


Figure 86: Hydrogen Cooled Alternator

# **Excitation Systems**

## **Function**

- The alternators are provided with shaft or gear mounted exciters for providing dc excitation to their field windings.
- For a large alternator the main exciter is a separately excited dc machine supplied by a pilot exciter.

## **Exciter Design**

- Excitation power required for large turbo-generators is of the order of 0.4-0.5% of the generator rating .
- Usually main exciter separately excited from a pilot exciter.
- The advantage of using pilot exciter is to improve voltage response to changes of the field current.

## Minimum Requirements for the Main Exciter

• Rated current must not be less than 110% of rotor current for rated generator output.

- Rated voltage must not be less than 110% of the slip ring voltage for rated generator output. The exciter voltage is generally 230V.
- in some cases nominal voltage of 440V is used.
- ceiling voltage must not be less than 120 percent of rated slip ring voltage.
- Nominal response must not be less than .5

## **Types of Excitation Systems**

- 1) DC Excitation using DC Generators
- 2) AC Excitation using AC Generators along with Rectifiers
- 3) Static Excitation (from alternator terminals)

# DC Excitation System

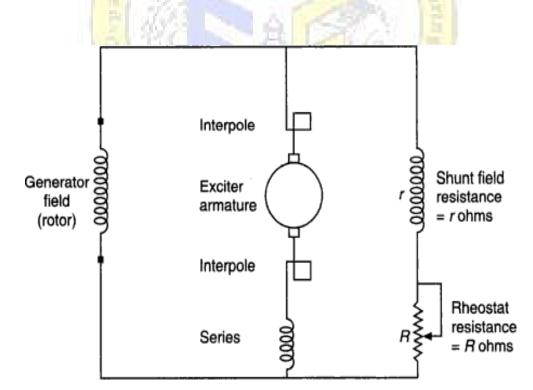


Figure 87: DC Excitation

- The pilot exciter is a d.c shunt machine. The main exciter is a d.c shunt machine with a number of control field windings.
- The main and pilot exciters are coupled to the main generator shaft.
- A d.cmotor drives an amplidyne or rotating amplifier which is cross field machine. It has a number of control windings.
- The voltage transformers secondaries supply AVR and magnetic amplifier circuits.

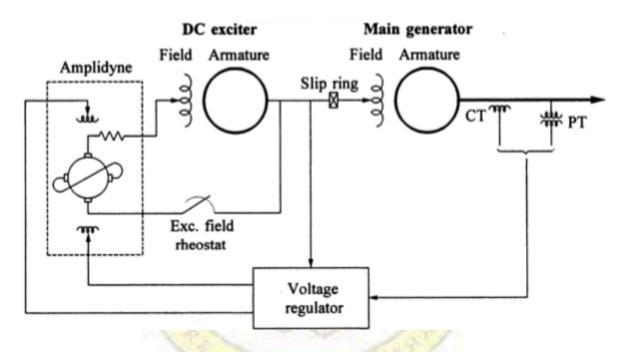


Figure 88: Excitation System with Amplidyne

## **AC Excitation System**

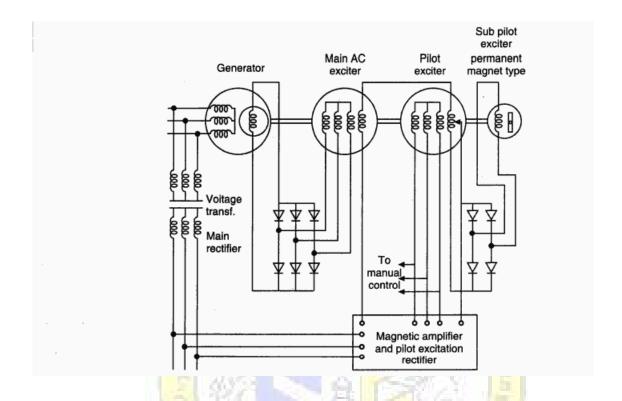


Figure 89: AC Excitation System

Table 8: AC versus brushless excitation

AC Excitation System	Brushless Excitation System
The rectifier is on the floor.	Rectifier is rotating
Cooling and maintenance problem of slip rings and brushes	No need of brushes and slip rings, however it is impossible to meter and read main generator filed quantities as it is rotating

## **Static Excitation Systems**

- The supply of power to the rectifier is from the main generator through the station auxiliary bus, using step down transformer.
- The rectifier output is fed directly to the field of the main generator by means of slip rings.

- There can be two arrangements:
  - o Power to the excitation using voltage only
  - o Using voltage as well as current from main generator

Field flashing: from battery bank, initial supply is given for starting up the alternator.

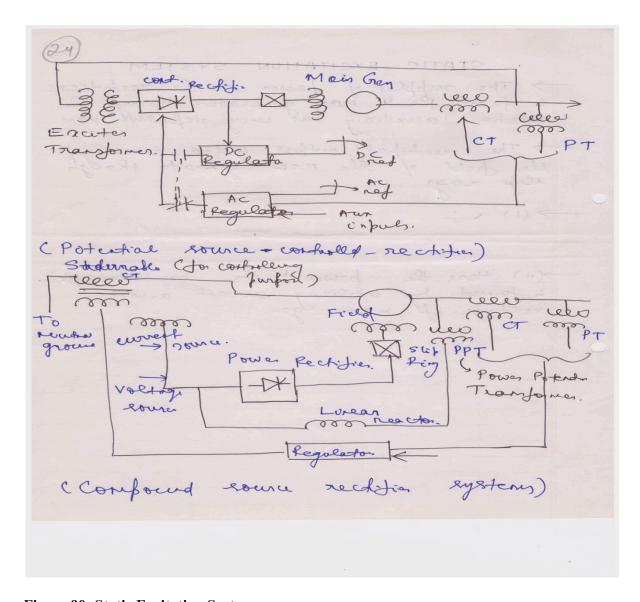


Figure 90: Static Excitation System

## **DISTRIBUTION SYSTEMS**

That part of power system which distributes electric power for local use is known as distribution system. In general, the distribution system is the electrical system between the sub-station fed by the transmission system and the consumer's meters. It generally consists of feeders, distributors and the service mains. Fig. 12.1 shows the single line diagram of a typical low tension distribution system. (i) Feeders: A feeder is a conductor which connects the sub-station (or localized generating station) to the area where power is to be distributed. Generally, no tapings are taken from the feeder so that current in it remains the same throughout. The main consideration in the design of a feeder is the current carrying capacity. (ii) Distributor: A distributor is a conductor from which tapings are taken for supply to the consumers. In Fig. 12.1, A B, BC, CD and DA are the distributors. The current through a distributor is not constant because tapings are taken at various places along its length. While designing a distributor, voltage drop along its length is the main consideration since the statutory limit of voltage variations is  $\pm$  6% of rated value at the consumers' terminals. (iii)Service mains. A service mains is generally a small cable which connects the distributor to the consumers' terminals.

- 12.2. Classification of Distribution Systems A distribution system may be classified according to; I) Nature of current. According to nature of current, distribution system may be classified as (a)d.c. distribution system (b) a.c. distribution system. Now-a-days, a.c. system is universally adopted for distribution of electric power as it is simpler and more economical than direct current method.
- (II) Type of construction. According to type of construction, distribution system may be classified as (a) overhead system (b) underground system. The overhead system is generally employed for distribution as it is 5 to 10 times cheaper than the equivalent underground system. In general, the underground system is used at

places where overhead construction is impracticable or prohibited by the local laws. (iii) Scheme of connection: According to scheme of connection, the distribution system may be classified as (a) radial system (b) ring main system (c) inter-connected system. Each scheme has its own advantages and disadvantages and those are discussed in Art.12.7. 12.3 A.C. Distribution: Now-a-days electrical energy is generated, transmitted and distributed in the form of alternating current. One important reason for the widespread use of alternating current in preference to direct current is the fact that alternating voltage can be conveniently changed in magnitude by means of a transformer. Transformer has made it possible to transmit

a.c. power at high voltage and utilize it at a safe potential. High transmission and distribution voltages have greatly reduced the current in the conductors and the resulting line losses. There is no definite line between transmission and distribution according to voltage or bulk capacity. However, in general, the a.c. distribution system is the electrical system between the step-down substation fed by the transmission system and the consumers' meters. The a.c. distribution system is classified into (i) primary distribution system and(ii) secondary distribution system. (i) Primary distribution system. It is that part of a.c. distribution system which operates at voltages somewhat higher than general utilization and handles large blocks of electrical energy than the average low-voltage consumer uses. The voltage used for primary distribution.

**Principles of Power System**: To depend upon the amount of power to be conveyed and the distance of the substation required to be fed. The most commonly used primary distribution voltages are 11 kV, 6·6kV and 3·3 kV. Due to economic considerations, primary distribution is carried out by 3-phase, 3-wire system. Fig. 12.2 shows a typical primary distribution system. Electric power from the generating station is transmitted at high voltage to the substation located in or near the city. At this substation, voltage is stepped down to 11 kV with the help of

step-down transformer. Power is supplied to various substations for distribution or to big consumers at this voltage. This forms the high voltage distribution or primary distribution. (ii) Secondary distribution system. It is that part of a.c. distribution system which includes the range of voltages at which the ultimate consumer utilizes the electrical energy delivered to him. The secondary distribution employs 400/230 V, 3-phase, 4-wire system. Fig. 12.3 shows a typical secondary distribution system. The primary distribution circuit delivers power to various substations, called distribution sub-stations. The substations are situated near the consumer's localities and contain step-down transformers. At each distribution substation, the voltage is stepped down to 400V and power is delivered by 3- phase,4-wire a.c. system. The voltage between any two phases is 400 V and between any phase and neutral is 230V. The single phase domestic loads are connected between any one phase and then neutral, whereas 3-phase 400 V motor Power transformer loads are connected across 3-phase lines directly.

**D.C. Distribution**: It is a common knowledge that electric power is almost exclusively generated, transmitted and distributed as a.c. However, for certain applications, D.C. supply is absolutely necessary. For instance, d.c. supply is required for the operation of variable speed machinery (i.e., d.c. motors), for electro-chemical work and for congested areas where storage battery reserves are necessary. For this purpose, a.c. power is converted into d.c. power at the substation by using converting machinery e.g., mercury arc rectifiers, rotary converters and motor-generator sets. The d.c. supply from the substation may be obtained in the form of (i) 2-wire or (ii) 3-wire for distribution. (i) 2-wire d.c. system: As the name implies, this system of distribution consists of two wires. One is the outgoing or positive wire and the other is the return or negative wire. The loads such as lamps, motors etc. are connected in parallel between the two wires as shown in Fig. 12.4. This system is never used for transmission purposes due to low

efficiency but may be employed for distribution of d.c. power. Principles of Power System: (ii)3-wire d.c. system:. It consists of two outers and a middle or neutral wire which is earthed at the substation. The voltage between the outers is twice the voltage between either outer or neutral wire as shown in Fig. 12.5. The principal advantage of this system is that it makes available two voltages at the consumer terminals viz., V between any outer and the neutral and 2V between the outers.

Loads requiring high voltage (e.g., motors) are connected across the outers, whereas lamps and heating circuits requiring less voltage are connected between either outer and the neutral. The methods of obtaining 3-wire system are discussed in the following article.

Methods of Obtaining 3-wire D.C. System: There are several methods of obtaining 3-wire d.c. system. However, the most important ones are: (i) Two generator method. In this method, two shunt wound d.c. generators G1 and G2 connected in series and the neutral is obtained from the common point between generators as shown in Fig. 12.6 (i). Each generator supplies the load on its own side. Thus generator G1 supplies a load current of I1, whereas generator G2 supplies a load current of I2. The difference of load currents on the two sides, known as out of balance current (I1– I2) flows through the neutral wire. The principal disadvantage of this method is that two separate generators are required.

(ii) 3-wire D.C. generator: The above method is costly on account of the necessity of two generators. For this reason, 3-wire D.C. generator was developed as shown in Fig. 12.6 (ii). It consists of a standard 2-wire machine with one or two coils of high reactance and low resistance, connected permanently to diametrically opposite points of the armature winding. The neutral wire is obtained from the common point as shown. (iii) Balancer set. The 3-wire system can be obtained from 2-wire D.C. system by the use of balancer set as shown in Fig. 12.7. G is the main 2-wire D.C. generator and supplies power to the whole system. The balancer

set consists of two identical d.c shunt machines A and B coupled mechanically with their armatures and field windings joined in series across the outers. The junction of their armatures is earthed and neutral wire is taken out from here. The balancer set has the additional advantage that it maintains the potential difference on two sides of neutral equal to each other. This method is discussed in detail in the next chapter. 12.6 Overhead Versus Underground System: The distribution system can be overhead or underground. Overhead lines are generally mounted on wooden, concrete or steel poles which are arranged to carry distribution transformers in addition to the conductors. The underground system uses conduits, cables and manholes under the surface of streets and sidewalks. The choice between overhead and underground system depends upon a number of widely differing factors. Therefore, it is desirable to make a comparison between the two. (i) Public safety: The underground system is safer than overhead system because all distribution wiring is placed underground and there are little chances of any hazard. (ii) Initial cost:. The underground system is more expensive due to the high cost of trenching, conduits, cables, manholes and other special equipment. The initial cost of an underground system may be five to ten times than that of an overhead system. (iii) Flexibility: The overhead system is much more flexible than the underground system. In the latter case, manholes, duct lines etc., are permanently placed once installed and the load expansion can only be met by laying new lines. However, on an overhead system, poles, wires, transformers etc., can be easily shifted to meet the changes in load conditions. (iv) Faults: The chances of faults in underground system are very rare as the cables are laid underground and are generally provided with better insulation. (v) Appearance: The general appearance of an underground system is better as all the distribution lines are invisible. This factor is exerting considerable public pressure on electric supply companies to switch over to underground system. (vi) Fault location and

repairs: In general, there are little chances of faults in an underground system. However, if a fault does occur, it is difficult to locate and repair on this system. On an overhead system, the conductors are visible and easily accessible so that fault locations and repairs can be easily made. (vii) Current carrying capacity and voltage drop: An overhead distribution conductor has a considerably higher current carrying capacity than an underground cable conductor of the same material and cross-section. On the other hand, underground cable conductor has much lower inductive reactance than that of an overhead conductor because of closer spacing of conductors. (viii) Useful life: The useful life of underground system is much longer than that of an overhead system. An overhead system may have a useful life of 25 years, whereas an underground system may have a useful life of more than 50 years. (ix) Maintenance cost: The maintenance cost of underground system is very low as compared with that of overhead system because of fewer chances of faults and service interruptions from wind, ice, and lightning as well as from traffic hazards. (x) Interference with communication circuits: An overhead system causes electromagnetic interference with the telephone lines. The power line currents are superimposed on speech currents, resulting in the potential of the communication channel being raised to an undesirable level. However, there is no such interference with the underground system. It is clear from the above comparison that each system has its own advantages and disadvantages. However, comparative economics (i.e., annual cost of operation) is the most powerful factor influencing the choice between underground and overhead system. The greater capital cost of underground system prohibits its use for distribution. But sometimes noneconomic factors (e.g., general appearance, public safety etc.) exert considerable influence on choosing underground system. In general, overhead system is adopted for distribution and the use of underground system is made only where overhead construction is impracticable or prohibited by local laws. 12.7 Connection

Schemes of Distribution System All distribution of electrical energy is done by constant voltage system. In practice, the following distribution circuits are generally used: i) Radial System: In this system, separate feeders radiate from a single substation and feed the distributors at one end only. Fig. 12.8 (i) shows a single line diagram of a radial system for d.c. distribution where a feeder OC supplies a distributor A B at point A. Obviously, the distributor is fed at one end only i.e., point A is this case. Fig. 12.8 (ii) shows a single line diagram of radial system for a.c. distribution. The radial system is employed only when power is generated at low voltage and the substation is located at the centre of the load. This is the simplest distribution circuit and has the lowest initial cost. However, it suffers from the following drawbacks: a) The end of the distributor nearest to the feeding point will be heavily loaded. b) The consumers are dependent on a single feeder and single distributor. Therefore, any fault on the feeder or distributor cuts off supply to the consumers who are on the side of the fault away from the substation. c) The consumers at the distant end of the distributor would be subjected to serious voltage fluctuations when the load on the distributor changes. Due to these limitations, this system is used for short distances only. ii) Ring main system. In this system, the primaries of distribution transformers form a loop. The loop circuit starts from the substation bus-bars, makes a loop through the area to be served, and returns to the substation. Fig. 12.9 shows the single line diagram of ring main system for a.c. distribution where substation supplies to the closed feeder LMNOPQRS. The distributors are tapped from different points M, O and Q of the feeder through distribution transformers. The ring main system has the following advantages: a) There are less voltage fluctuations at consumer's terminals. b) The system is very reliable as each distributor is fed via \*two feeders. In the event of fault on any section of the feeder, the continuity of supply is maintained. For example, suppose that fault occurs at any point F of section SLM of the feeder.

Then section SLM of the feeder can be isolated for repairs and at the same time continuity of supply is maintained to all the consumers via the feeder SROPONM.

- iii) Interconnected system: When the feeder ring is energized by two or more than two generating stations or substations, it is called inter-connected system. Fig. 12.10 shows the single line diagram of interconnected system where the closed feeder ring ABCD is supplied by two substations S and S at points D and C respectively. Distributors are connected to points O, P, Q and R of the feeder ring through distribution transformers. The interconnected system has the following advantages: a) It increases the service reliability. b) Any area fed from one generating station during peak load hours can be fed from the other generating station. This reduces reserve power capacity and increases efficiency of the system.
- 12.8 Requirements of a Distribution System A considerable amount of effort is necessary to maintain an electric power supply within the requirements of various types of consumers. Some of the requirements of a good distribution system are: proper voltage, availability of power on demand and reliability. i) Proper voltage. One important requirement of a distribution system is that voltage variations at consumer's terminals should be as low as possible. The changes in voltage are generally caused due to the variation of load on the system. Low voltage causes loss of revenue, inefficient lighting and possible burning out of motors. High voltage causes lamps to burn out permanently and may cause failure of other appliances. Therefore, a good distribution system should ensure that the voltage variations at consumer's terminals are within permissible limits. The statutory limit of voltage variations is  $\pm$  6% of the rated value at the consumer's terminals. Thus, if the declared voltage is 230 V, then the highest voltage of the consumer should not exceed 244 V while the lowest voltage of the consumer should not be less than 216 V. ii) Availability of power on demand. Power must be available to the consumers in any amount that they may require from time to time. For example,

motors may be started or shut down, lights may be turned on or off, without advance warning to the electric supply company. As electrical energy cannot be stored, therefore, the distribution system must be capable of supplying load demands of the consumers. This necessitates that operating staff must continuously study load patterns to predict in advance those major load changes that follow the known schedules. iii) Reliability. Modern industry is almost dependent on electric power for its operation. Homes and office buildings are lighted, heated, cooled and ventilated by electric power. This calls for reliable service. Unfortunately, electric power, like everything else that is man-made, can never be absolutely reliable.

However, the reliability can be improved to a considerable extent by (a) interconnected system (b) reliable automatic control system (c) providing additional reserve facilities. 12.9Design Considerations in Distribution System Good voltage regulation of a distribution network is probably the most important factor responsible for delivering good service to the consumers. For this purpose, design of feeders and distributors requires careful consideration. i) Feeders. A feeder is designed from the point of view of its current carrying capacity while the voltage drop consideration is relatively unimportant. It is because voltage drop in a feeder can be compensated by means of voltage regulating equipment at the substation. ii) Distributors. A distributor is designed from the point of view of the voltage drop in it. It is because a distributor supplies power to the consumers and there is a statutory limit of voltage variations at the consumer's terminals (± 6% of rated value). The size and length of the distributor should be such that voltage at the consumer's terminals is within the permissible limits.

#### **UNIT-III**

#### **SUB**

### **STATIONS**

An Electrical Power Substation receives electric power from generating station via transmission lines and delivers power via the outgoing transmission lines. Substations are integral parts of a power system and form important links between the generating stations, transmission systems, distribution systems and the load points. Various power substations located in generating stations, transmission and distribution systems have similar layout and similar electrical components.

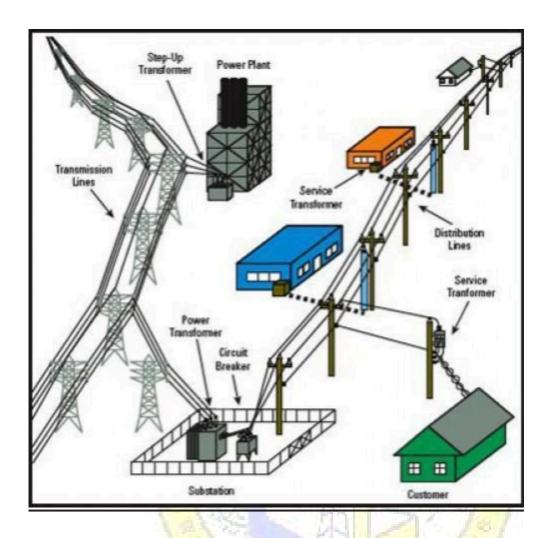
Electrical power substation basically consists of number of incoming circuit connections and number of outgoing circuit connections connected to the bus bars. Bus bars are conducting bars to which number of circuit connections is connected. Each circuit has certain number of electrical components such as circuit breakers, Isolators, earth switches, current transformers, voltage transformers, etc. In a Power Substation there are various indoor and outdoor switchgear and equipment. Transformers are necessary in a substation for stepping up and stepping down of

a.c voltage. Besides the transformers, the several other equipment include bus bars, circuit breakers, isolators, surge arresters, Substation Earthing System, Shunt reactors, Shunt Capacitors etc. Each equipment has certain functional requirement. The equipment is either indoor or outdoor depending upon the voltage rating and local conditions.

In a large power System large number of Generating stations, Electrical Power Substations and load centers are interconnected. This large internetwork is controlled from load dispatch center. Digital and voice signals are transmitted over the transmission lines via the Power substations. The substations are interlinked with the load control centers via Power Line Carrier Systems (PLCC). Modern

Power System is controlled with the help of several automatic, semi - automatic equipment. Digital Computers and microprocessors are installed in the control rooms of large substations, generating stations and load control centers for data collection, data monitoring, automatic protection and control. Functions of Electrical Power Substations are: Supply electric power to the consumers continuously• Supply of electric power within specified voltage limits and frequency• limits shortest possible fault duration.• Optimum efficiency of plants

and the network Supply of electrical energy to the consumers at lowest cost Types Of Electrical Power Substations: Based ON Nature Of Duties: Step up or primary Electrical Power substation: Primary substations are associated with the power generating plants where the voltage is stepped up from low voltage (3.3, 6.6, 11, 33kV) to 220kV or 400kV for transmitting the power so that huge amount of power can be transmitted over a large distance to load centers. Primary Grid Electrical Power Substation: Such substations are located at suitable load centers along with the primary transmission lines. At primary Grid Power Substations the primary transmission voltage (220kV or 400kV) is stepped down to secondary transmission voltages (110kV). This Secondary transmission lines are carried over to Secondary Power Substations situated at the load centers where the voltage is further stepped down to Sub transmission Voltage or Primary Distribution Voltages (11kV or 33kV). Step Down or Distribution Electrical Power Substations: Such Power Substations are located at the load centers. Here the Sub transmission Voltages of Distribution Voltages (11kV or 33kV) are stepped down to Secondary Distribution Voltages (400kV or 230kV). From these Substations power will be fed to the consumers to their terminals.



# **Basis Of Service Rendered:**

### **Transformer Substation:**

Transformers are installed on such Substations to transform the power from one voltage level to other voltage level.

# **Switching Substation:**

Switching substations are meant for switching operation of power lines without transforming the voltages. At these Substations different connections are made between various transmission lines. Different Switching Schemes are employed depends on the application to transmit the power in more reliable manner in a network.

### **Converting Substation:**

Such Substations are located where AC to DC conversion is required. In HVDC transmission Converting Substations are employed on both sides of HVDC link for converting AC to DC and again converting back from DC to AC. Converting Power Substations are also employed where frequency is to be converted from higher to lower and lower to higher. This type of frequency conversion is required in connecting to Grid Systems.

### **Based on Operation Voltage:**

### **High Voltage Electrical Power Substation:**

This type of Substation associated with operating voltages between 11kV and 66kV.

### Extra High Voltage Electrical Power Substation:

This type of Substation is associated where the operating voltage is between 132kV and 400kV.

# Ultra High Voltage Electrical Power Substation:

Substations where Operating Voltages are above 400kV is called Ultra High Voltage Substation

# **Based On Substation Design:**

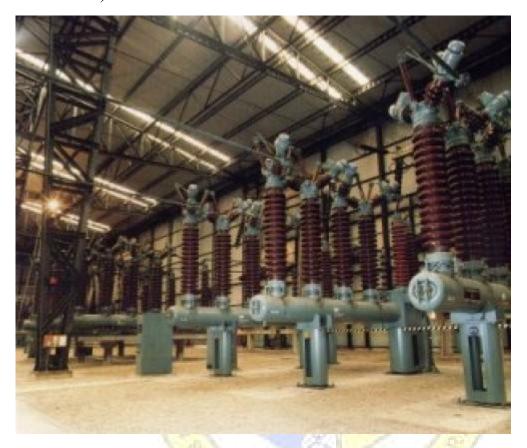
#### **Outdoor Electrical Power Substations:**

In Outdoor Power Substations, the various electrical equipments are installed in the switchyard below the sky. Electrical equipment are mounted on support structures to obtain sufficient ground clearance.

#### **Indoor Electrical Power Substation:**

In Indoor Power Substations the apparatus is installed within the substation building. Such substations are usually for the rating of 66kV. Indoor

Substations are preferred in heavily polluted areas and Power Substations situated near the seas (saline atmosphere causes Insulator Failures results in Flashovers)



**Indoor Substation** 

# **Based on Design Configuration:**

### **Air Insulated Electrical Power Substation:**

In Air Insulated Power Substations busbars and connectors are visibe. In this Power Substations Circuit Breakers and Isolators, Transformers, Current Transformers, Potential Transformers etc are installed in the outdoor. Busbars are supported on the post Insulators or Strain Insulators. Substations have galvanized Steel Structures for Supporting the equipment, insulators and

incoming and outgoing lines. Clearances are the primary criteria for these substations and occupy a large area for installation.

#### **Gas Insulated Electrical Power Substation:**

In Gas Insulated Substation Various Power Substation equipments like Circuit Breakers, Current Transformers, Voltage Transformers, Busbars, Earth Switches, Surge Arresters, Isolators etc are in the form of metal enclosed SF6 gas modules. The modules are assembled in accordance with the required Configuration. The various Live parts are enclosed in the metal enclosures (modules) containing SF6 gas at high pressure. Thus the size of Power Substation reduces to 8% to 10% of the Air Insulated Power Substation.

### **Hybrid Electrical Power Substation:**

Hybrid Substations are the combination of both Conventional Substation and Gas Insulated Substation. Some bays in a Power Substation are Gas Insulated Type and some are Air Insulated Type. The design is based on convenience, Local Conditions available, area available and Cost

WANTED CO



Gas Insulated Substation

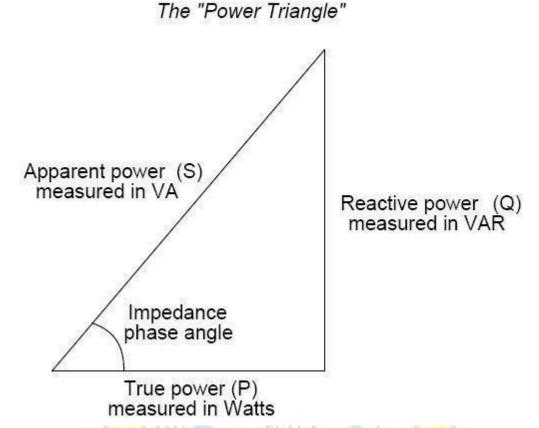
### **Power Factor Defined:**

In power systems, wasted energy capacity, also known as poor power factor, is often overlooked. It can result in poor reliability, safety problems and higher energy costs. The lower your power factor, the less economically your system operates.

Power factor is the ratio between the real power and the apparent power drawn by an electrical load. Like all ratio measurements it is a unit-less quantity and can be represented

power that actually does the work, KVA is the apparent power and KVAR (not included in the equation) is the reactive power. In an inductive load, such as a motor, active power performs the work and reactive power creates the electromagnetic field. The three types of power relate to each other in a

trigonometric form as seen in Figure 5 below.



### The Power Triangle

For the purely resistive circuit, the power factor is 1 (perfect), because the reactive power equals zero. Here, the power triangle would look like a horizontal line, because the opposite (reactive power) side would have zero length.

For the purely inductive circuit, the power factor is zero, because true power equals zero. Here, the power triangle would look like a vertical line, because the adjacent (true power) side would have zero length. The same could be said for a purely capacitive circuit. If there are no dissipative (resistive) components in the circuit, then the true power must be equal to zero, making any power in the circuit purely reactive. The power

triangle for a purely capacitive circuit would again be a vertical line (pointing down instead of up as it was for the purely inductive circuit). -5-

Power factor can be an important aspect to consider in an AC circuit; because any power factor less than 1 means that the circuit's wiring has to carry more current than what would be necessary with zero reactance in the circuit to deliver the same amount of (true) power to the resistive load. The poor power factor makes for an inefficient power delivery system. Poor power factor can be corrected, paradoxically, by adding another load to the circuit drawing an equal and opposite amount of reactive power, to cancel out the effects of the load's inductive reactance. Inductive reactance can only be canceled by capacitive reactance, so we have to add a capacitor in parallel to our example circuit as the additional load. The effect of these two opposing reactance's in parallel is to bring the circuit's total impedance equal to its total resistance (to make the impedance phase angle equal, or at least closer, to zero). (3\_

Power factor measures how efficiently the current is being converted into real work— with a low power factor, more electrical current is required to provide the same amount of real power. All current causes dissipation in a distribution system. These losse<sub>2</sub> R is the resistance. A power factor of 1 will result in the most efficient loading of the supply; a load with a power factor of 0.5 will result in higher losses in the distribution system. [3] The reactive load of an industrial power system typically consists of a large number of AC induction motors. This can cause the total load to be up to 50% inductive. Large inductive loads cause the apparent power to be 25% to

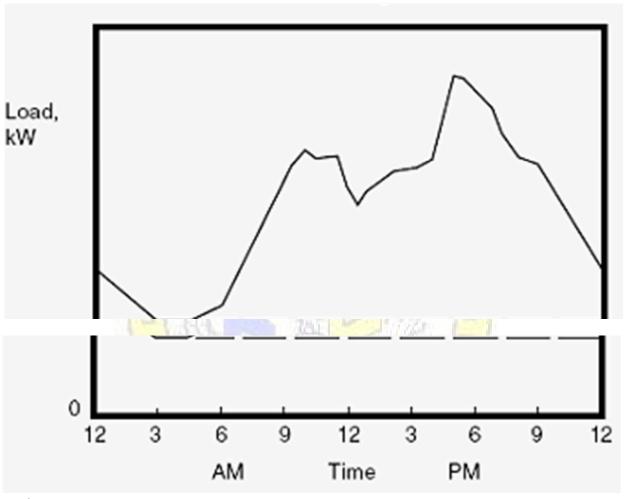
41% higher than the real power. If the utility billing is based on real power (KW) only, the utility must provide up to 41% more capacity than they are billing for. Since it takes more capacity and is more expensive to serve a customer with a low power factor, that customer has to pick up the tab. Most electrical rate. Tariffs contain provisions that include a minimum power factor. Customers who fall short of the minimum power factor level receive a power factor charge. Power factor charges may range from \$5 to thousands of dollars per month. [2]

Overall there are several consequences of a low power factor; these consequences include decreased system capacity, increased system losses, and extra cost. Benefits of increasing a low power factor include eliminated or reduced power factor charges on utility bills, more efficient operations with increased capacity and reduced current draw.

### **UNIT-V**

### **ECONOMIC ASPECTS OF POWER GENERATION AND TARIFF**

Load Curves The curve showing the variation of load on the power station (power plant) with reference to time is known as load curve.



Daily load curve

# Maximum Load (Peak Load)

It represents the maximum power that consumed by the load during a specific given time. It is also equal to the maximum actual power generated by the plant when the transmission losses are neglected.

# **Average Load**

It is the average power that consumed by the load during a certain period of time and it is equal to the average power that generated by the plant during the same period of time when neglecting transmission line losses.

Average Load =[Area under the load curve (kWh)/ no. of hours (h)] (kW)

#### **Load Factor**

It is the ratio of the average load to the maximum load for a certain period of time. The load factor is called *daily load factor* if the period of time is a day, and if the period of time is a month, the load factor is called *monthly load factor*, and similarly for the *year load factor*.

Load Factor = Average Load/Max. Load

### **Installed Capacity** (Plant Capacity, nameplate capacity)

It represents the maximum possible power that could be produced (generated) from the power plant. The value of the installed capacity depends on the plant design. Installed Capacity = Nominal power value of the plant (kW or MW)

# **Reserve Capacity**

Reserve Capacity = Installed Capacity - Max. Demand (kW or MW)

# **Plant Capacity Factor**

The capacity factor of a power plant is the ratio of its average output power over a period of time, to its maximum possible power that could be produced. It can be determined as below:

Plant Capacity Factor = Average Demand (kW)/Installed Capacity (kW)

#### **Utilization Factor**

Utilization Factor = Max. Demand (kW)/Installed Capacity (kW)

### **Plant Use Factor**

Plant Use Factor = Actual energy produced  $(kWh)/(Installed Capacity (kW) \times no. of operation hours(h))$ 

Or

Where

T = 24 h if the time is a day

 $T = 24 \times 30 \text{ h}$  if the time is a Month

### **Diversity Factor**

Diversity Factor =Sum of Individual Max. Demand (kW)/Max. Demand on power Plant (kW)

#### **Load Duration Curve**

In this curve, the load elements of a load curve are arranged in order of descending magnitudes. So, the area under the load duration curve and the area under the load curve are equal. The following figure shows an example of the load curve and the load duration curve.

### **Tariff:**

A tariff is the rate of charge per kilowatt hour of energy supplied to a consumer. The cost of generation of electrical energy may be conveniently split into two parts e.g. fixed charges plus the operating charges. So a tariff should be adjusted in such a way that the total receipts balance the total expenditure involved in generating the energy. There are several solutions to this problem, some of which are given below:

#### 1. Uniform Rate Tariff:

In this case there is a fixed rate per unit amount of energy consumed. The consumption of energy is measured by the energy meter installed at the premises of the consumer. This type of tariff accounts for all the costs involved in the generation of power. This is the simplest tariff easily understood by consumers. However, this type of tariff does not distinguish between small power domestic consumer and bulk power industrial consumers.

#### 2. Two Part Tariff:

In this the total charges are split into two parts - fixed charges based on maximum demand (in kW) plus the charges based on energy consumption (in kWh). This method suffers from the drawback that an additional provision is to be incorporated for the measurement of maximum demand. Under such tariff, the consumers having 'peaked' demand for short duration are discouraged.

#### 3. Block Rate Tariff:

In this the fixed charges are merged into the unit charges for one or two blocks of consumption, all units in excess being charged at low or high unit rate. Lower rates for higher blocks are fixed in order to encourage the consumers for more and more consumptions. This is done in case the plant has got larger spare capacity. Wherever the plant capacity is inadequate, higher blocks are charged at higher rate in order to discourage the consumers for higher than minimum consumption.

### 4. Three Part Tariff:

It is an extension of the two part tariff in that it adds to the consumer some fixed charges irrespective of the energy consumption or maximum demand. In this ever if the consumer has got zero power consumption, he has to pay some charges merely because a connection has been provided to him.

#### 5. Power Factor Tariff:

In ac power supply size of the plant is determined by the kVA rating. In case the power factor of a consumer installation is low, the energy consumption in terms of kW will be low. In order to discharge such consumers, power factor tariff is introduced, which may be of the following types. (a) Maximum kVA demand Tariff:

In this instead of kW. The kVA consumption is measured and the charge are Based partly or fully on this demand.

# (b) Sliding Scale tariff:

In this case the average power factor is fixed say at 0.8 lagging. Now if the power factor of a consumer falls below by 0.01 or multiples thereof, some additional charges are imposed. A discount may be allowed in case the power factor is above 0.8.

The depreciation on the plant is charged by any of the following methods

- 1. Straight Line method
- 2. Sinking fund method
- 3. Diminishing value method.