① Energy sources (Renewable & non renewable) 11 Hours

1.1) Hydropower plants :

A) selection of turbines for Hydropower plants : 16/F (points only)

I) Head at the turbine :

- Reaction turbines of various types are used for heads upto 500 m, the Francis type for heads of 70 m to 500 m and the propeller type for heads less than 70 m. For fairly constant load, fixed vane propeller turbine are used. For heads lower than 30 m & for variable load operation, Kaplan or movable-vane turbine are used.

- For heads above 500m upto about 1700 m, Pelton wheels with a single or multijet arrangements are used.

- The design head of a turbine is the head for which the runner is designed to run at the best speed and to operate at the highest efficiency. Where the load on the turbine varies considerably from the nominal head, the lower head should be used; & where there is a small difference between the maximum and minimum heads not exceeding 10% above or below the nominal head, the higher head should be used.

- The maximum head under which the Francis turbine operates should not exceed 125% of the design head, & the minimum head should not be less than 65% of the design heads in order to facilitate stable operation and avoid excessive cavitation. The maximum head under which a fixed blade propeller head should not exceed 110% of the design head, and the minimum head should not be less than 90% of the design head. For the adjustable blade or Kaplan turbine the range of operation is from

50% to 150% of the design head. Generally, the design head is selected as the head, above and below which the average annual generations of power are approximately equal. This is thus, the point of best efficiency, at the weighted average head. The rated heat is that at which the full gate output of the turbine will produce the rated capacity of the generator in kilowatts.

- For run off river plants having approximately constant heads, the design and rated heads are usually the same.

II) Efficiency of turbines at various loads :

- The nature of the efficiency curves for the various types of turbine are shown in figure. Francis turbine are suitable for operation of plant from 75% load to full load. Propeller turbines with fixed blade constructions are used at fairly constant load between 75% and 100% of their capacity and if the variations of head is very small, the units can be operated at a point near their best efficiency.

- The Kaplan turbine efficiency curve shows that it is useful for frequent part load operation. It is possible to obtain considerably better efficiency at part gate openings with adjustable blade turbines than with fixed blade turbines. An adjustable blade unit is smaller than a fixed blade unit of the same rating, and it will operate at a higher speed. An adjustable blade unit require a smaller power house than a fixed blade unit.

- The efficiency curves shown are representative of particular types. The actual values will depend on the head, the size of turbine and its speed. The maximum efficiencies of Francis, fixed blade propeller and kaplan turbines are approximately 92% to 93%.

- The adjustable blade kaplan turbine is used efficiently at loads from 40% to 80% or higher, the efficiency curve within this range being practically flat.

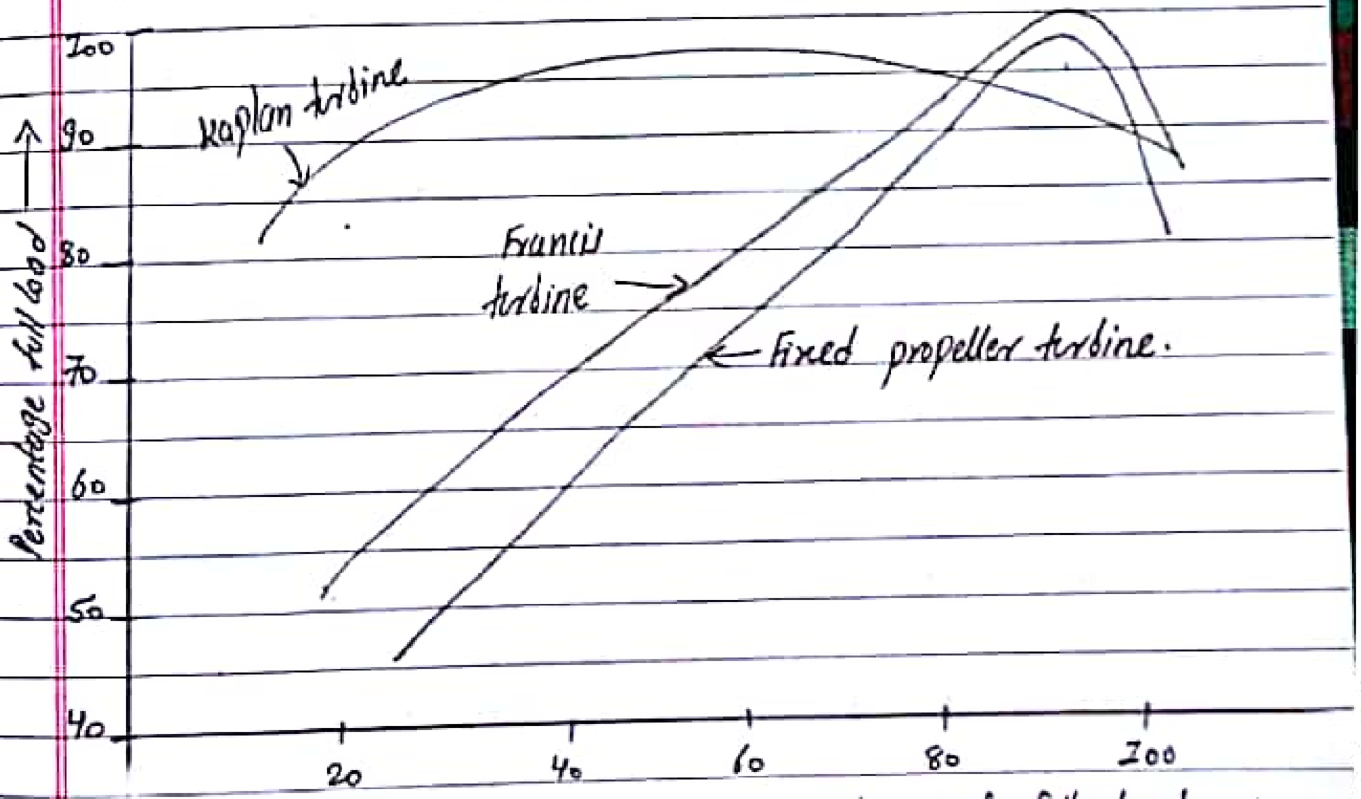

Fig: Reaction turbine. percentage of full load →

- The efficiency curve of a pelton wheel remain slightly lower than that of a Francis turbine, but will be less affected by variations of loads. Pelton wheels are used for high head plants.

- Fig below shows a typical curve of a pelton wheel unit. The efficiency curve doesnot vary much from 40% to 100% load, and so the unit can work well within this range. The efficiency of pelton wheel unit is about 87% to 88%.

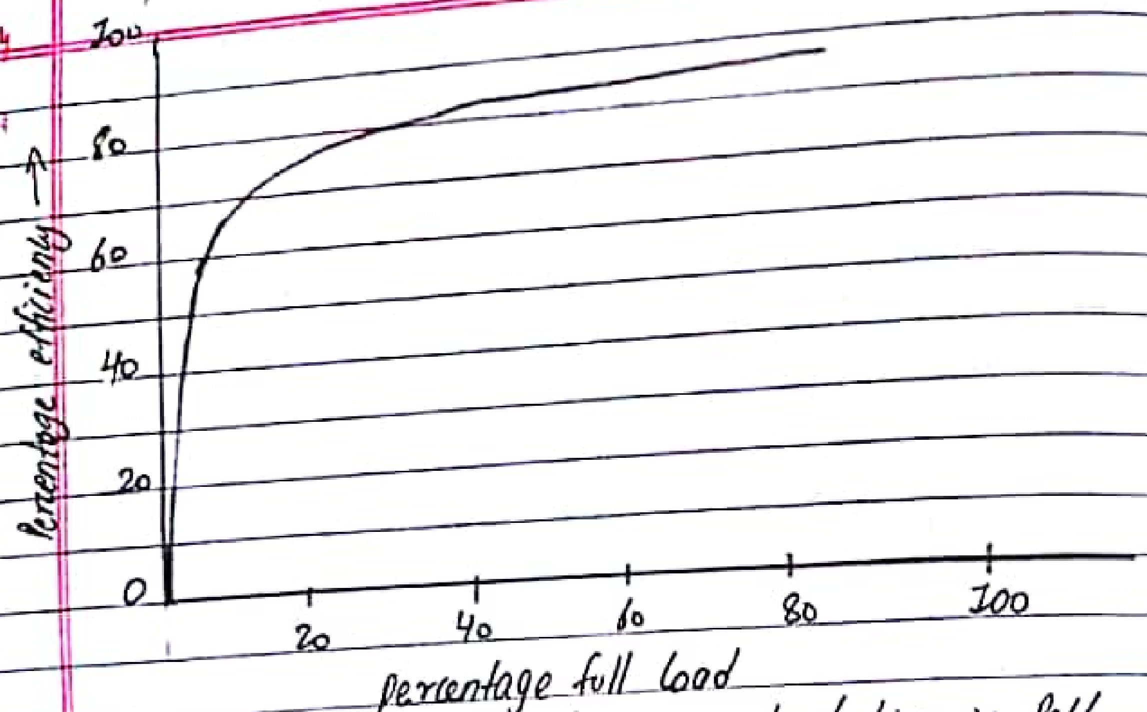

Fig: efficiency/load curve of an impulse turbine i.e Pelton

III) specific speed of Turbine :

— The basis for comparision of the characteristics of hydraulic turbine is the specific speed ns or the speed at which a turbine would run if the runner were reduced to a size which would develop 1 metric horsepower under 1 m head. This speed is proportional to the square root of the horse power and inversely proportional to the 5/4 power of the head i.e,

$$\therefore \quad n_s = \frac{n \cdot P^{1/2}}{h^{5/4}} \text{ rpm}$$

where,
ns = specific rotational speed.
n = actual rotational "
P = metric horse power.
h = head, m
hence,

$$\therefore \quad n = \frac{n_s \cdot h^{5/4}}{P^{1/2}}$$

- In general, the higher the specific speed for a given head and horse power output, the lower is the cost of the installation as a whole. There are certain limitations of n_s of a runner for a given head and horse power. Too high a specific would reduce the dimensions of the turbine to such a size that the discharge velocity of the water into the throat of the draft tube would be relatively high. This is undesirable because the energy of the discharging water can be only partially regained in the draft tube, In the extreme case a vacuum may be created.

- Too high a specific speed with a high head would increase the cost of the turbine disproportionately, on account of the high mechanical strength required. Too low a specific speed with a low head would increase the cost of the generator installation owing to the low turbine speed.

- An increase in specific speed is usually accompanied by a lower maximum efficiency and a greater depth of excavation for the draft tube.

- For an impulse wheel, the specific speed may be found for a single jet turbine. If a greater output is required, a multi jet turbine may be used. For a multi jet turbine,

$$n_{sn} = n_s \times \sqrt{\text{no. of jets}}$$

- For high head plants, where impulse and pelton wheels would be used, the specific speed is low. For reaction turbines the specific speed is higher, depending on the head, and is higher in the order

: Francis, fixed blade and kaplan:

• Francis turbine :

$$n_s (metric) = \frac{6850}{h + 9.8} + 84 \text{ rpm}$$

h = head in m

Fixed blade propeller turbines :

$$n_s (metric) = \frac{9500}{h + 9.8} + 84 \text{ rpm}$$

adjustable blade or kaplan turbine,
Add 10 % to the specific speed of the corresponding fixed blade turbine.

• Impulse Turbine :

$$n_s (metric) = \frac{422\, h^{3/4}}{P^{1/2}} \text{ rpm}$$

P = metric horsepower.

– The speed of a turbine has to match the generator speed which to give the correct frequency is fixed by the number of pairs of poles.

IV) Turbine setting :

– Reaction turbines have to be set correctly with reference to the tailrace water level so as to avoid cavitation in the draft tube portion. Thus, a francis turbine runner should be placed at a level very near or below the lowest tailrace level. Francis turbine adjust themselves better to varying water levels in the storage reservoir & hence use the storage to better advantage and with improved mean efficiency.

- Fixed blade propeller turbines have higher specific speeds than Francis turbines and are therefore, set at lower level. Adjustable blade turbines have still higher specific speeds. and so for the same head, the adjustable blade runner would be set considerably lower than the fixed blade runner.

- A pelton wheel is always set at a higher level than the highest tailrace level. This results in loss of head compared to the Francis turbine, which makes use of total available head on account of the draft tube. A pelton wheel is set atleast 2 m above the highest tailrace water level.

v) speed and pressure regulation :

- When the load on the generator coupled to the turbine changes suddenly, the governor comes into action to regulate the inflow of water into the turbine, but this take some time and depends on the speed at which the governor acts. With a sudden closing of the gates there is a pressure rise in the penstock. Part of it is sometimes counter balanced by a suitable choice of surge tank installed at the end of the penstock line near the power station.

- Pressure release openings or valves are sometimes provided on the pipelines at suitable places. It is necessary to study the problem of speed regulation and pressure rise with a given length of penstock. The ability to predetermine the speed changes in a turbine in terms of maximum change in speed or variations in speed with respect to time permits of the complete study of regulation problems in advance of the actual constructions of a Hydro electric project.

- The normal maximum pressure rise permissible with Francis turbines is the order of 30% ; with pelton wheels it is between 10% and 20%. The governor time is usually 2 to 3 seconds, but in modern machines with automatic operation this has now been reduced considerably. with the pressure regulator, the permissible range of pressure rise changes and is improved.

- In additions, turbines are selected to operate at a load factor of not less than 50% of the rated capacity for multi purpose jets and not less than 60% for run off river developments.

B) Technical specification of generators to be used in hydro power plants : 17/5

- The specification of the generator for a hydro station includes mainly the following information:

- Continous rated output in kilowatts.
- Kilovolt ampere capacity.
- number of phases (always 3)
- frequency
- Connection of stator winding.
- Voltage
- Current
- Power Factor
- speed

- method of cooling.
- temperature rise
- types of excitation
- excitation voltage
- short circuit ratio
- reactances of the machines.

The last two are more connected to the designer than the user, and are seldom mentioned on the name plate.

- Hydroelectric generators are low speed machines of the salient pole type, having a large number of poles, a large diameter & a short rotor. Thus, they are quite different from turbo alternators which are high speed machines so that they are generally 2 pole and have a small diameter and a very long rotor.

1.2) steam power plants :

A) selection of turbines for steam power plants :

- The steam turbines used for power station purposes are impulse or reaction types. or use a mixed arrangement of both principles. The rotor shaft of the turbine is of forged steel and the turbine blading is fixed onto it in the required number of stages. The blades are milled from solid steel blocks.

- Industrial types of turbines are generally back pressure or non condensing. These have very poor thermal efficiencies. Their capacities are up to 2250 kW. Some small condensing plant up to 7500 kW capacity are used in industry. The non condensing types are characterized by short rotors, relatively few stages and small exhaust openings. These are less expensive than the condensing turbines.

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- For power stations, all steam turbines are of the condensing types with as high as vacuum as possible. Surface condensers are used. Cooling water is circulated to cool and condense the exhaust steam. The capacities of turbines have been increased considerably. Units are now available upto 550 MW and sizes upto 1200 MW are being designed and installed.

- Small steam turbines have a steam flow at no load corresponding to 20% to 25% of the full or rated load flow. Large central stations have a no load steam flow corresponding to 3% to 10% of the full load steam flow.

B) Salient features of the generators to be used in steam power plant : 15/5

- Turboalternators have cylindrical rotors and therefore, a uniform air gap.

- The air gap of the turboalternator is also long compared to that of a salient pole machine.

- The rotors of turbo alternators have large axial length and small diameters.

- Damping torque is provided by the rotor itself and so there is no necessary for additional damper winding.

- They are suitable for high speed operations and so number of poles is usually 2 or 4.

- Turboalternators are generally rated at 0.8 power factor lagging.

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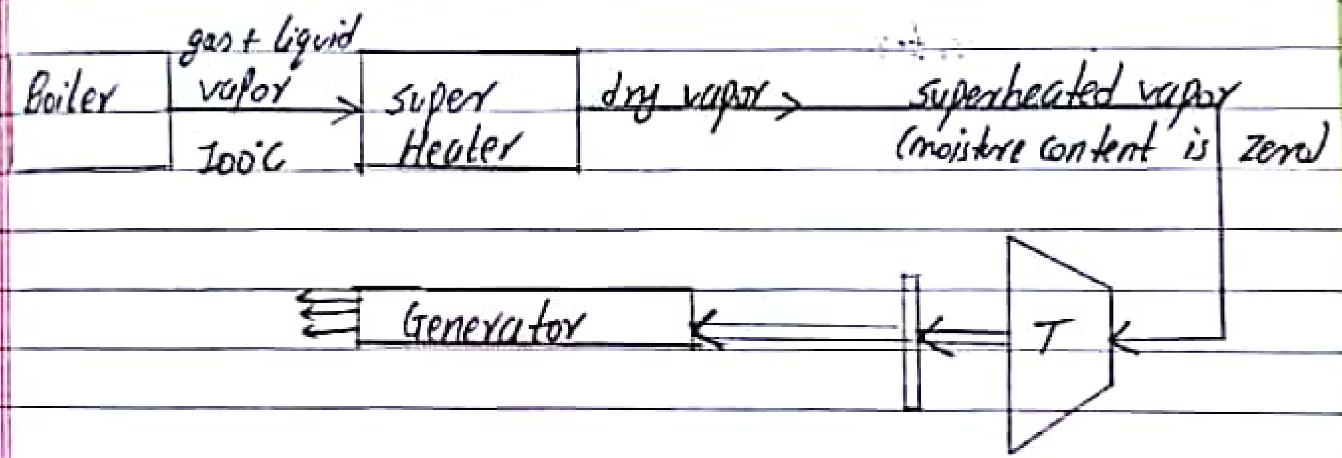
- A turbogenerator is the combination of a turbine directly connected to an electric generator for the generation of electric power.

i) Production of superheated steam using coal and using nuclear fuel:

Superheated steam is an extremely high temperature vapor generated by heating the saturated steam obtained by boiling water. Superheated steam is preferred in steam turbine application and is commonly used in main supply steam distribution systems to reduce the number of drip traps and the possibility of water hammer in pipe erosion.



Advantages of superheated steam:

i) Doesnot produce corrosion effect on turbine.
ii) Heat losses due to condensation of steam on cylinder walls are avoided to a great extent.
iii capacity to do work is increased without increasing its pressure.
iv High temperature of super heated steam results in an increase in thermal efficiency.
v. efficiency of the turbine is increased.
vi). steam consumption of the engine or turbine is reduced.

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Disadvantages of superheated steam:

- The high superheated temperatures posses problems in the lubrication.
- Higher depreciation and initial cost.

mechanism of superheating in coal plant & nuclear power plant: 17 IF, 18 IF

i) Convection mechanism
ii) Radiation " "
iii) separated superheating mechanism.

- super heating is the procedure in which wet steam coming out from boiler at 100°C is further heated upto 152°C to get saturated steam.

① Convection method:

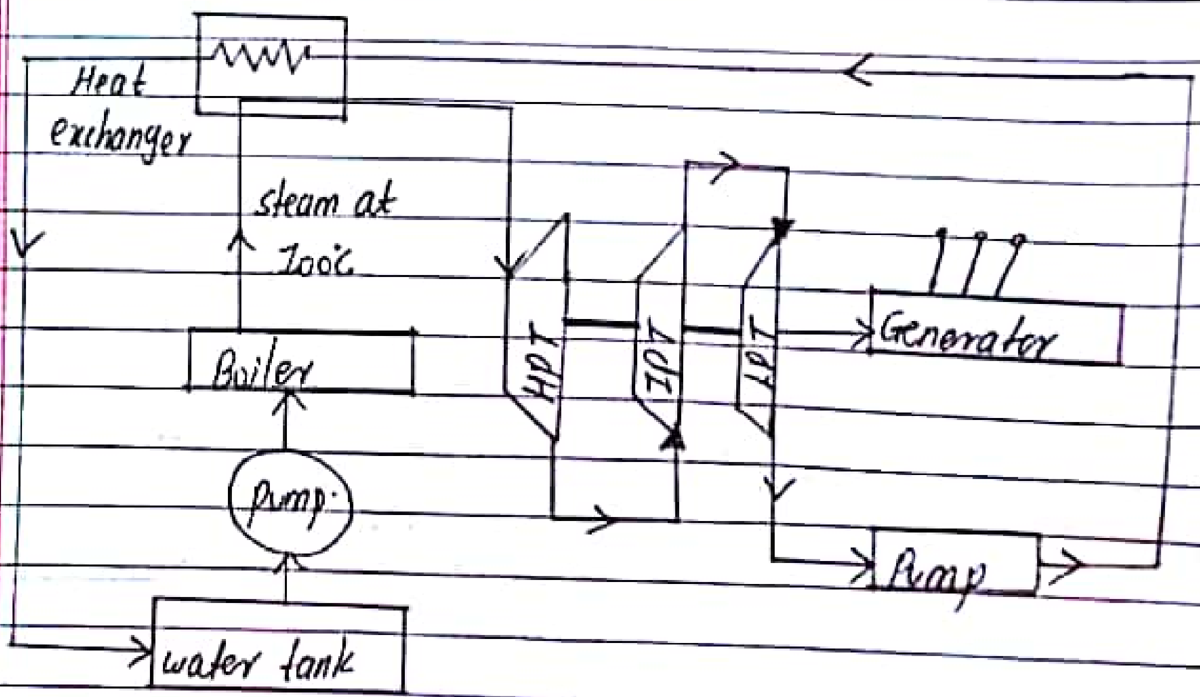

Fig: Convection method for steam power plant.

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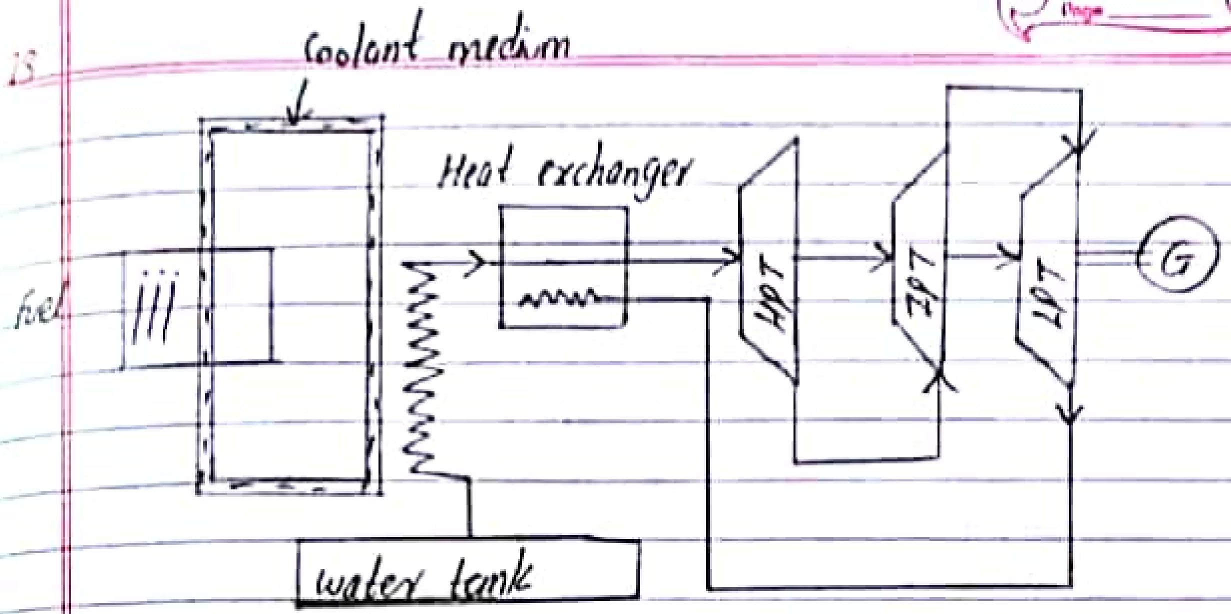
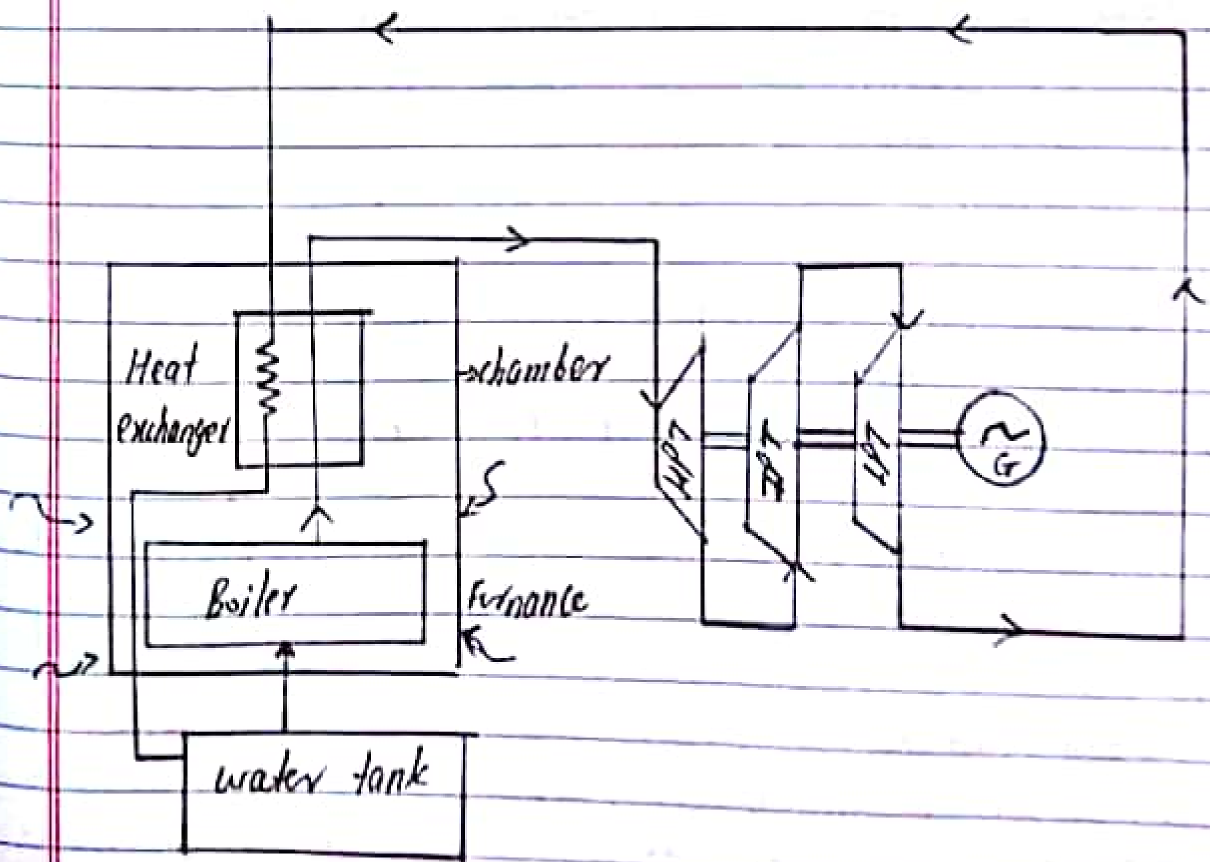


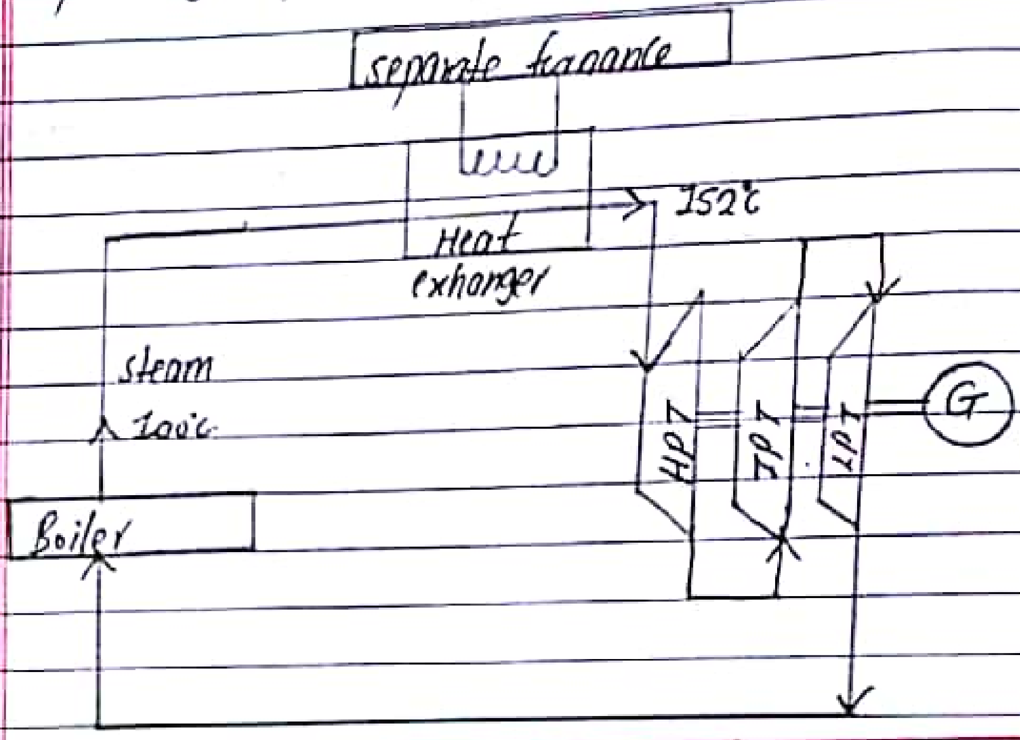
Fig: Convection method for nuclear power plant.

HPT = High pressure Turbine
LPT = low " "

① Radiation method:



(iii) Separately superheating mechanism:



1.3) Diesel Power Plants:

main application of diesel power plant are :

i) Central station
ii) Standby plant
iii) emergency "
iv) peak load plant
v) private power plant for small industries.
vi) Nursery stations
vii) power to sparsely populated areas.

A) Important features of IC engine used in diesel power plant: 15/S, 16/F

- engine used in diesel power plant is 2 stroke type.
- In DPP, IC engine works on diesel cycle.
- such engine must be started and stopped quickly.

- Doesnot require large amount of water for cooling.
- IC engine finds application in locations where water supply is limited and loads are relatively small.

- such engines have efficiency betwen 40 to 45 %.
- " " must be compact in size.
- High thermal efficiency.
- Fuel cost is high.
- Required less space.
- Combustion of fuel takes place inside the engine cylinder.
- Produce more noise.
- simple construction.
- cycle of operation is completed in two stroke.
- Consumes more lubricating oil.

B) characteristics of generator used in DPP : 16/S, 16/F

- cylindrical rotor type generator are used.
- Such generator must be started and stopped quickly.
- These generators are used for peak loads.
- Are of three types:
  - low speed generator - 300 - 500 rpm
  - medium " " - 500 - 1000 rpm
  - High " " - 1000 - 3000 rpm.

- generators used are of salient pole type having large diameters and short lengths.

- The generator needs an exciter to build up the necessary voltage on no load and then to keep it constant on load, when greater excitation will be required.

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Technical specification of generators:

- number of cylinders must be mentioned.
- KVA rating of generator
- no. of phases
- short circuit ratio
- limitation of speed
- Type of cooling
- " " fuel used
- " " service for which generator is to be used
- supply frequency.

1.4) Energy production from solar, wind, geothermal and Biomass power plants:

A) Solar power plants: 15/F, 20/S, 16/F

solar energy is produced when sunlight strikes solar panels which then turn solar power into usable electricity. This photovoltaic transformation is the way solar energy is generated.

Advantages:

- environmentaly friendly; renewable
- no noise, no moving parts.
- no emissions
- long life time
- no use of fuels and water.
- minimal maintenance required.
- Reduce dependence on imported oil.
- Backup and storage devices available.

- Pollution free.
- Rebates from government.

Disadvantages :

- High initial investment
- cannot be used during night times
- Large area needed for large scale applications.
- cannot be built everywhere.
- Panels can deteriorate.

Solar cell efficiency formula:

$$\eta_{max} = \frac{P_{max}}{E \times A_c} \times 100\%$$

where,

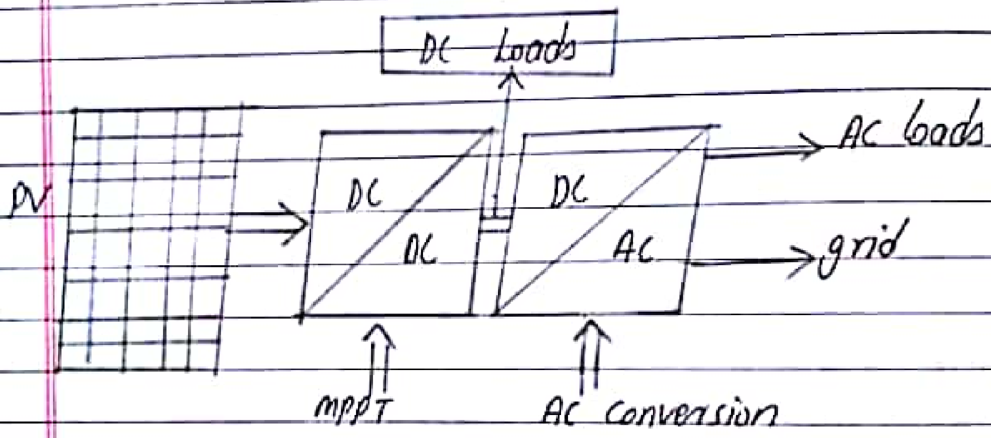
P_{max} = max. output power in watt (w)
E = incident radiation flux (in w/m^2)
A_c = area of collector (in m^2)

Typical power plant efficiencies:

Type	efficiency
Hydro power plant	85 – 90 %
wind turbine	30 – 45 %
Solar thermal system	15 % annually
geo " "	35 %
Nuclear power plant	0.27 %
Diesel engine	35 – 42 %

Solar voltaic system : 17/S, 16/F

A photovoltaic system, also PV system or solar power systems in a power system designed to supply usable solar power by means of photovoltaic. It consists of an arrangement of several components including solar panels to absorb and convert sunlight into electricity a solar inverter to change the electric current from DC to AC as well as mounting, cabling and other electrical accessories to keep/set a working system.



- Photovoltaic (PV) is method of generating electrical power by converting solar radiation into direct current using semiconductor which exhibit PV effect.

- The heart of a photovoltaic system is a solid state device called a solar cell. PV system consists of
  - Electricity meter
  - AC isolator
  - Fuse box
  - DC isolator
  - generation meter
  - mounting
  - cabling
  - charge controller
  - Battery

- Inverter

- 8 Factors that affect PV system efficiency:
- cable thickness
- Temperature
- shading
- charge controller and solar cell's IV characteristics.
- Inverter efficiency
- Battery "
- Soiling
- Ageing

B). wind : 141F, II S, 20 S, 181F, 24 S

- wind turbines convert the kinetic energy of the wind into mechanical power. This mechanical power can be used for specific task (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity to power homes, schools etc.

- wind turbines, like aircraft propeller blades, turn in moving air and power an electric generator that supplies an electric current. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity.

- Types of wind turbine:
- Horizontal axis wind turbine
- vertical " " "

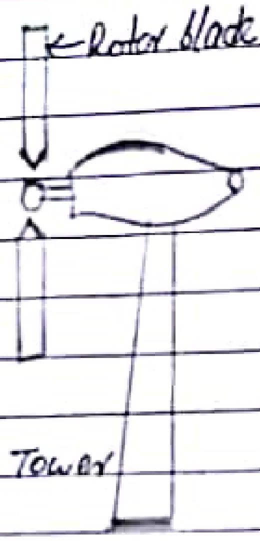


Fig: Horizontal axis W.T.

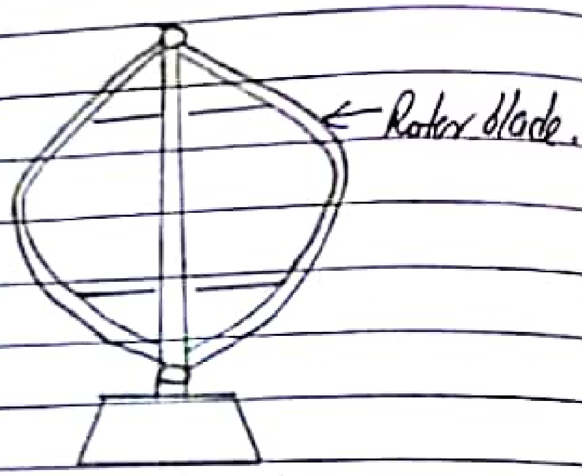


Fig: vertical axis Wind Turbine

Advantages of Horizontal axis W.Turbine are:

- most are self starting
- can be sited in forest above the tree line.
- Tall tower allows placement on uneven land
- " " " access to stronger wind in sites with wind shear.
- ability to pitch the rotor blades in a storm to minimize damage.
- Blades are to the side of the turbines center of gravity, helping stability.

Disadvantages:

- Difficult in maintenance.
- effect radar in proximity.
- Difficulty to install
- " operating in near ground winds.
- " to transport.
- Local opposition to aesthetics.

Vertical axis WT:

In vertical axis turbines, the shaft of blades are connected to vertical to the ground. All of the main components are close to the ground. Also the wind turbine itself is near to the ground, unlike horizontal where everything is on a tower. There are two types of vertical axis wind turbines:

- lift based
- drag "

Advantages:

- easy to maintain
- Lower construction and transportation costs
- not directional
- most effective at mesas, hilltops.

Disadvantages:

- Blades constantly spinning back into the wind
- less efficient
- operate in lower, more, more turbulent wind
- low starting torque and may require energy to start turning.

Advantages of wind power plant:

i) Renewable resource. wind will never run out.
ii) Relatively low cost to build and maintain.
iii) clean energy because it produces no emission or polluting waste.
iv). Installation and maintenance is fast.
v). It can coexist with other land uses such crops.
vi) no need of fossil fuel.

vii) wind doesnot need a factory to be produced, so it is producing the environment.
viii) large potential for growth.
ix. economically viable.
x. Flexible, efficient
xi) Doesnot produce greenhouse gases.

Disadvantages of wind power plant:

i) expensive to store
ii). unreliable source of energy.
iii). makes a lot of noise
iv). needs big open spaces of land to be on
v). Produce negative visual impacts on the landscape.
vi). generate acoustic impacts.
vii They can be danger to flying animals.
viii) wind power can only be generated in windy areas.
ix. wind turbines can be destroyed by severe storms or lightning.

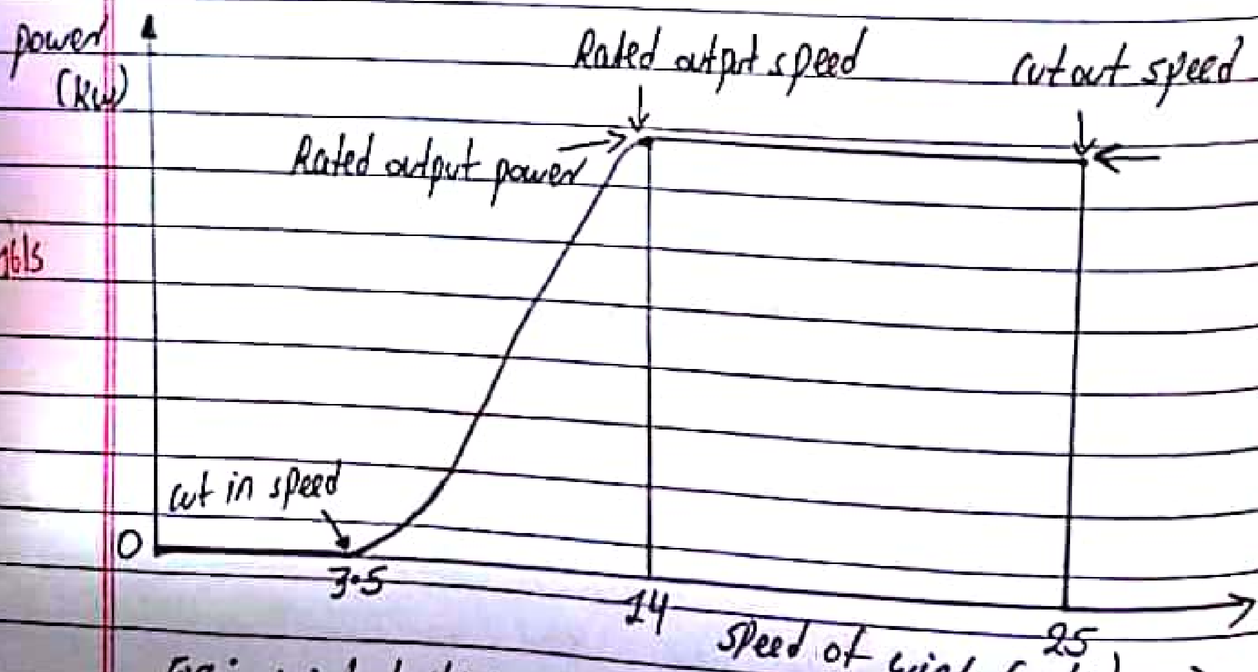


Fig: wind turbine power curves (characteristics) cut in speed:

The speed at which the turbine first starts to rotate and generate power is called the cut in speed and is typically between 3 to 4 meter per second.

cut out speed:

The speed at which blades rotation has to be stopped to avoid mechanical damage to it. and is usually between 25 m/s. – 28 m/s

output power obtained from w.P.P : 16/s

Power output $= \frac{1}{2} \times m \times V^2$

$= \frac{1}{2} \times \rho \times v \times V^2$

where, m = mass
ρ = density
V = velocity
v = volume

$P = \frac{1}{2} \times \rho \times$ Area covered by blade rotation $\times$ speed of wind $\times V^2$

$= \frac{1}{2} \times \rho \times A \times V \times V^2$

$= \frac{1}{2} \times \rho \times \pi r^2 \times V^3$

$\because$ r = length of 1 blade

Now,

$P = \frac{1}{2} \rho \times \pi \times \left(\frac{D}{2}\right)^2 \times v^3$

$\therefore P = \frac{1}{8} \times D^2 \times \rho \times \pi \times V^3$ watt.

- efficiency of wind Power plant is usually 40-45 %.

c) Geothermal energy: 15/S, 14/F, 13/F, 12/F, 11/S, 14/S

- Geothermal energy is the thermal energy generated and stored in the Earth. It is clean and sustainable. It uses steam produced from reservoirs of hot water found a few miles or more below the Earth's surface to produce electricity. The steam rotates the turbine that activates a generator, which produces electricity. There are three types of geothermal power plants:
  - dry steam Power plants
  - flash " " "
  - Binary cycle. " "

- Components of a G.P.P are:
  - Production walls
  - Injection "
  - Rock catchers
  - Pump
  - Condenser
  - Generator
  - Turbine

i) Dry steam plants uses steam directly from a geothermal reservoir to turn generator turbines.

ii). Flash steam plants take high pressure hot water from deep inside the earth and convert it to steam to

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drive generator turbines. When the steam cools, it condenses to water and is injected back into the ground to be used again. Most geothermal power plants are flash steam plants.

iii. Binary cycle power plants transfers the heat from geothermal hot water to another liquid. The heat causes the second liquid to turn to steam, which is used to drive a generator turbine.

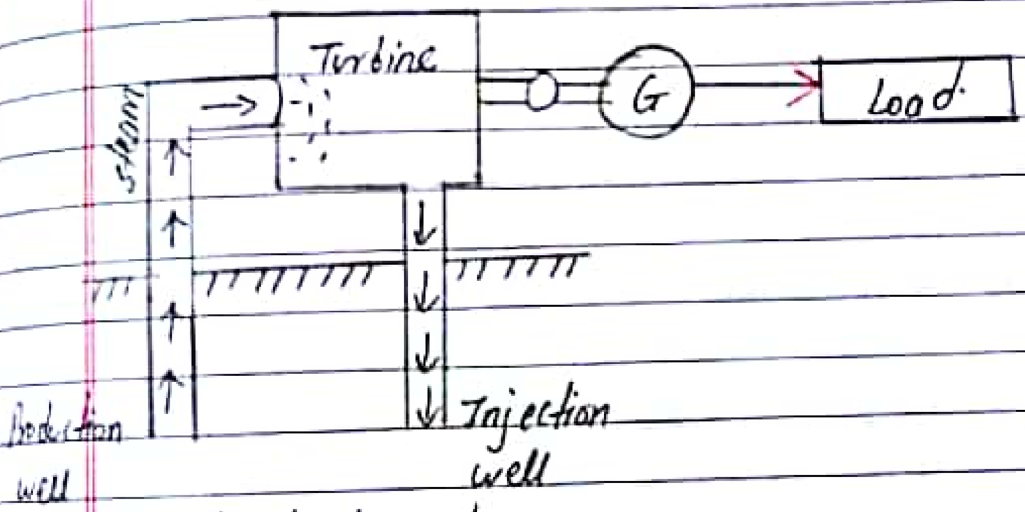


Fig: direct dry steam.

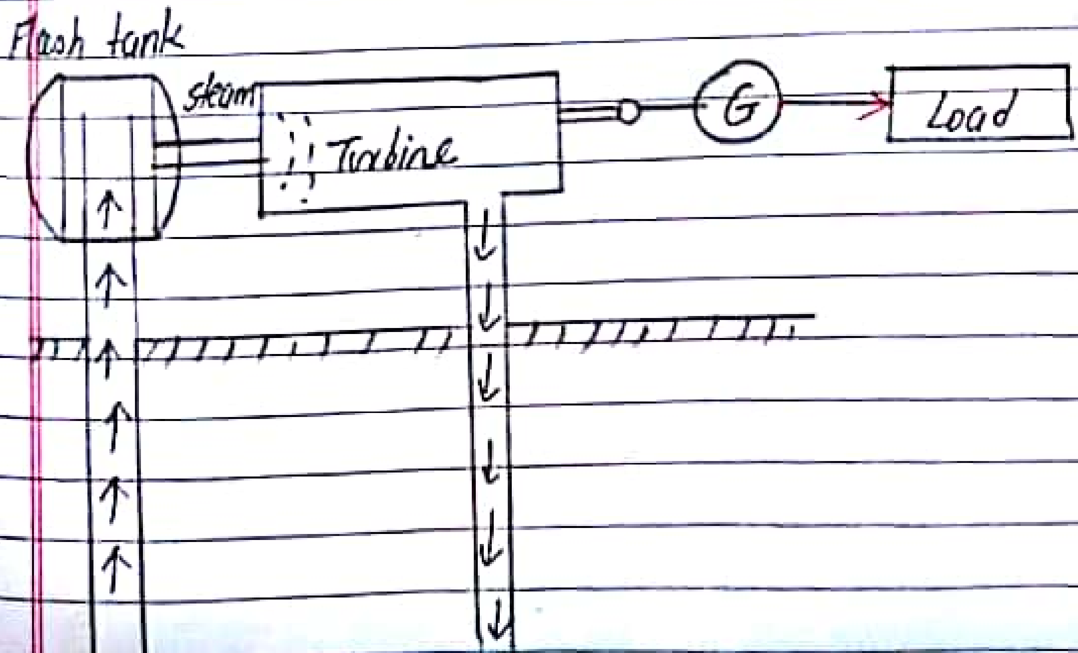


Fig: Flash steam power plant. (J5K)

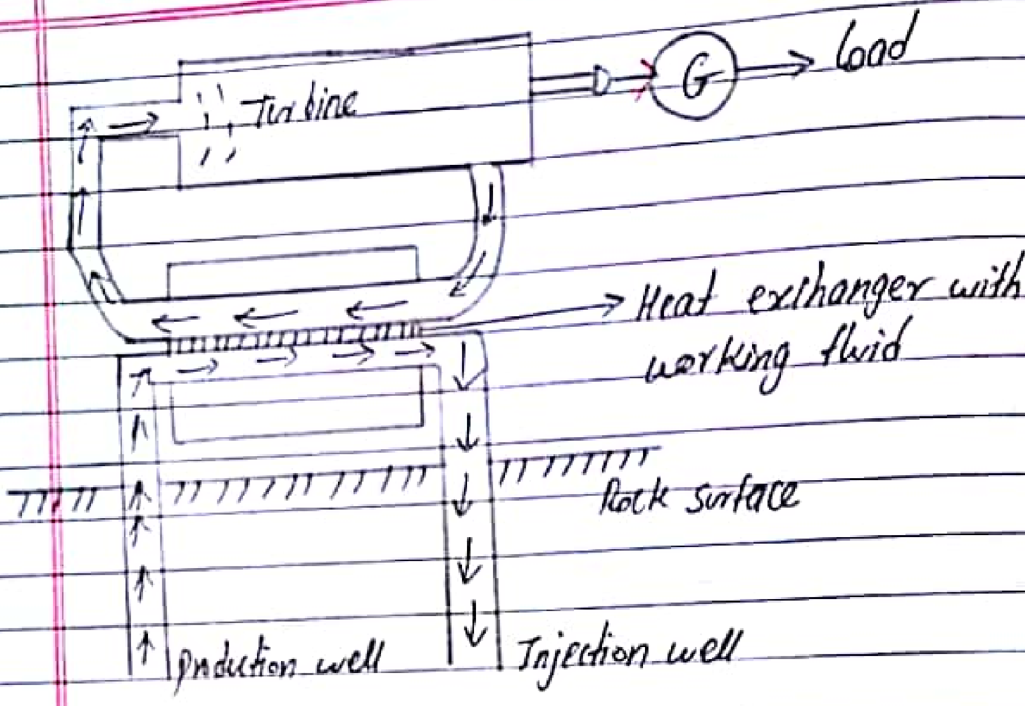


Fig: Binary cycle. GPP.

Advantages of GPP are:

i) Low cost
ii) No environmental impact
iii) Pumps can store heat for later use.
iv Inexhaustible.
v It reduces our reliance on fossil fuels.
vi) very efficient and lost lasting.
vii) doesnot require large space to build on.

Disadvantages of GPP are:

i) Source is close to volcanic activity.
ii) High startup cost
iii) not widespread source of energy
iv). Releasing steam is loud.
v) Hard to transport to consumer.

vii) H_2S pollution.
viii) Can run out of steam.

Uses of GPP:

- Direct use – geothermal heating and heat pump
- Indirect use – electricity production.

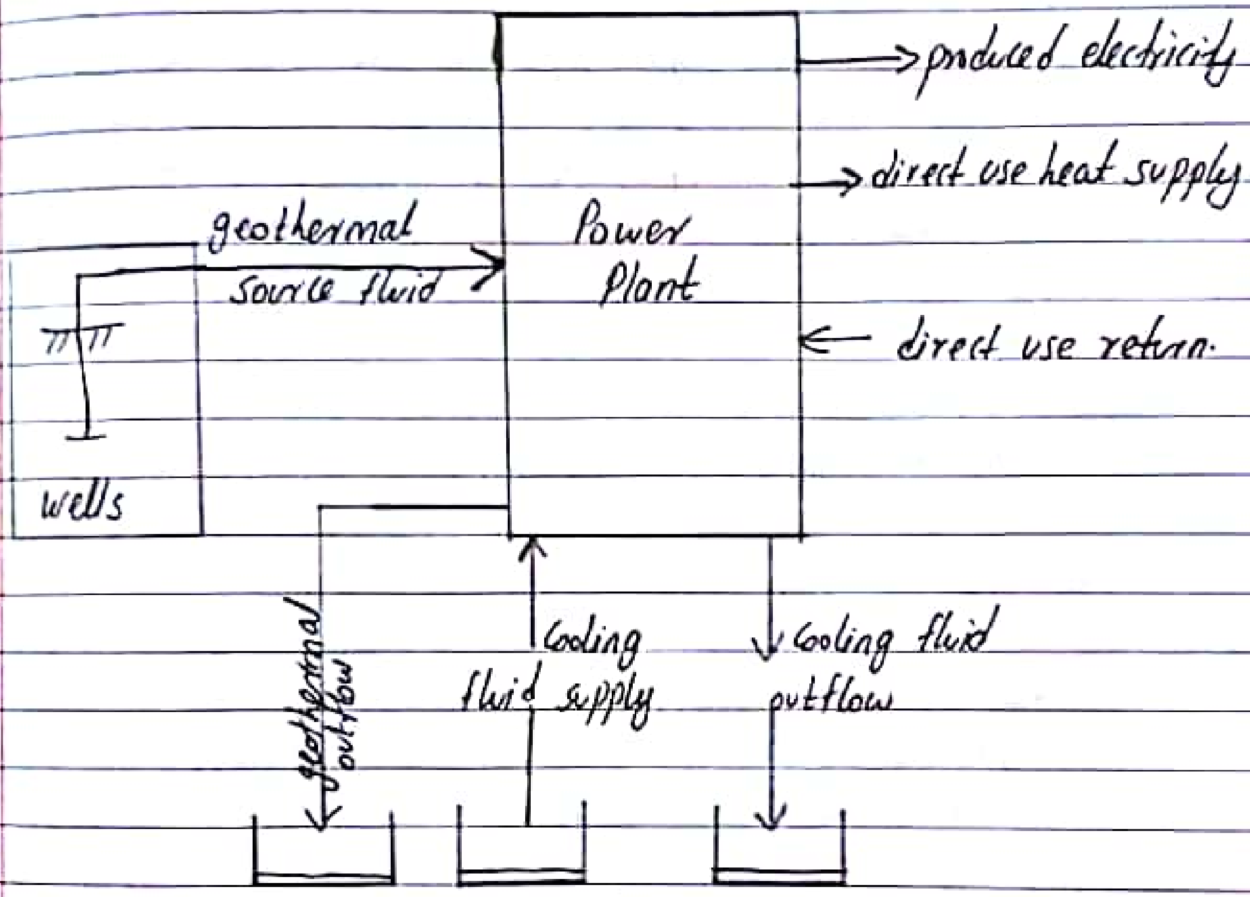


Fig: Schematic of a G.P.P.

- At present, the use of geothermal spring water in Nepal is largely confined to bathing and laundering purposes.

B) Bio mass energy: 131F

- Biomass is organic material that comes from plants and animals and it is a renewable source of energy. The energy obtained from the biomass products is known as biomass energy.

Types of Bio mass:

- Concentrated Biomass : industrial waste, food waste, seewage waste
- dispersed biomass : agricultural products, forest products.

Conversion of Biomass into energy:

There are 3 ways for converting biomass into useful energy.

- Biochemical process:

In this process, bio mass is converted into fuel by using aerobic process and termination process.
eg: Biofuel like methane.

- Thermochemical process:

In this process organic matter is treated with some chemical for few days under specific temperature, after few days that biomass is converted into liquid or solid fuel. eg: ethano, biodiesel.

- Direct combustion:

It is the process in which thermal energy & electrical energy is converted from organic matter directly ie, biomass by directly burning the Biomass.

Advantages of Biomass:

i) Biomass is a renewable fuel source.

ii) availability of Biomass fuels is universal.
iii) Alcohol fuels are efficient and clean.
iv) employment generation in rural areas.
v) Biomass energy production results in minimal environmental impact.
vi) can be sustainable.
vii) High energy efficiency.
viii) Solve energy crisis in the future.
ix) utilizes waste material.

Disadvantages of Biomass energy:

i) Puts out some pollution.
ii) chemicals are released when you burn biomass.
iii) seasonability.
iv) expensive to make.
v) difficult to store biomass energy.

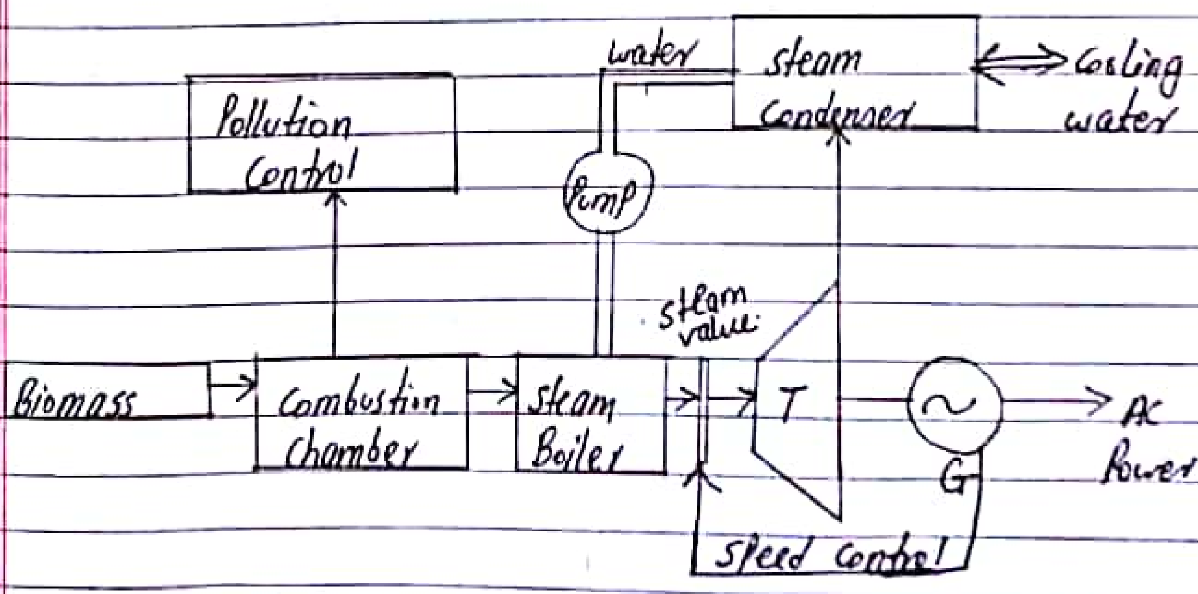


Fig: electricity generation powered by Biomass. (13/E).

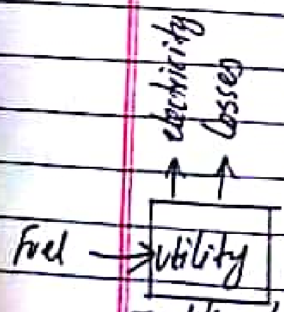
1.5 Cogeneration and Total energy system:

A) Cogeneration: 17/S, 17/F, 16/S, 12/F, 10/S

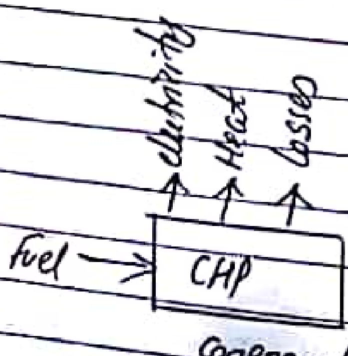
- Cogeneration or combined heat and power (CHP) is the use of a heat engine or power station to generate electricity and useful heat at the same time. Cogeneration is a more efficient use of fuel because otherwise wasted heat from electricity generation is put to some productive use.

- Cogeneration is a method of energy conservation that involves the production of two types of energy at a single power plant. Cogeneration power plant often operate at 50 to 70 % higher efficiency rates than single operation /generation facilities.

- Cogeneration is the most optimum, reliable, clean and efficient way of utilizing fuel. The fuel used may be natural gas, oil, diesel, propane, wood, coal etc. It works on very simple principle ie, the fuel is used to generate electricity and this electricity produces heat and this heat is used to boil water to produce steam, for space heating and even in cooling buildings.



Traditional system



Cogeneration system

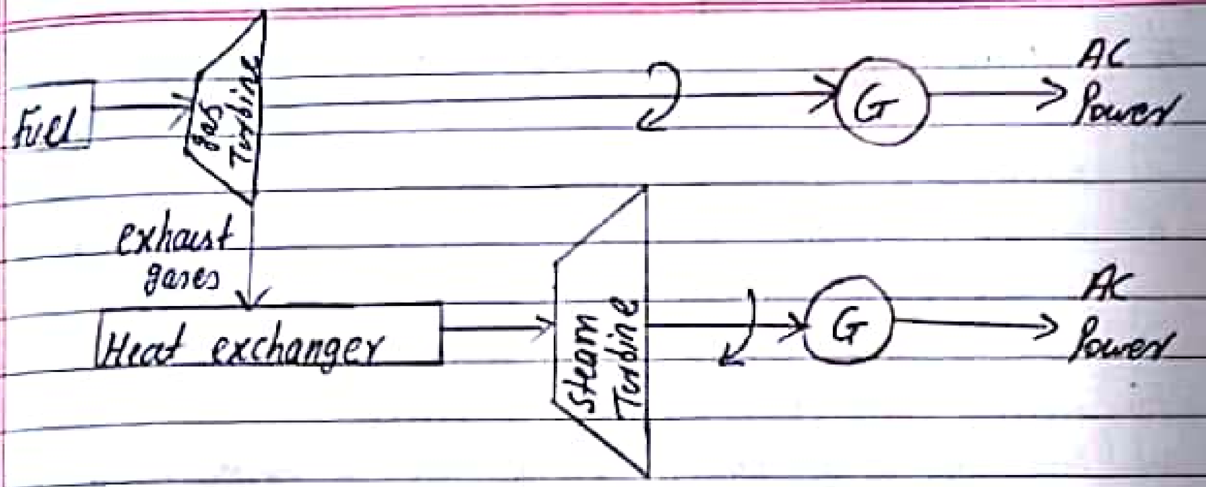


Fig: electricity cogeneration.

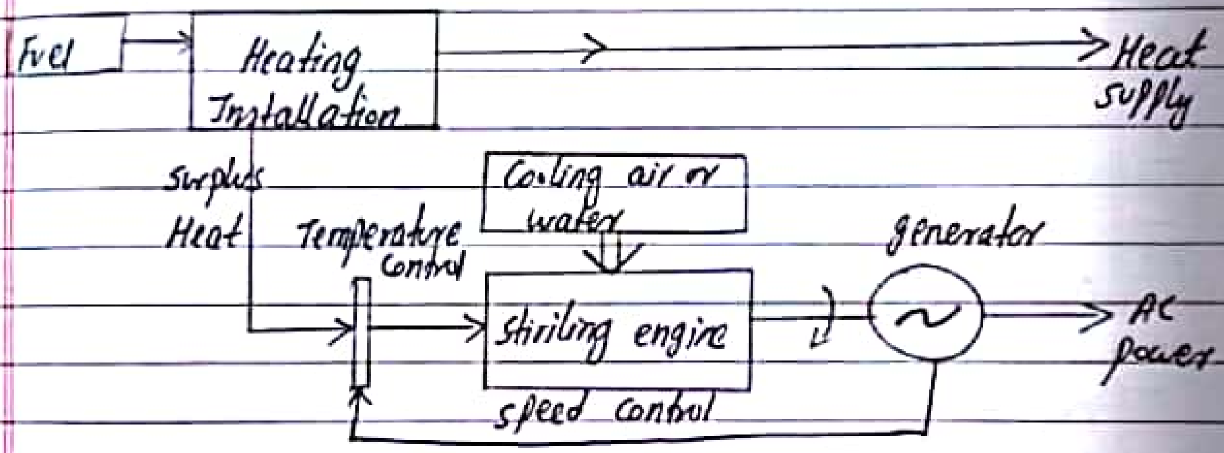


Fig: Combined Heat and power (CHP).

Advantages:

i) Security of supply
ii) Steam raising capabilities.
iii) Reduced primary energy cost
iv) Stabilized electricity costs over a fixed period.
v) Improved fuel efficiency.
vi) Reduced CO_2 emissions.
vii) Promoting liberalization in energy markets.
viii) ability to use waste materials.
ix) Increased efficiency of energy conversion & use.

Disadvantages:

i) Have high investment and operation costs.
ii) Require utilization of the generated heat in the case of the generated electricity is fully generated.
iii) Not suitable for all sites
iv) Heating demand must be continuous.
v) Not an actual energy source, only a means of extending energy.
vi) High maintenance costs.

Application of Cogeneration:

- Food processing
- Pulp and Paper
- oil refining
- Commercial
- Hospitals
- Hotels.

B) Total energy system: 15/S, 72/F

" " " is the system in which maximum utilization of fuel is done.
E.g: Total energy system of Cogeneration.

1.6) Energy storage systems: 15/S, 73/S, 73/F, 71/S, 70/S, 76/F

Energy storage is the capture of energy produced at one time for use at a later time. Some of the energy storage system are:

1) Pumped storage plants. 75/S, 73/F

ii) Compressed air storage
iii) Battery storage.

A) Pumped storage systems : 76/S, 75/S, 75/F, 73/S, 73/F, 72/S, 72/S, 70/S

- A pumped storage plant is useful in the system to supply sudden peak loads of brief duration. The pumped storage plant is useful in combination with a hydro plant having limited storage so that the water discharged from the turbine to the tailrace can be used again economically. The pumped storage plant can be made more effective by the use of reversible pump turbine sets.

- The pumped storage plants transfers peak load & energy from peak to off peak periods which permits more economical loading of thermal plants. It minimizes wastages of availability of off peak energy.

- Pumped storage hydroelectricity allows energy from intermittent sources (such as solar, wind) and other renewables or excess electricity from continuous base load sources (such as coal or nuclear) to be saved for periods of higher demand.

- Advantages:

i) Relatively low capital cost; thus economic source of peaking capacity.
ii). Rugged and dependable.
iii). There is an improvement in the load factor of plant.
iv). Readily adaptable to automation as well as remote control.
v. Allow great deal of flexibility in operational schedules of system.

see figure at page - 41

B). Compressed Air storage (CAS): 17/S, 15/S, 13/F, 11/S, 16/F

- CAS is a way to store energy generated at one time for use at at another time using compressed air. At utility scale, energy generated during periods of low energy demand (off peak) can be released to meet higher demand (peak load) periods.

- Advantages:
  - wide availability of air and its compressibility
  - doesnot cause any pollution.
  - easier maintenance and cost effectiveness.
  - Reliability of operation and remote controlling
  - free from fire Hazards.
  - ease of handling with control of pressure, force, motion etc.

- Area of applications of CAS plants:
  - Provision of black start services
  - price arbitrage
  - Balancing energy
  - Higher utilization and greater utilization of renewable energy.
  - stabilizing conventional generations.

- Air storage can be:
  - Adiabatic
  - Diabatic
  - Isothermal

C) Battery storage: 15/S, 13/F, 11/S

A battery stores electrical energy in a reversible chemical reaction. most batteries employed

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in renewable energy systems use the same electrochemical reactions as the lead acid battery. Battery capacity is rated in amp-hours. 1 Ahr is equivalent of drawing 1 amp steadily for one hour.

Types of Battery :

- Lead acid battery
- Lithium-ion "
- Flow "
- Sodium Nickel chloride Battery.

- Advantages:

• storage capability
• power density
• Better leakage current than capacitors.
• Constant voltage that can be turn off and on.

- Disadvantages:

• Limited cycle life
• Voltage and current limitations.
• Long charging times
• more temperature sensitive than capacitors.

Board exam solutions

1) A) Discuss the various factors which should be considered for the choice of generator during the design of a power plant. Also mention the significance of short circuit ratio in the selection of generator. 17/S

⇒ Various factors which should be considered for the choice of generator during the design of a power plant are:

i) Continuous rated output in kW

Continuous power is similar to prime power but has a base load rating. It can supply power continuously to a constant load but doesnot have the ability to handle overload conditions or work as well with variable loads.

ii) Kilo volt ampere capacity:

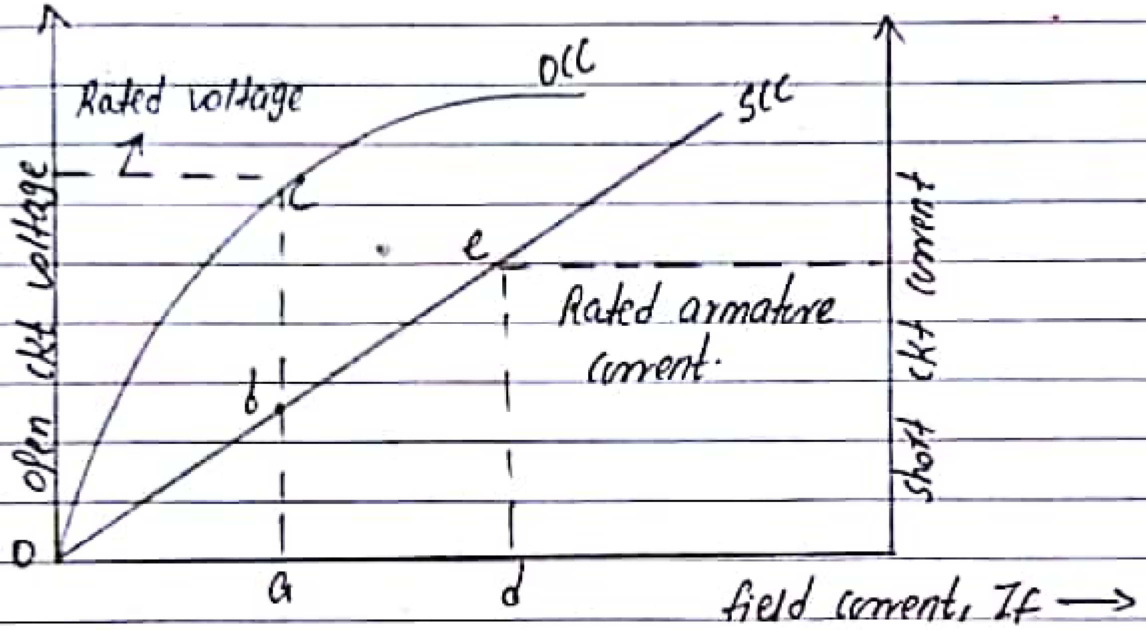
The kVA rating is limited by the maximum permissible current.

iii number of phases (always 3).
iv Voltage
v current
vi power factor
vii speed
viii method of cooling
ix Temperature rise
x. Type of excitation
xi excitation voltage
xii short ckt ratio
xiii) reactance of machine
xiv frequency
xv Connection of stator winding. (always star)

Significance of short circuit ratio in the selection of the generator are :

- Short circuit ratio (SCR) is the measure of the generator stability characteristics. It is the ratio of field current to produce rated armature voltage i.e. at open circuit to the field current required to produce the rated armature current at short circuit.

-



$$SCR = \frac{Oa}{Od} = \frac{ab}{de}$$

$$= \frac{\text{If for rated OC voltage}}{\text{'' '' '' S.C current}}$$

- SCR affects the operating characteristics, physical size and cost of the machines. For the small value of the SCR, the synchronizing power is small. As the synchronizing power keeps the machine in synchronism, a lower value of the SCR has a low stability limit. ie, a machine with a low SCR is less stable when operating in parallel with the other generators.

A synchronous machine with the high value of SCR had a better voltage regulation and improved steady state stability limit, but the SCR fault current in armature is high. It also affects the size and cost of the machine.

$$SCR \propto \frac{1}{\text{reluctance of air gap } (l_s)}$$

Hence, SCR is inversely proportional to the air gap reluctance or air gap length.

Hence, large value of SCR will increase the size, weight and cost of the machine.

B). Define energy storage. And discuss the need of energy storage. Also explain the compressed air storage plant in detail. 17/S, 13/F, 18/F

⟹ Energy storage is the capture of energy produced at one time for use at a later time. Energy storage systems are the set of methods and technologies used to store various forms of energy. There are many different forms of energy storage:

- Solid state Battery
- Flow battery
- Fly wheel
- Compressed air
- pumped hydro power
- Thermal.

Need of energy storage are: 15/S, 13/S

We need a secure, reliable electricity 24 hours a day. We also need to make more use of renewable energy resources, such as solar, wind to reduce air reliance on non renewable fossil fuels such as oil and gas. But it's not easy to just switch over to using solar and wind for all our energy needs. The cloud pass · the sun and the wind gusts fast and slow. This means that solar power and wind power are not always available when needed.

The solution to this problem lies in the energy storage.

- The energy storage along with renewable energy storages IPV is required to increase the reliability and flexibility.

- The intermittent natre of renewable sources like solar & wind needs storage to deliver the right amount of power at right quality.

- To accomodate the projected high penetration of solar and wind energy in future grids with lower grid rejection loss.

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Compressor → Control receiver → Dryer → Filter → Dry receiver → end use.

Fig: Simplified Block diagram of compressed air system.

c) What are the selection criteria of generator size, transformer scheme and types? 17/F

⇒ selection criteria of transformer are:

i) Continuity of services
ii) load factor
iii) Losses

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iv initial cost
v cost of losses
vi methods of cooling and corresponding advantages and costs involved
vii Insulation
viii) Percentage impedance
ix voltage regulation
x. Floor area
xi Height and weight of Transformer.

selection criteria of Generator are as:
copy from page no – 36

D. Salient features of generators to be used in Hydro power plant : 15/5

i) Air gap length is not uniform.
ii). mechanically strong.
iii). In this generator, flywheel are important consideration.
iv Such generator must be simple in construction, efficient and easily controllable.
v. Separate damping winding is provided.
vi) Diameter is large than axial length.
vii) Rotor used is of a salient pole type.
viii) They are usually rated for 0.90 – 0.95 power factor lagging.

ix. such generator must be able to work for peak load as well as base load.
x. low speed machine
xi Such generators must be able to start in the range of short duration during peak loads.

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E) Pumped storage plant diagram: 16/s, 75/s, 75/F, 73/s, 72/s, 71/s, 70/s

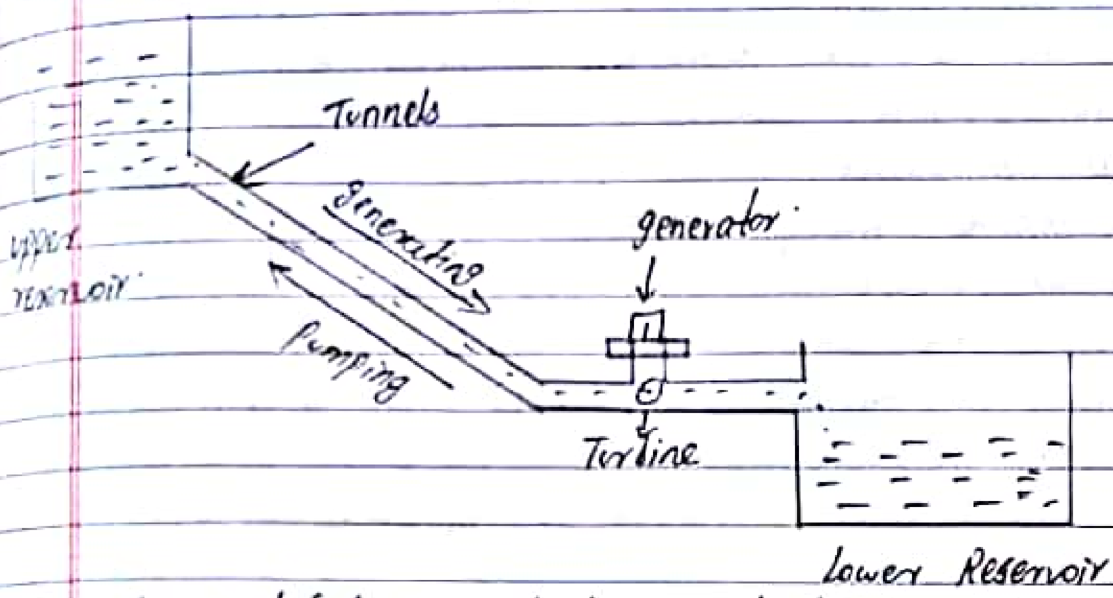

Fig: simplified pumped storage plant.

F. What are different types of renewable energy sources? 75/F 70/S

⇒

- Solar energy
- Wind "
- Hydroelectric energy
- Biomass "
- Hydrogen and fuel cells
- Geothermal energy.

G. What are the advantages and disadvantages of renewable and non renewable form of energy. Explain. 74/F, 74/s

⇒ Advantages of renewable form of energy are:

i) It is renewable ie, it is sustainable and so will never run out
ii) It can also brings economic benefits to many regional areas.
iii) It produces little or no waste products such as carbon dioxide or other chemical pollutants, so has minimal impact

on the environment.

iv. Continuous supply.
v. can be replenished within a short period time.
vi. Reliable energy sources.
vii) No radioactive wastes.
viii) Concentrated energy sources.
ix). cheap to operate.
x. safe and clean.
xi Provides the fondation for energy independence.

Disadvantages of Renewable energy:

i) Difficult to generate in large quantity.
ii) Large capital cost
iii) Large tracts of land is required.
iv) wild life could be affected.
v) cannot be built anywhere.
vi) Pollution in case of poor technology.

Advantages of non-renewable energy:

i) Reasonably cheap
ii) easy to get.
iii) widely available and affordable
iv) Reliable supply.
v easy to store.
vi) available in highly concentrated form.
vii) Large amount of energy are produced from small amount of resources.
viii) able to be used to many different applications.
ix easy to transport.

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Disadvantages of non renewable energy:

i) causes greenhouse gases to be emitted.
ii) Danger of explosion.
iii) can't be replaced or revitalized.
iv) They produce toxic gases in the air when burnt which are the major cause for global warming.
v) mining impact on the land.
vi) Price will rise in the future as supplies run out.

Example: Coal, oil, natural gas, uranium, petroleum products.

H) Difference between: 13/F

	Solar energy	wind energy.
i)	It is available only during the day time.	It is available even at night.
ii)	It can be mechanical or purely electrical.	It is mechanical.
iii	Average efficiency is 16-18 %.	Avg efficiency is about 40-45 %.
iv	solar energy is the energy that is provided by the sun via solar radiation.	wind energy is the process of air flow through wind turbines to automatically generate power.
v	Solar energy is generated with the use of solar panels.	wind energy is generated with the use of turbine.

I. Enumerate the major sources of energy. 13/F

i) Solar energy
ii) Wind "

iii) Geothermal "
iv) Hydrogen "

v) Tidal "
vi) Wave "

vii) Hydroelectric "
viii) Bio mass "

ix Nuclear "
x. Fossil fuels (Coal, oil, natural gases).

J. Justify how Bioenergy may be useful for rural applications. 13 b

⇒ Biomass mass energy systems not only offer significant possibilities for clean energy production and agricultural waste management but also foster sustainable development. The increased utilization of biomass wastes will be instrumental in safeguarding the environment, generation of new job opportunities, sustainable development and health improvements in rural areas.

— Biomass energy has the potential to modernize the agricultural economy and catalyze the rural development. The development of efficient biomass handling technology, improvement of agro forestry systems & establishments of small, medium and large scale biomass based power plants can play a major role in rural development.

- Rural areas are preferred hunting ground for the development of biomass sector worldwide. By making use of various biological and thermal processes (anaerobic digestion, combustion, gasification, pyrolsis), agricultural wastes can be converted into biofuels, heat or electricity and thus catalyzing sustainable development of rural areas economically, socially and environmentally.

Advantages of Biomass energy:

i) waste can be used as an excellent fertilizers.
ii) Potential for rural areas.
iii) Biogas can be used for cooking purpose.
iv) can be used for operating small engines for pumping water, for lighting etc.
v) carbon cycle to reduce build up of green house gases.

- Growing biomass is a rural labour intensive activity, and can, therefore creates jobs in rural areas and help stop rural to urban migration.

k) Renewable Vs non renewable energy sources. 12/5, 20/5

	Renewable energy sources	non renewable energy sources
i)	These resources are renewed or replenished by nature in a short span of time.	These resources may not be replenished by nature or take very long geological time to be formed again.
ii)	often these are available continuously like solar energy, tidal, wind energy etc.	These resources are exhausted after use: eg: fossil fuel etc.
iii	Renewable resources can be	Non renewable resources can be

	divided into continuous or flow.	recyclable or non recyclable.
iv.	Not a reason behind global warming.	main reason behind global warming
v.	These are the free gift of nature.	These are not the free gift of nature.
vi	These donot cause any pollution to the environment.	These cause pollution to the environment.
vii)	- are available in unlimited quantities.	are available in limited quantities.
viii	They are non conventional.	They are conventional.
ix.	Doesnot cause any health problems to living beings.	adversely affect the health of living beings by releasing smoke, radiation etc.
x).	are obtained free of cost or at very less cost in nature.	are very costly and not easily available.

1). Explain why steam power plants are best to meet the base load of a load curve. 12/F

⇒ The fuel (ie coal) used is quite cheap. The cost of generation is lesser than that of the diesel power station. They can be located conveniently near the load centre. A portion of steam generated can be used as a process steam in different industries. They are

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reliable during peak and off peak times and blackouts are extremely rare.

In most countries steam power plants are used as base load power stations. This is because steam power plants are slow to start and cannot be used to cater for peak loads that generally occur for a short duration. They are kept running very close to full efficiency for 24 hours a day.

M) Wind energy conversion system: 18/F

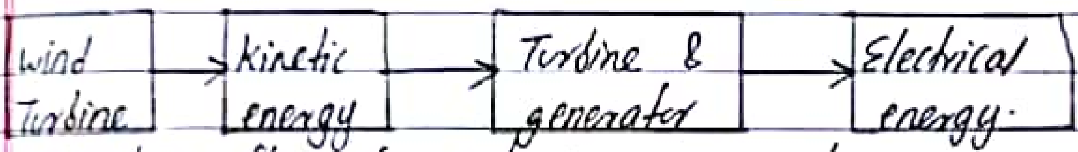
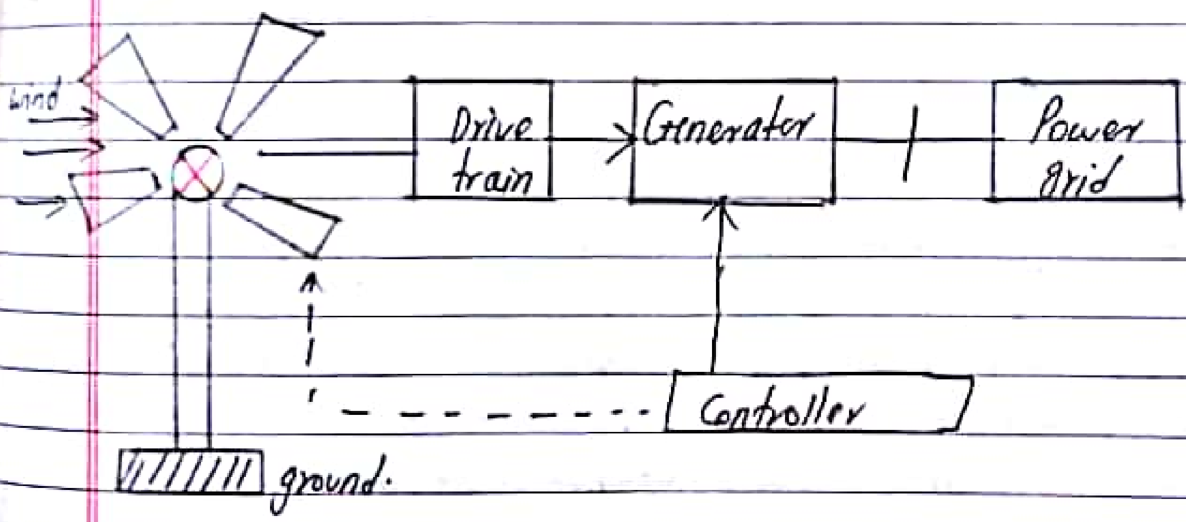


Fig: basic flow of wind power generation.



N). Factors for selecting location of power plant: 14/F, 14/S

- Raw materials availability
- location
- availability of suitable land.
- environmental impact and effluent disposal.
- Transport.

- availability of labours.
- " " utilities
- government policy
- suitability of climate.
- local taxes and restrictions.
- finance and research facilities.
- civil amenities for workers.
- accessibility of the site.
- Distance from load center.
- Public problems.
- size of plant.

Q. Briefly describe about cogeneration with its types. 2015

⇒ Need for cogeneration are:

i) Cogeneration helps to improve the efficiency of the plant.
ii) It reduce cost of production and improve productivity.
iii) It helps to save water consumption and water costs.
iv) It is more economical as compared to conventional power plant.
v) It reduces air emissions of particulate matter, nitrous oxides, sulpher dioxide, mercury which would otherwise leads to green house effect.

Types:

i) Topping cycle power plant.
ii) Bottoming " " "

i) Topping cycle power plant:
In a typical combined heat & power

plant (CHP) system, there is a steam or gas turbine which take steam and drives an alternator. In this type of combined heat and power plant, electricity is generated first and then waste or exhaust steam is used to heating water or building. There are basically 4 types of topping cycles.

- Combined cycle topping CHP Plant
- steam turbine topping CHP "
- water " " " "
- gas " " " "

(ii) Bottoming cycle power plant:

As it names indicates, bottoming cycle is exactly opposite to topping cycle. In this type of CHP plant, excess heat from a manufacturing process is used to generate steam and this steam is used for getting electrical energy. In this type of cycle, no extra fuel is required to produce electricity, as fuel is already burnt in production process.

P.) What are the advantages of total energy system? 12/s, 15/s 12/F, 10/S

⇒ Total energy system can be used whenever thermal energy is needed in addition to electrical and possibly mechanical energy and where the required quantities of energy allow an economic combination of these types:

- Private households are best served by public utilities. Public utilities operates one or several systems and supply the user with electric power and heating energy.

- Public service facilities such as hospitals, office buildings, super markets and industries operate their own total energy systems which however are coordinated with the public utilities to meet their special requirements.

Advantages of total energy systems are:

(i) Cost efficiency:

A total energy system requires additional expenditure for maintenance and supervision, compared to conventional energy utilities, the electric energy and thermal energy can be sold more cheaply since the utilization is about twice as good.

(ii) Reliability:

Since the operation of a total energy systems subdivides the total output several units, necessary maintenance operation requires that only a small part of the overall output must be shut down at any time. Where a standby unit is included in the system, there will be 100% dependability even in the even of maintenance operations or failure of any one unit.

iii) Flexibility:

Increasing energy requirements can be met in an optimum manner by developing a total energy systems in several stages.

iv). Independence:

Total energy systems are independent of external effects. There will not be any frequently fluctuation and voltage peaks due to automatic control and supervision.

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Q. With the help of simple design/diagram, discuss how the waste heat from thermal power plant is utilized to produce process steam and power. 20/S, 22/F

⇒

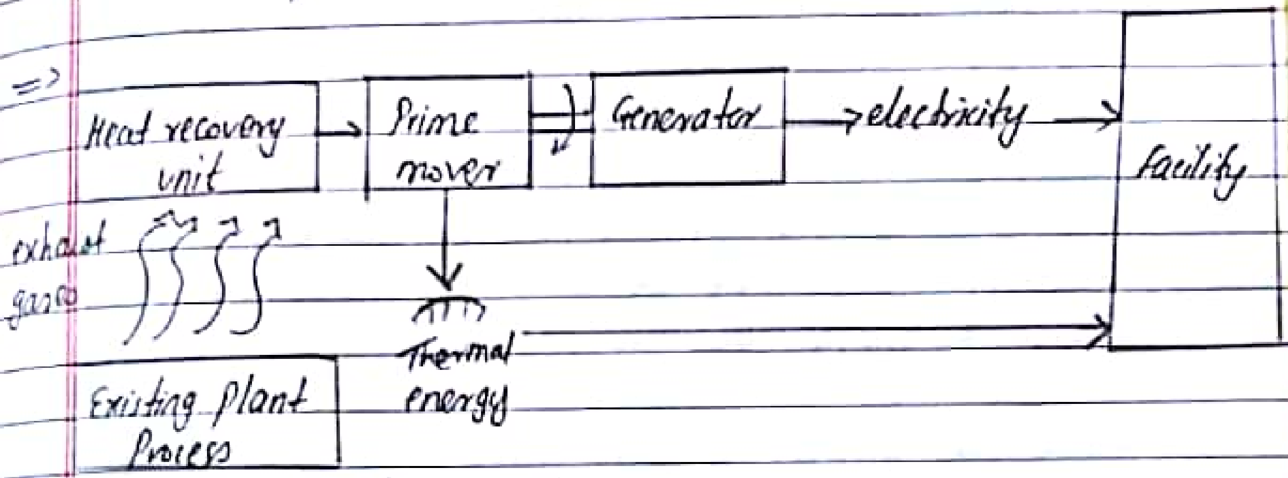

Fig: Bottoming cycle CHP.

The primary fuel produces high temperature thermal energy and the heat rejected from the process is used to generate power through a recovery boiler and a turbine generator. Bottoming cycles are suitable for manufacturing processes that requires heat at high temperature in furnances and kilns, and reject heat at significantly high temperature. Typical areas of application include cement, steel, ceramic gas, and petrochemical industries. Bottoming cycle plants are much less common than the topping cycle plants.

The waste gases coming out of the furnance is utilized in a burner to generate steam which drives the turbine to produce electricity/power.

Q. What are the methods to maintain constant speed of the wind plant. 24/S

⇒ Variable speed fixed pitch configuration continuously adjusts the rotor speed relative to the wind speed through power

electronics controlling the synchronous speed of generator.
This type of control assumes that the generator is from the grid so that the generator's rotor and drive train are free to rotate independently of grid frequency.
Fixed pitch relies heavily on the blades design to limit power through passive stalling.

- Fixed speed variable pitch configuration operates at a fixed pitch angle below the rated wind speed & continuously adjusts the angle above the rated wind speed.

5. Name the different types of turbine generally used in Hydropower plant. 16/F

⇒ Impulse turbine:
- Pelton
- Turgo
- crossflow
- multi jet pelton
- undershot waterwheel.

(ii) Reaction turbine:
- Francis turbine
- propeller "
- Kaplan "

(iii) Gravity type:
- overshot waterwheel.
- Archimedes screw.

7. What is solar energy? Discuss in brief, the following methods to convert solar energy to electrical energy.

(i) Direct conversion method 16/F.
(ii) Conventional boiler ".

=> Solar energy is energy created by the heat and light of the sun. Solar energy is radiant light and heat from the sun that is harnessed using a range of ever evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis.

methods to convert solar energy to electrical energy:

(i) Direct conversion method = PV system = solar voltaic system
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(ii) Conventional Boiler method:
- Parabolic trough system
- A dish/ engine "
- A power tower "
- Solar powe " power plant.
- solar chimney power plants.

v. Compressed Air energy storage: 16/F, 17/S, 15/S, 73/F, 71/S

The purpose of the compressed air energy storage is to help manage the supply of electricity in the grid. For example, when the wind blows, a wind turbine will produce power, but this power may be produced when there is no demand for it. At this time, it becomes necessary for us to be able to store the electricity, so we can use it when there is a peak demand. Compressed air energy storage is the second biggest form of energy storage currently behind pumped storage.

Compressed air energy storage involves converting electrical energy into high pressure compressed air that can be released at a later time to drive a turbine generator to produce electricity. This means it can work alongside technologies such as wind turbines to provide and store electricity

The surplus energy is pumped and compressed into storage tanks on smaller scale, but on utility scale stored in underground caverns. The amount of energy that is stored in compressed air is directly related to the air's density. The storage tank or cavern that holds this air has to be robust enough to handle the high pressure and density. carbon fiber is usually the material used in storage tanks on smaller scale, while salt caverns store compressed air much as we would with natural gas on utility scale.

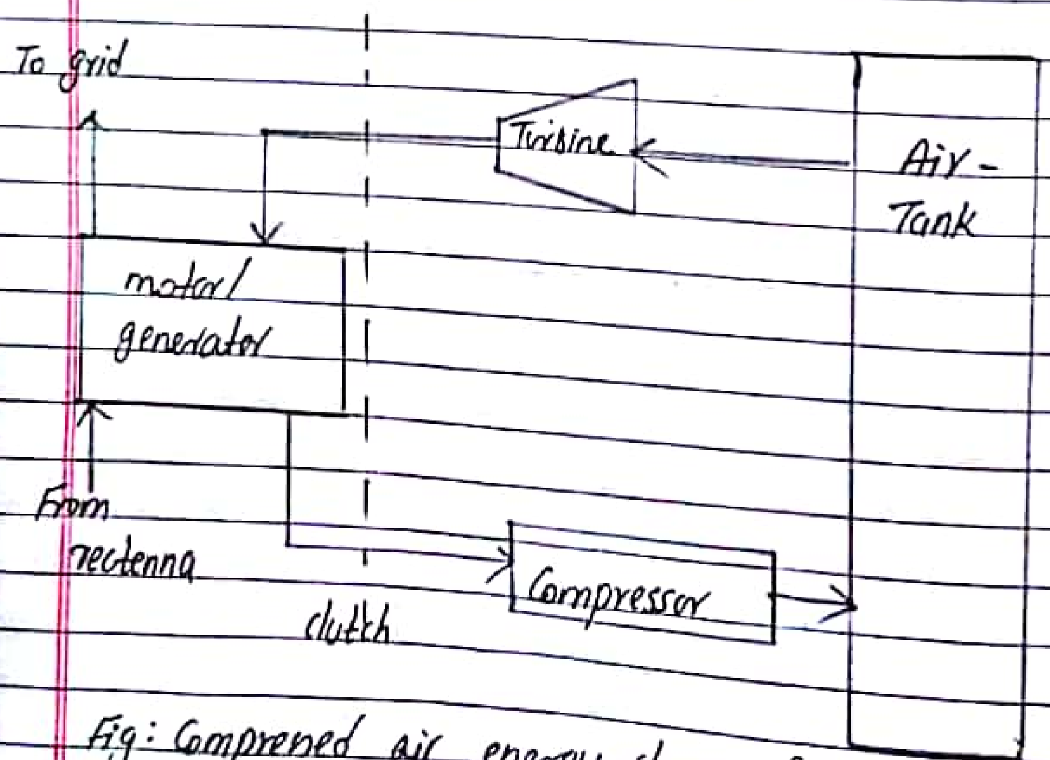


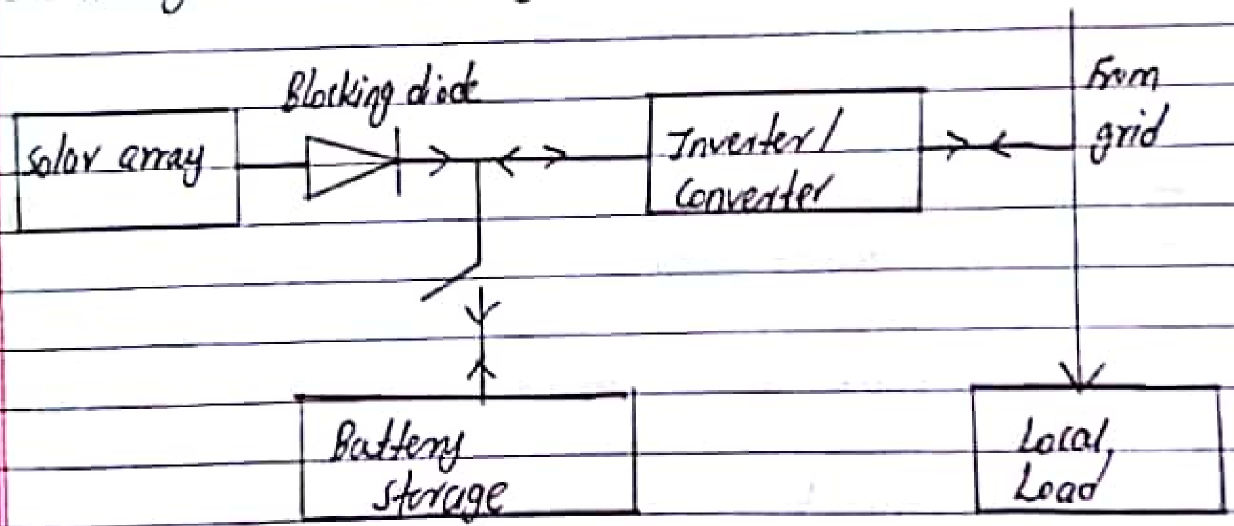
Fig: Compressed air energy storage Block diagram.

Compressed air energy storage plants are gas turbines plants with a compresser and a separate turbine. Each turbine is linked to a motor/generator through a clutch. With a CAES system, the energy received from the rectenna is used to run the compressor. The compressed air is then stored in a tank that if available could be a huge underground cavern.

When energy is needed, air from the tank is released, expanded and sent through the turbine. The shaft of the turbine then turns a generator and the energy produced is transferred to the utility grid.

V. Basic photovoltaic system integrated with Grid:

A basic photovoltaic system consists of (i) Solar array (ii) Blocking diode (iii) Battery storage (iv) Inverter/Converter



The solar array converts the insolation of the sun to useful DC electric power. The blocking diode lets array generated power flow only towards the battery or grid. When the power generated by the solar cell array is more than required by the local load, it is used to charge the battery. The inverter is provided (solid state) to convert battery dc voltage to AC

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of frequency and phase to match with that of grids so that the system can be integrated.

W. classification of power plants:

(I) Conventional power plants
(II) non- " " "

(I) Conventional power plants:
- steam engines Power plant
- " turbine " "
- Diesel " "
- Gas turbine " "
- Hydro - electric " "
- Nuclear " "

(II) Non conventional power plants:

- Thermo electric generator
- Thermo ionic "
- Fuel cells power plant
- MHD power "
- Fusion reactor & NPP power plant
- wave and Tidal wave
- energy plantation scheme
- ocean thermal energy conversion (OTEC)
- photovoltaic solar cells power system.
- Bio gas, Biomass energy power system.
- Geo thermal energy.

X. World energy consumption
Source: IEA electricity information, 2024

Coal = 40.2 %
Gas = 22.4 %
Nuclear = 10.8 %
Hydro = 16.5 %
Solar & wind = 2.7 %
other = 7.4 %

Y. A 10 m/s wind is at 1 standard atmosphere and 15°C, find
i) Total power density in the wind stream.
ii) max. obtainable power density
iii) A reasonably obtainable power density
iv) Total power produced if turbine diameter is 120 m.

Sol^n,

=> Air density, $\rho = \dfrac{P}{RT}$

$$= \frac{(1.01325 \times 10^5)}{287 \times (15+273)}$$

$$= 1.226 \ kg/m^3$$

(i) Total power density,

$$\frac{\rho_{total}}{A} = \frac{\rho \cdot V_i^3}{2}$$

$$= 1.226 \times \frac{10^3}{2}$$

$$= 613 \ W/m^3$$

(ii) maximum power density,

$$\frac{\rho_{max}}{A} = \frac{8}{27} \cdot \rho \cdot V_i^3$$

$$= \left(\frac{8}{27}\right) \times 1.226 \times 10^3$$

$$= 363 \ W/m^3$$

(iii) let, $\eta = 40\%$.

Actual power density,

$$\frac{P}{A} = 0.4 \times \left(\frac{P_{wt}}{A}\right)$$

$$= 0.4 \times 613$$

$$= 245 \ W/m^3$$

iv) Total power produced,

$$P = \left(\frac{P}{A}\right) \times \frac{\pi D^2}{4}$$

$$= 0.245 \times \pi \times \frac{120^2}{4}$$

$$= 2770 \ KW$$

Z: selection of type of Generation:

while choosing the type of generation, the following points should be taken into consideration:

(i) Fuel transportation cost
(ii) plant life
(iii) cost of transmitting the energy.
iv. Reliability in operation.
v. availability of cooling water
vi. The type of load to be taken by the power plant.
vii. Foundation cost.
viii) land required.
ix. Type of fuel available or availability of suitable sites for water power generation.

2) A. A number of electrical equipments which are available in a power plant are listed below:

- Generators
- Transformers
- Exciters
- Reactors
- Busbars
- Switch gear and protective equipment
- Control Board equipment
- circuit Breakers
- standby generators etc.

B) Nuclear power plant site selection:

- meterology
- seismology
- population distribution
- Geology
- Hydrology
- Land use
- Proximity to load centre.

K). Explain in detail the various methods of converting solar energy into electrical energy. 11K

⇒ In the solar power plant, solar energy is used to generate electricity. Sunrays are focused using concave reflectors on to copper tubes filled with water and painted black outside.

The water in the tubes then boils and become steam. This steam is used to drive steam turbine, which in turn causes the generator to work.

(I) Parabolic trough systems: 1b/F
" " " concentrate the sun's energy through long rectangular, curved mirrors. The mirrors are tilted towards the sunlight, focusing sunlight on a pipe that runs down the center of the trough. This heats the oil flowing through the pipe. The hot oil then is used to boil water in a conventional steam generator to produce electricity.

(II) A dish/engine system: 1b/F
" " " uses a mirrored dish. The dish shaped surface collects and concentrates the sun's heat onto a receiver, which absorbs the heat and transfers it into fluid within the engine. The heat causes the fluid to expand against the piston or turbine to produce mechanical power. The mechanical power is then used to run a generator or alternator to produce electricity

(III) A power tower system: 1b/F
" " " uses a large field of mirrors to concentrate sunlight onto the top of a tower, where a receiver sits. This heats molten salt flowing through the receiver. Then, the salt's heat is used to generate electricity through a conventional steam generator. molten salt retains heat efficiently, so it can be stored for days before being converted into electricity. That means electricity can be produced on cloudy days or even several hours after sunset.

iv) Solar power tower power plant : 16 IF

The first is the solar power plant tower design which uses thousands of sun tracking reflectors or heliostats to direct and concentrate solar radiations onto a boiler located a top of tower. The temperature in the boilers rises to 500°–7000°C & the steam raised can be used to drive a turbine, which in turn drives an electricity producing turbine. These are also called as central received solar power plants.

v) Solar chimney power plants : 16 IF

The air steam is heated by solar radiation absorbed by the ground and covered by a transparent cover. The hot air flow through or chimney which gives the air a certain velocity due to pressure drop caused by chimney effect. The hot air flows through an air turbine to generate power.

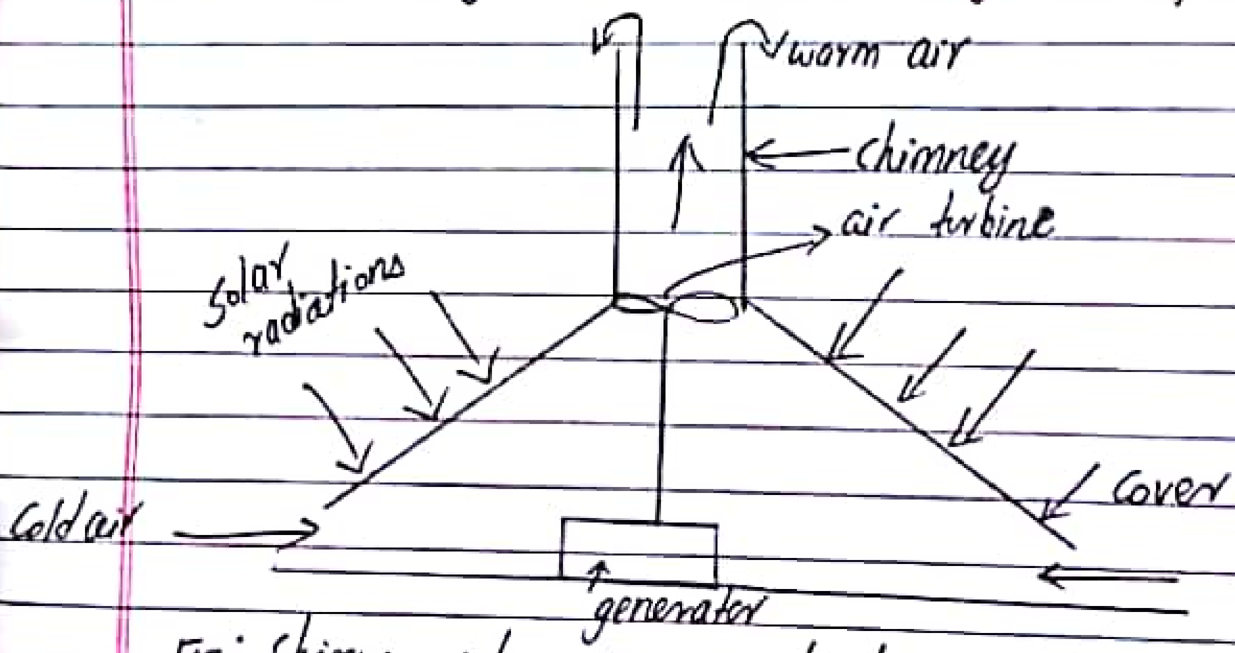

Fig: chimney solar power plant.

2.1 Storage Systems

Energy storage technologies are of great interest to electric utilities, energy service companies, and automobile manufacturers (for electric vehicle application). The ability to store large amounts of energy would allow electric utilities to have greater flexibility in their operation because with this option the supply and demand do not have to be matched instantaneously. The availability of the proper battery at the right price will make the electric vehicle a reality, a goal that has eluded the automotive industry thus far. Four types of storage technologies (listed below) are discussed in this section, but most emphasis is placed on storage batteries because it is now closest to being commercially viable. The other storage technology widely used by the electric power industry, pumped-storage power plants, is not discussed as this has been in commercial operation for more than 60 years in various countries around the world.

- Flywheel storage
- Compressed air energy storage
- Superconducting magnetic energy storage
- Battery storage

2.1.1 Flywheel Storage

Flywheels store their energy in their rotating mass, which rotates at very high speeds (approaching 75,000 rotations per minute), and are made of composite materials instead of steel because of the composite's ability to withstand the rotating forces exerted on the flywheel. In order to store energy the flywheel is placed in a sealed container which is then placed in a vacuum to reduce air resistance. Magnets embedded in the flywheel pass near pickup coils. The magnet induces a current in the coil changing the rotational energy into electrical energy. Flywheels are still in research and development, and commercial products are several years away.

2.1.2 Compressed Air Energy Storage

As the name implies, the compressed air energy storage (CAES) plant uses electricity to compress air which is stored in underground reservoirs. When electricity is needed, this compressed air is withdrawn, heated with gas or oil, and run through an expansion turbine to drive a generator. The compressed air can be stored in several types of underground structures, including caverns in salt or rock formations, aquifers, and depleted natural gas fields. Typically the compressed air in a CAES plant uses about one third of the premium fuel needed to produce the same amount of electricity as in a conventional plant. A 290-MW CAES plant has been in operation in Germany since the early 1980s with 90% availability and 99% starting reliability. In the U.S., the Alabama Electric Cooperative runs a CAES plant that stores compressed air in a 19-million cubic foot cavern mined from a salt dome. This 110-MW plant has a storage capacity of 26 h. The fixed-price turnkey cost for this first-of-a-kind plant is about $400/kW in constant 1988 dollars.

The turbomachinery of the CAES plant is like a combustion turbine, but the compressor and the expander operate independently. In a combustion turbine, the air that is used to drive the turbine is compressed just prior to combustion and expansion and, as a result, the compressor and the expander must operate at the same time and must have the same air mass flow rate. In the case of a CAES plant, the compressor and the expander can be sized independently to provide the utility-selected "optimal" MW charge and discharge rate which determines the ratio of hours of compression required for each hour of turbine-generator operation. The MW ratings and time ratio are influenced by the utility's load curve, and the price of off-peak power. For example, the CAES plant in Germany requires 4 h of compression per hour of generation. On the other hand, the Alabama plant requires 1.7 h of compression for each hour of generation. At 110-MW net output, the power ratio is 0.818 kW output for each kilowatt input. The heat rate (LHV) is 4122 BTU/kWh with natural gas fuel and 4089 BTU/kWh with fuel oil. Due to the storage option, a partial-load operation of the CAES plant is also very flexible. For example, the heat rate of the expander increases only by 5%, and the airflow decreases nearly linearly when the plant output is turned down to 45% of full load. However, CAES plants have not reached commercial viability beyond some prototypes.

2.1.3 Superconducting Magnetic Energy Storage

A third type of advanced energy storage technology is superconducting magnetic energy storage (SMES), which may someday allow electric utilities to store electricity with unparalled efficiency (90% or more). A simple description of SMES operation follows.

The electricity storage medium is a doughnut-shaped electromagnetic coil of superconducting wire. This coil could be about 1000 m in diameter, installed in a trench, and kept at superconducting temperature by a refrigeration system. Off-peak electricity, converted to direct current (DC), would be fed into this coil and stored for retrieval at any moment. The coil would be kept at a low-temperature superconducting state using liquid helium. The time between charging and discharging could be as little as 20 ms with a round-trip AC–AC efficiency of over 90%.

Developing a commercial-scale SMES plant presents both economic and technical challenges. Due to the high cost of liquiud helium, only plants with 1000-MW, 5-h capacity are economically attractive. Even then the plant capital cost can exceed several thousand dollars per kilowatt. As ceramic superconductors, which become superconducting at higher temperatures (maintained by less expensive liquid nitrogen), become more widely available, it may be possible to develop smaller scale SMES plants at a lower price.

2.1.4 Battery Storage

Even though battery storage is the oldest and most familiar energy storage device, significant advances have been made in this technology in recent years to deserve more attention. There has been renewed interest in this technology due to its potential application in non-polluting electric vehicles. Battery systems are quiet and non-polluting, and can be installed near load centers and existing suburban substations. These have round-trip AC–AC efficiencies in the range of 85%, and can respond to load changes within 20 ms. Several U.S., European, and Japanese utilities have demonstrated the application of lead–acid batteries for load-following applications. Some of them have been as large as 10 MW with 4 h of storage.

The other player in battery development is the automotive industry for electric vehicle application. In 1991, General Motors, Ford, Chrysler, Electric Power Research Institute (EPRI), several utilities, and the U.S. Department of Energy (DOE) formed the U.S. Advanced Battery Consortium (USABC) to develop better batteries for electric vehicle (EV) applications. A brief introduction to some of the available battery technologies as well some that are under study is presented in the following (Source: http://www.eren.doe.gov/consumerinfo/refbriefs/fa1/html).

2.1.4.1 Battery Types

Chemical batteries are individual cells filled with a conducting medium-electrolyte that, when connected together, form a battery. Multiple batteries connected together form a battery bank. At present, there are two main types of batteries: primary batteries (non-rechargeable) and secondary batteries (rechargeable). Secondary batteries are further divided into two categories based on the operating temperature of the electrolyte. Ambient operating temperature batteries have either aqueous (flooded) or nonaqueous electrolytes. High operating temperature batteries (molten electrodes) have either solid or molten electrolytes. Batteries in EVs are the secondary-rechargeable-type and are in either of the two subcategories. A battery for an EV must meet certain performance goals. These goals include quick discharge and recharge capability, long cycle life (the number of discharges before becoming unserviceable), low cost, recyclability, high specific energy (amount of usable energy, measured in watt-hours per pound [lb] or kilogram [kg]), high energy density (amount of energy stored per unit volume), specific power (determines the potential for acceleration), and the ability to work in extreme heat or cold. No battery currently available meets all these criteria.

2.1.4.2 Lead–Acid Batteries

Lead–acid starting batteries (shallow-cycle lead–acid secondary batteries) are the most common battery used in vehicles today. This battery is an ambient temperature, aqueous electrolyte battery. A cousin to this battery is the deep-cycle lead–acid battery, now widely used in golf carts and forklifts. The first electric cars built also used this technology. Although the lead–acid battery is relatively inexpensive, it is very heavy, with a limited usable energy by weight (specific energy). The battery's low specific energy and poor energy density make for a very large and heavy battery pack, which cannot power a vehicle as far as an equivalent gas-powered vehicle. Lead–acid batteries should not be discharged by more than 80% of their rated capacity or depth of discharge (DOD). Exceeding the 80% DOD shortens the life of the battery. Lead–acid batteries are inexpensive, readily available, and are highly recyclable, using the elaborate recycling system already in place. Research continues to try to improve these batteries.

A lead–acid nonaqueous (gelled lead acid) battery uses an electrolyte paste instead of a liquid. These batteries do not have to be mounted in an upright position. There is no electrolyte to spill in an accident. Nonaqueous lead–acid batteries typically do not have as high a life cycle and are more expensive than flooded deep-cycle lead–acid batteries.

2.1.4.3 Nickel Iron and Nickel Cadmium Batteries

Nickel iron (Edison cells) and nickel cadmium (nicad) pocket and sintered plate batteries have been in use for many years. Both of these batteries have a specific energy of around 25 Wh/lb (55 Wh/kg), which is higher than advanced lead–acid batteries. These batteries also have a long cycle life. Both of these batteries are recyclable. Nickel iron batteries are non-toxic, while nicads are toxic. They can also be discharged to 100% DOD without damage. The biggest drawback to these batteries is their cost. Depending on the size of battery bank in the vehicle, it may cost between $20,000 and $60,000 for the batteries. The batteries should last at least 100,000 mi (160,900 km) in normal service.

2.1.4.4 Nickel Metal Hydride Batteries

Nickel metal hydride batteries are offered as the best of the next generation of batteries. They have a high specific energy: around 40.8 Wh/lb (90 Wh/kg). According to a U.S. DOE report, the batteries are benign to the environment and are recyclable. They also are reported to have a very long cycle life. Nickel metal hydride batteries have a high self-discharge rate: they lose their charge when stored for long periods of time. They are already commercially available as "AA" and "C" cell batteries, for small consumer appliances and toys. Manufacturing of larger batteries for EV applications is only available to EV manufacturers. Honda is using these batteries in the EV Plus, which is available for lease in California.

2.1.4.5 Sodium Sulfur Batteries

This battery is a high-temperature battery, with the electrolyte operating at temperatures of 572°F (300°C). The sodium component of this battery explodes on contact with water, which raises certain safety concerns. The materials of the battery must be capable of withstanding the high internal temperatures they create, as well as freezing and thawing cycles. This battery has a very high specific energy: 50 Wh/lb (110 Wh/kg). The Ford Motor Company uses sodium sulfur batteries in their Ecostar, a converted delivery minivan that is currently sold in Europe. Sodium sulfur batteries are only available to EV manufacturers.

2.1.4.6 Lithium Iron and Lithium Polymer Batteries

The USABC considers lithium iron batteries to be the long-term battery solution for EVs. The batteries have a very high specific energy: 68 Wh/lb (150 Wh/kg). They have a molten-salt electrolyte and share many features of a sealed bipolar battery. Lithium iron batteries are also reported to have a very long cycle life. These are widely used in laptop computers. These batteries will allow a vehicle to travel distances and accelerate at a rate comparable to conventional gasoline-powered vehicles. Lithium polymer batteries eliminate liquid electrolytes. They are thin and flexible, and can be molded into a variety of shapes and sizes. Neither type will be ready for EV commercial applications until early in the 21st century.

2.1.4.7 Zinc and Aluminum Air Batteries

Zinc air batteries are currently being tested in postal trucks in Germany. These batteries use either aluminum or zinc as a sacrificial anode. As the battery produces electricity, the anode dissolves into the electrolyte. When the anode is completely dissolved, a new anode is placed in the vehicle. The aluminum or zinc and the electrolyte are removed and sent to a recycling facility. These batteries have a specific energy of over 97 Wh/lb (200 Wh/kg). The German postal vans currently carry 80 kWh of energy in their battery, giving them about the same range as 13 gallons (49.2 liters) of gasoline. In their tests, the vans have achieved a range of 615 mi (990 km) at 25 miles per hour (40 km/h).

1.A Technical characteristics of other power plants :

Solar powerplants –
– Solar cells
– Charger and Inverters
– Batteries
– Costing and design
– Some statistics

Other power plants
Wind powerplants –
– conceptual description, environmental impacts, characteristics
– uses for irrigation and power

Tidal powerplants –
– conceptual description, environmental impacts, characteristics

Nuclear powerplant –
– Principles, environmental impacts, characteristics

Internal Combustion – Oil and gas – basics

Biomass–
– basics,
– conceptual description, environmental impacts, characteristics
– drying and transportation, gasification, steam or combined cycle.

Geothermal and Thermal
– principle and processes in brief, environmental impacts, characteristics

1.B Power Plant Design

• Design Guidelines and Standards applicable for electrical system design
• Electro-Mechanical Componentsof Hydro-Power plant.
• Electro-mechanical Design of Hydro Power Plants - Turbine selection, general mechanical parameters
• Electrical Scheme and Bus selection
• Generator Design parameters
• Excitation system selection
• Circuit Breaker selection
• Transformer selection
• Auxiliaries selection
• Ancillaries selection
• Control, Instrumentation and SCADA

10 Hours

2) Electric Power Generations :

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2.1) Technical characteristics of various alternatives for electric Power generation :

⇒ Already discussed in chapter -1
Technical characteristics of various power plant:
- steam power plant
- Hydro " "
- Diesel " "
- Solar, wind, geothermal and biomass power plants.

2.2) Comparative study of pollution and environmental hazards caused by different types of power plants :

A) Hydro power plants : 17/S, 14/F, 16/F, 14/S

i) A dam that creates a reservoir may obstructs fish migration. A dam and reservoir can also change natural water temperature, water chemistry, river flow characteristics and silt loads. All of these changes can affect the ecology and physical characteristics of the river. These changes may have negative effects on the native plants and on animals in and around the river.

ii) manufacturing the concrete and steel in hydropower dams requires equipment that may produce emissions.

iii) Greenhouse gases such as carbon dioxide and methane may also form in reservoirs and be emitted into atmosphere. The exact amount of greenhouse gases that form in hydropower reservoirs is uncertain.

iv) Hydropower dams are responsible for the extinction & near extinction of a number of species. and are a major contributor to the significant loss of aquatic biodiversity.

v) Hydropower plants often divert water around entire sections of river, leaving them dry or worse constantly alternating between unnatural drought and flood like conditions.

B) steam Power Plants : 17/S, 17/F, 15/F, 14/F, 13/S, 12/F, 18/F, 16/F, 14/S

- changes the local ecosystem
- Huge impacts on environment and health.
- High particulate matter emission levels due to burning of inferior grade coal which leads to generation of large quantities of fly ash. emission of SO_2, NOx and green house gas (CO_2) are also matter of concern.

- mainly caused by the effluent discharge from ash ponds condenser cooling/cooling tower, DM plant and boiler blow down.

- High noise levels due to release of high pressure steam and running of fans and motors.

- The disposal of large quantities of fly ash has occupied thousands hectares of land which includes agricultural and forest land too.

- Smog formation
- effects on photosynthesis of plants.
- water pollution.
- air "
- Noise "

classmate

Date ______
Page ______

15

C) Solar power plants:

i) PV power plants can damage land and ecosystem. large scale PV power plants arise concerns about land degradation & habitat loss. The major influence on the wildlife and habitat is due to land seizure by the power plant itself.

ii) PV power plants can spoil scenic beauty

iii) There is negative effect of hazardous materials during manufacture and operation. The PV cell manufacturing process includes a number of hazardous materials, most of which are used to clean and purify the semiconductor surface.

iv) In addition, thin films PV cells contain a large number of more toxic materials than those used in traditional silicon PV cells.

v) chemical pollution due to battery disposal (mercury, lead).

vi) Due to the limitability of recycling the panels, those recoverable metals may be going to waste which may result in resource scarsity in the future.

D) wind power plants:

i) wind turbine generate noise. wind turbine donot affect human health from noise when properly placed.

ii) The generation of electricity from wind energy using large numbers of wind turbines can disrupt both landscapes & habitats, as well as the rotating turbine blades can sometimes kill birds and bats.

iii) Wind turbine effect on the environment and those living near to the wind farm installation is that of shadow flicker.

E) Geothermal power plants :- 17/S, 16/S, 12/F

i) Drying of hot springs and geysers in the surrounding area leading to loss of scenery and tourism and loss of rare thermophillic plants and algal growth.

ii) Toxic waste water entering clean aquifers due to lowering of the water table.

iii) Violent explosions caused by build up of a steam pillow in empty hot underground reservoirs, which have previously killed people working in geothermal plants.

iv) Landslides can occur due to temperature and water level in rocks, especially in techtonically active areas.

v) Subsidence or sinking of land.

vi) Air and chemical pollution.

vii) Induced earthquakes caused by lubrication of faults when waste fluid is reinjected into the rocks.

F) Nuclear Power Plant : 16/S, 15/F, 14/F, 13/S, 12/F

i) Nuclear energy doesnot produce carbon emissions directly

17

the constructions of plants, uranium mining and manufacturing operations all produces CO2 commisions on a huge scale. This all contributes to global warming.

ii) A major environmental concern related to nuclear power plant is the creation of radioactive wastes such as uranium mill tailings, spent reactor fuel, and other radioactive wastes.

iii) water pollution

iv Fish, plankton and benthos are all effected at various degrees. by thermal discharges from power plants.

G. Ocean thermal energy conversion (OTEC):

i) OTEC facilities would emit an amount of noise pollution.

ii) The physical platform of the system could attract or deter organisms and its mooring would pose the threat of entanglement to marine organisms.

iii) OTEC systems have cable emitting electromagnetic waves in the process of bringing the generated electricity to shore. The EM field could impact navigation and behaviour of marine species.

2.3) Isolated vs Grid connected systems: 17/S, 17/F, 15/F, 20/S

	Interconnected system	Isolated power systems.
i)	on grid system	off grid system
ii)	Reliable during fault condition.	less reliable
iii)	operation is complex.	simple.
iv)	synchronous is needed.	no synchronization.

v).	old power plant also can be used.	Healthy power plant is needed.
vi)	Continuous & uninterruptable power supply if any power plant is under maintenance and fault condition.	No continuous power supply if any p. plant is under maintenance or fault condition.
vii)	Cost of generation is minimal.	more.
viii)	more economical.	less economical.
ix.	Peak load can be meet easily.	Peak load condition cannot be made without proper installed capacity
x.	Generation power plants are connected to the other generation power plant.	Generating power plants are not connected to other generating power plant.
xi	Tariff agreed with utility	Tariff depends on the acceptance of the end users.
xii)	Plant factor limited by the available flow (about 0.5 to 0.6).	Plant factor limited by the demand (0.15 – 0.3 typically).
xiii)	Full automatic control	manually operated.

Load curve, load duration curve:

i) Load factor:

" " indicates how long the peak demand was sustained. ie, $L \cdot F = \frac{\text{avg load}}{\text{max Load}}$

- measures the variation of load.

(ii) Diversity factor:

" " is the ratio of sum of the individual maximum demands of the various subdivisions of a system to the maximum demand of a whole system. It is always more than one.

(iii) Demand factor:

" " is the ratio of sum of the maximum demand of a system to the total connected load on the system. It is always less than 1.

(iv) Plant use factor

$$= \frac{\text{amt of energy generated by plant during given time}}{\text{capacity of plant} \times \text{time use factor}}$$

v) Utilization factor $= \frac{\text{average load}}{\text{plant capacity}}$

vi) Plant capacity factor $= \frac{\text{amt of generated energy}}{\text{Installed capacity} \times \text{time of operation}}$.

vii) Installed capacity = rating of power plant + reserve capacity of power plant.

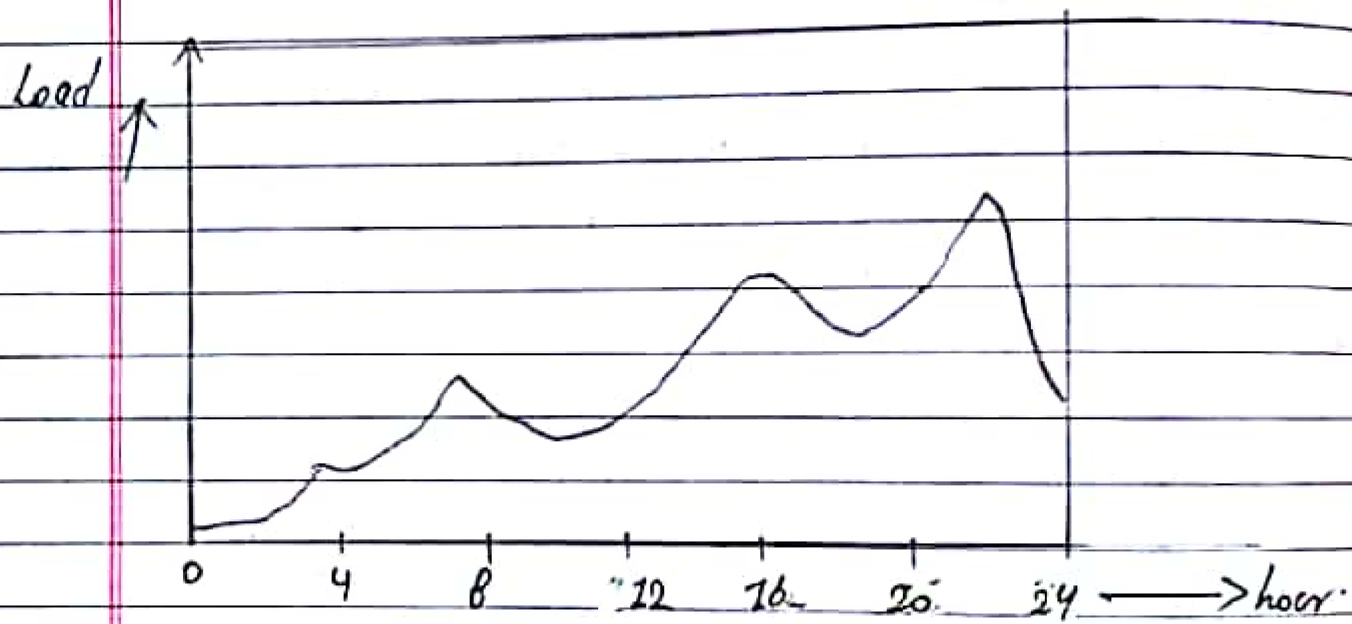
Diversity factor $= \frac{\Sigma \text{individual max load}}{\text{max load of system}}$.

maximum demand $<$ connected load.

Load factor $\propto$ inversely proportional to cost of generation.

viii) Load curve : I4IF.

The curve showing the variation of load on the power station with respect to time is known as load curve. The load curve of power station is never constant; it varies from time to time. The load curve helps in selecting the size and number of generating units. The load curve helps in preparing the operation schedule of the station.



ix) Load duration curve : I4IF

" " " is the arrangement of all load levels in a descending order of magnitude. The area under the LDC represents the energy demanded by the system. It can be used in economic dispatching, system planning and reliability evaluation. It is more convenient to deal with than the load curve.

A load duration curve is used in electric power generation to illustrate the relationship between generating capacity requirements and capacity utilization. It can be extended for any period of time.

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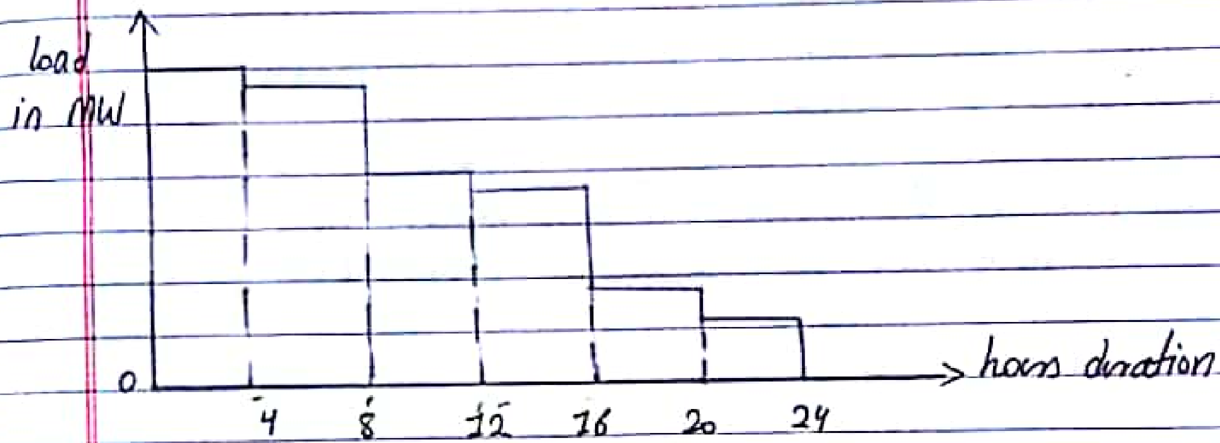
- units generated / day = area under the daily load curve in kW

- Load curve = area under daily load curve / area of rectangle having daily load curve.



$$\text{Average demand} = \frac{\text{kWh consumed in a given period of time}}{\text{hours in the time Period}}$$

$$\text{avg demand} = \frac{\text{area under the load duration curve}}{\text{base of the load duration curve}}$$

A) The maximum demand of power station is 96000 kW and daily load curve is described as below:

Time (hr)	0–6	6–8	8–12	12–14	14–18	18–22	22–24
Load (MW)	48	60	72	60	84	96	48

(i) Determine load factor of power station. 16/5

(ii) What is the load factor of standby equipment rated at 30 MW that takes up all load in excess of 72 MW? Also calculate its use factor.

=> Soln,

max. demand = 96000 kW = 96 MW.

$$\text{Load factor} = \frac{\text{avg load}}{\text{max load}}$$

$= \dfrac{\text{total amt of energy generated in 24 hours}}{24 \times \text{max. load}}$

$= \dfrac{6 \times 48 + 2 \times 60 + 4 \times 72 + 2 \times 60 + 4 \times 84 + 4 \times 96 + 2 \times 48}{24 \times 96}$

or $L.F = \dfrac{1632}{24 \times 96}$

(i) $\therefore L.F = 0.708$

(ii) L.F for standby equipment rated at 30 MW :

$L.F = \dfrac{(84-72) \times 4 + (96-72) \times 4}{96}$

$=$

Plant use factor $= \dfrac{(84-72) \times 4 + (96-72) \times 4}{(4+4) \times 30}$ ⟶ rating of standby equipment

$= \dfrac{144}{8 \times 30}$

$= 0.60$

B). What are benefits of interconnection power system over isolated power system network. 16 LS, 15 LS, 12 IF, 17 LS, 18 IF, 16 IF

⇒ The connection of several generating stations in parallel is known as interconnected grid system. Some of the advantages of interconnected grid system are listed below:

(1) Exchange of Peak loads:

An important advantage of interconnected grid system is that the peak load of the power station can be exchanged. If the load curve of a power station shows peak demand that is greater than the rated capacity of the plant, then the excess load can be shared by other stations interconnected with it.

(ii) use of old plants :

The interconnected grid systems makes it possible to use the older and less efficient plants to carry peak loads of short duration maybe inadequate when used alone yet they have sufficient capacity to carry short peaks of load when interconnected with other modern plants. Hence, interconnected grid system gives a direct key to the use of obsolete plants.

(iii) Ensure economical operation :

The interconnected grid system makes the operation of concerned power station quiet economical. It is because sharing of load among these power stations is arranged in such a way that more efficient stations works continuously throughout the year at a high power factor. And the less efficient plants work for peak load hours only.

(iv) Reduces plant reserve capacity :

Every power station is required to have a standby unit for emergencies. However, when several power stations are connected in parallel, the reserve capacity of the system is much reduced. This increases the system efficiency.

v) Increase diversity factor :

The load curves of different interconnected grid system, are generally different. The result is that maximum demand on the system is much more reduced as compared to the sum of individual maximum demand and different stations. ie, the diversity factor of the system is improved. Hence, increasing the effective capacity of the system.

vi) Increase reliability of supply:

Interconnected grid system increases the reliability of supply. If a major breakdown occurs in one station, continuity of supply can be maintained by other healthy stations.

vii) Savings in operating costs:

In an interconnected system, it would be possible to allocate the total system load to the various individual power stations in the most economic manner and the load dispatching will be fully coordinated resulting in large savings in operating costs.

viii) Provides a means for energy Trading.

c) A generating station has a maximum demand of 10 MW and daily load on the operation is as follows: 15/F, 74/F

Time	demand (kW).	13/S 13/F
11 pm – 6 am	2000	
6 am – 8 am	3000	
8 am – 12 noon	8000	
12 noon – 1 pm	3000	
1 pm – 5 pm	7500	
5 pm – 7 pm	8500	
7 pm – 9 pm	10,000	
9 pm – 11 pm	4500	
11 pm – 12 pm.	2000	

Sol^n,

⇒ maximum demand = 10 MW

Choose size and no of generating units. what reserve is necessary. Also find load factor & plant capacity

Scanned by CamScanner

latter:

Time	23-6	6-8	8-12	12-13	13-17	17-19	19-21	21-23
Load (MW)	2	3	8	3	7.5	8.5	10	4.5

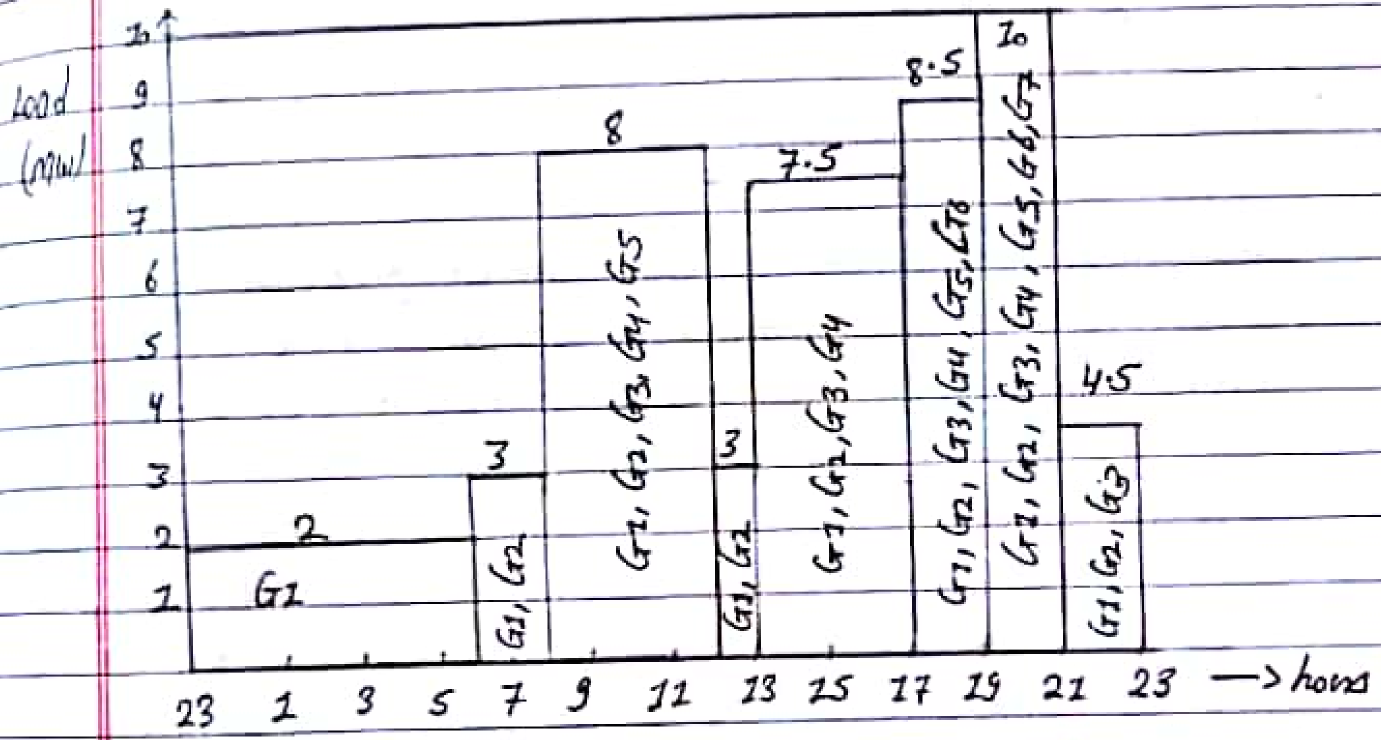


Fig: Load curve.

∴ sizes and no of generating units:

$G_1 = 2$ MW

$G_2 = 1$ MW

$G_3 = 1.5$ MW

$G_4 = 3$ MW

$G_5 = 0.5$ MW

$G_6 = 0.5$ MW

$G_7 = 1.5$ MW

Reserve capacity :

The size of reserve capacity plant is always taken as equal to size of largest generating unit. It is always taken as 1 in quantity.

Hence, reserve capacity = 2 MW

load factor $= \frac{7\times2 + 2\times3 + 4\times8 + 1\times3 + 4\times7.5 + 2\times8.5 + 2\times10 + 2\times4.5}{24\times10}$

$= \frac{131}{240}$

$\therefore$ LF $= 0.545$

$\therefore$ Plant capacity factor $= \frac{\text{average amt of generated energy}}{\text{Installed capacity} \times \text{time of operation}}$

Installed capacity $= 2+1+1.5+3+0.5+0.5+1.5+2$
$= 12$ MW

PCF $= \frac{131}{12\times24}$

$\therefore$ PCF $= 0.455 = 45.50\ \%$

$\therefore$ Plant use factor $= \frac{\text{amt of energy generated by plant}}{\text{capacity of plant} \times \text{time of operation}}$

$= \frac{131}{131} \times 100$

$= 1 \times 100$

$= 100\ \%$

$\therefore$ utilization factor $= \frac{\text{max. demand of system}}{\text{rated system capacity}}$

$= \frac{10}{12}$

$= 0.833$

Reserve capacity = Installed capacity − Peak demand.

daily energy produced = average demand $\times$ 24

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1). Peak demand of a generating station is 90 MW and load factor is 0.60. The plant capacity factor and plant use factor are 0.50 and 0.80 resp. Determine (i) daily energy produced (ii) installed capacity of plant. (iii) reserve capacity (iv) utilization factor.

sol^n,

$\Rightarrow$ maximum demand = 90 MW
load factor = 0.60

$\therefore$ avg demand = max. demand X load factor
= 90 X 0.60
= 54 MW

$\therefore$ Daily energy produced = average demand X 24
= 54 X 24
(i) = 1296 MWhr.

(ii) plant factor = $\dfrac{\text{actual energy produced}}{\text{maximum plant rating X T}}$

maximum plant rating = $\dfrac{1296}{0.50 \times 24}$
= 108 MW

$\therefore$ Installed capacity = 108 MW

(iii) Reserve capacity = Installed capacity − Peak demand
= 108 − 90 MW
= 18 MW

(iv) utilization factor = $\dfrac{\text{max demand of system}}{\text{Rated system capacity}}$
= $\dfrac{90}{108}$
= 0.833

E) The daily demand of 3 consumers are given below 72k

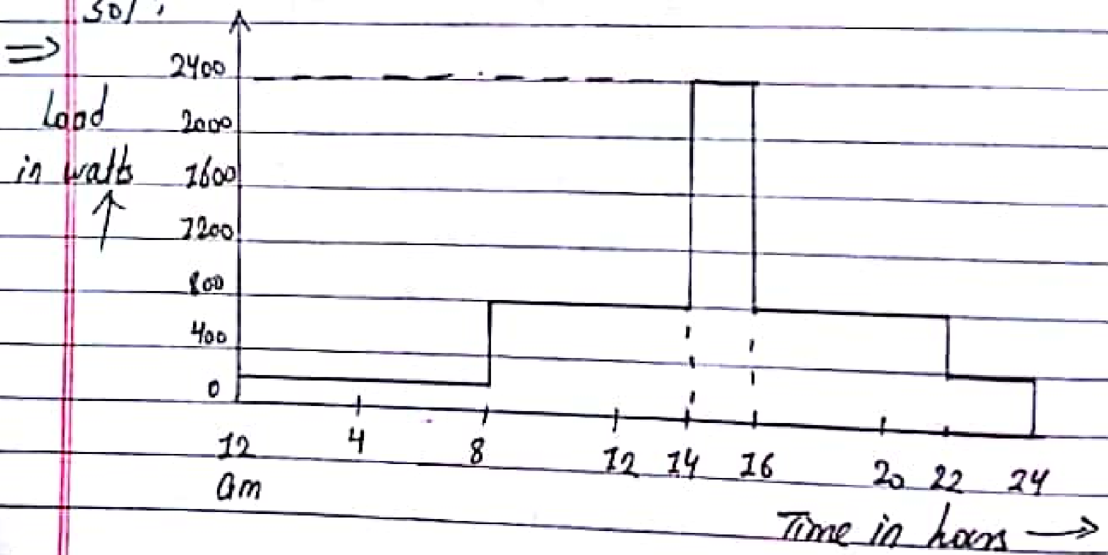
Time	Consumer-1	2	3
12 mid night - 8 am	No load	200 W	No load
8 am - 2 pm	600 W	No load	200 W
2 pm - 4 pm	200 W	1000 W	1200 W
4 pm - 10 pm	800 W	No load	No load
10 pm - midnight	No load	200 W	200 W

plot the load curve and

i) Diversity factor.
ii) Load factor of station
iii) " " of individual consumer
iv) max. demand of individual consumer.

Sol^n.

$\Rightarrow$



(i) max demand of Consumer 1 = 800 W
" " " " 2 = 1000 W
" " " " 3 = 1200 W

(ii) LF of Consumer 1 = $\dfrac{\text{energy consumed/day}}{\text{max demand} \times \text{hours in a day}} \times 100$

$$= \frac{600 \times 6 + 200 \times 2 + 800 \times 6}{800 \times 24} \times 100$$

$= 45.8\ \%$

LF for consumer 2 $= \frac{200 \times 8 + 1000 \times 2 + 200 \times 2}{1000 \times 24} \times 100$

$= 16.7\ \%$

LF for consumer 3 $= \frac{200 \times 6 + 1200 \times 2 + 200 \times 2}{1200 \times 24} \times 100$

$= 13.8\ \%$

(iii) The simultaneous max demand on the station is $200 + 1000 + 1200 = 2400$ W and occurs from 2 pm to 4 pm

$\therefore$ Diversity factor $= \frac{800 + 1000 + 1200}{2400}$

$= 1.25$

iv) Station load factor $= \frac{\text{total energy consumed / day}}{\text{simultaneous max demand} \times 24} \times 100$

$= \frac{8800 + 4000 + 4000}{2400 \times 24} \times 100$

$= 29.1\ \%$

E) Importance of load factor / high load factor : 12ls, 11ls, 16ls

- Load factor is defined as the total load divided by the peak load in a specified time period. It is a measure of the utilization rate or efficiency of electrical energy usage; a low load factor i.e. indicates that load is not putting a strain on the electric system, whereas the consumers or generators with that put more of a strain on the electric distribution will have a high load factor.

- A high load factor means greater total output.
- A " " " " fixed costs are spread over more

KwH of output.

- A power plant may be less efficient at low load factors.

- A high load factor indicates high usage of the system's equipment and is a measure of efficiency. High load factor consumers are normally very desirable from a utility's point of view.

- Higher load factor means lesser maximum demand indicating reduced cost per unit generated.

G. Spinning Reserve : 7bk

Spinning reserve is the online reserve capacity that is synchronized to the grid system and ready to meet electric demand within 10 minutes of a dispatch instruction by the ISO. Spinning reserve is needed to maintain system frequency stability during emergency operating conditions and unforeseen load swings.

The spinning reserve is the extra generating capacity that is available by increasing the power output of generators that are already connected to the power system. For most generators, this increase in power output is achieved by increasing the torque applied to the turbine's rotor.

Spinning is derived from hydroelectric and combustion turbine technology. Reserve generator turbines can literally be kept spinning without producing any energy as a way to reduce length of time required to bring them online when needed.

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Spinning reserve = the unused capacity which can be activated on decision of the system required.

- Spinning reserve is provided by devices that are synchronized to the network and able to affect its active power.

- Also known as synchronized reserve.

H) Explain how the electricity generation cost is reduced by improving system load factor. 15/S, 71/S, 12/F, 16/F, 16/S

⇒ The load factor corresponds to the ratios between the actual energy consumption (kWh) and the maximum power recorded (demanded) for that period of time. Keeping the demand stable and increasing the consumption is often a cost effective way to increase production while maximizing the use of the power.

$$\text{Load factor} = \frac{\text{Consumption during the period}}{\text{Demand} \times \text{no of hours in that period}} \times 100$$

- A high load factor means power usage is relatively constant. Higher load factor means lesser maximum demand indicating reduced cost per unit generated.

I. What are the factors to be taken into consideration in selecting a site for a thermal power plant? 70/S, 75/F

⇒ Factors for selecting a site for thermal power plant are:

i) Transportation network:

Easy and enough access to transportation network is required in both power plant construction and operation.

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ii) Gas pipe network:

vicinity of the gas pipes reduces the required expenses.

iii) Power transmission network:

To transfer the generated electricity to the consumers, the plant should be connected to electrical transmission system.

iv) Geology, soil type and topography:

- need an area with soil and rock layers that could stand the weight and vibrations of the power plant.
- no high elevation topography.

v) water resources:

For the construction and operation of power plant different volumes of water are required.

vi) Environmental resources:

priority will be given to the locations that are far enough from national parks, wildlife protected area etc.

vii) Population centres:

The site should have an enough distance from population centres.

viii) climate:

parameters such as temperature, humidity, wind directions and speed affect the productivity of power plants and always should be taken into consideration.

ix) Availability of labor:

x. Public problems.
xi) Ash disposal facility
xii) Cost and type of land.
xiii) Nearness to load centers.

xi Ash disposal facilities:
Ash comes out in hot condition and handling is difficult. The ash can be disposed into sea or river.

J. What are the disadvantages of interconnected grid system? 18F

⇒ The fault level of the system increases as more & more power sources are connected. In case of any fault at any point, heavy fault current flow which are fed from sources, causing heavy voltage dip in the system. Thus, the ratings of the electrical equipment, cables etc have to be upgraded as per the increased fault level, which causes huge cost.

– The interconnected grid system also requires some extra care, because it's a huge system and huge parts to control or if anything ever happens accidently at any point it will affect the whole system and grid and as well as to the power plants.

– As almost all the power plants are connected in parallel so there is not much standby unit or power plants for emergency so it can be a dangerous in emergency situations.

K. What are the effect of load forecasting uncertainities. Discuss the method of determing load forecasting. 15F, 74S

⇒ Forecasting refers to the prediction of the load behaviour for the future. Load forecasting is used by power company to anticipate the amount of power needed to supply the demand. Forecasting accuracy depends on the quality and quantity of the historical data used, the validity of the forecaster's basic assumptions, and the accuracy of the forecasts of the demand influencing factors.

Advantages of load forecasting:

i). It is flexible and useful for analyzing load growth under different sectors.

ii). It provides separate load forecasts for residential, commercial and industrial loads.

iii). It provides detailed information on future levels of electricity demand, why future electricity demand increases or decreases, and how electricity demand is affected by various factors.

Forecasting Techniques:

3 broad categories based on:

① Extrapolation:

- Based on curve fitting to previous data available.
- With the trend curve obtained from curve fitted load can be forecasted at any future point.
- Simple method and reliable in some cases
- Deterministic extrapolation
- Probabilistic "
- Best trend curve is obtained using regression analysis.

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(ii) Correlation:
- relates system loads to various demographic and economic factors
- Knowledge about the interrelationship between nature of load growth and other measurable factors.
- No forecasting method is effective in all situations.
- Designer must have good judgement and experience to make a forecasting method effective.

methods of load forecasting:

(i) methods of short term load forecasting:
- similar day approach
- Regression methods
- Time series
- Neural networks
- Expert systems
- Fuzzy logic.

(ii) medium and long term forecasting:
- Historical data
- weather "
- no of customers in different categories.
- end use and econometric approach are broadly used.

4). With the help of a load curve, discuss about the reserve capacity needed for a plant supplying power to an isolated area. 75|F, 75|S, 70|S

⟹ The load curve is a graph which represents load on generation station recorded at the interval of half hour or hour (time) against the time. The load curve is

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defined as the curve which is drawn between loads Vs time in sequential order. The highest point on the load curve represents the maximum demand on the station on that day.

- The load curve helps in selecting the size & number of generating units. The load curve helps in preparing the operation schedule of the station.

- In an isolated area, power generated from one station is confined in the one station and local supply. So, reserve plant capacity is needed in an isolated area to supply the power to peak loads.
Reserve plant capacity = capacity of units of largest generating size.

- A power station is so designed that it has some reserve capacity for meeting the increased load demand in future.
Reserve capacity = plant capacity − max. demand.

2.4) Generation costs:

A). capital costs:
" " includes the following:
- Initial cost
- Interest
- Taxes
- Insurances.
- Depreciation costs

B) operational costs:

- Fuel costs
- operating labor cost
- supplies
- operating taxes
- supervision
- maintenance costs.

① Initial costs :

Some of the several factors on which cost of a generating station or a power plant depends are ;

- Location of power plant
- Time of construction
- size of units
- number of main generating units.

The initial cost of power station include the following.

- Land cost
- Building cost
- Installation cost
- equipment "
- overhead charges which will include the transportation cost, stores and store keeping charges, interest during constructions

- To reduce the cost of buildings, it is desirable to eliminate the superstructure over the boiler house and as far as possible on turbine house also.

- The cost of equipment can be reduced by adopting unit system system where one boiler is used for one turbogenerator.

① Interest :

Interest is the difference between money borrowed and mony returned. It may be charged at a simple rate expressed as % per annum or may be compounded in which the interest is reinvested and adds to the principal, hence earning more interest in subsequent years.

(III) Depreciation:

Depreciation accounts for the deterioration of the equipment and decrease in its value due to corrosion, wear and tear with use. It also covers the decrease in value of equipments due to absolescence.

IV) operational cost:

The elements that make up the operating expenditure of a power plant include the following costs:

- Costs of fuels
- " " supervision.
- Taxes.
- labour costs.

V) Cost of fuel:

The selection of the fuel and the maximum economy in its use are therefore very important considerations in thermal power plant design. The cost of fuel includes not only its price at the site of purchase but its transportation and handling cost also. The cost of fuel varies with the following:

- unit price of the fuel.
- efficiency of the plant.
- amount of the energy produced.

VI) Labour cost:

For plant operation, labour cost is another item of operating cost. In case of automatic power stations, the cost of labour is reduced to a great extent. However, labour cost cannot be completely eliminated even with fully automatic system as they will still require some manpower for periodic inspection.

vii) Cost of maintenance and repairs:

In order to avoid plant breakdown, maintenance is necessary. maintenance includes periodic cleaning, greasing, over hauling, adjustments of equipments. The materials used for maintenance is also charged under this head. sometimes an arbitary percentage is assumed as maintenance cost.

viii) Cost of stores:

The items of consumable stores other than fuel includes such as lubricating oils and greases, cotton wastes, small tools, chemicals, paints and other related materials.

ix. supervision costs:

In this head, the salary of supervising staff is included. A good supervision is reflected in lesser breakdowns and extended plant life. The supervising staff includes the station superintendent, chief engineer, chemist, engineers, supervisors, purchase officer and other establishments.

x Taxes:

The taxes under operating head includes the following:

- Income tax.
- sales tax.
- social security and employee's security etc.

1) A. State what is meant by base load and peak load. Discuss briefly the reasons why the hydro and nuclear power plants are generally used to operate on base loads and diesel plants are used to operate on peak loads.
14/S, 11/S, 17/S, 13/S

⇒ Base load:

The various loads which occurs almost on the whole day on the power plant is called base load.

Peak load:

The various peak demands of the load over and over the base load of the power plant is called peak load.

– Base load power plant: 13/F

A base load power plant is a power station that usually provides a continuous supply of electricity throughout the year with some minimum power generation requirement. Base load power plant are only be turned off during periodic maintenance, upgrading, overhaul or service.

Example:

- coal fired power plant
- nuclear power plant
- tidal " "
- geothermal " "
- hydro " "
- Biomass " "
- solar (pond) " "

– Peak load power Plant:

" " " " or peaking power plants are power plants that generally run only when there is a high demand, known as peak demand for electricity.

Because they supply power only occasionaly, the power supplied commands a much higher price per kwh than base load power. Peak load power plant are dispatched in combination with base load power plant.

Example :

- Diesel power plant
- wind " "
- solar (PV) power plant.
- Hydro power plants (Pumped storage)

- characteristics of Base load power plant:

i) Base load power plants should be such that they supply power at high capital cost but low cost of operation.
ii) low operating cost
iii) Requires few operating personnel.
iv) capability of operating for longer times.
v) maintenance should be simpler and requires less time. Time duration between the maintenance should be long.
vi) High load factors.

- characteristics of peak load power plants:

i) quick start
ii) Faster synchronization to the grid.
iii) Quick response to the load variations.
iv) Should be faster in taking up the systems loads.

Diesel engine power plants:

12IF " " " " are generally will have higher operational costs and is uneconomical to operate them continuously. Hence, it is mostly operated as peak load plants.

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- Nuclear power plants are suitable only for base load operation. They have the highest load factor over 0.80 to 0.90. The extremely low marginal costs of operation of a nuclear power plant conventionally favour maximal operations at all times. They need long time period to heat up the nuclear steam supply system and the turbine generator to operating temperature.

- The hydropower plants are well suited for both base load
12|F as well as peak load operational plants. The hydro power plants should be employed for base load operations as far as possible because of their higher capital cost. To cater the demand peaks, peak load power plants are used. Base load Power plants cannot be started up whenever there is a spike in demand and stopped when the demand recedes.

B). Black start: 15|F

- A black start is the process of restoring an electric power station or a part of an electric grid to operation without relying on the external electric power transmission network to recover from a total or partial shutdown.

- To provide a blackstart, some power stations have small diesel generators, normally called the black start diesel generator (BSDG), which can be used to start larger generators, which in turn can be used to start the main power station generators.

- Not all generating plants are suitable for black start capability: wind turbines are not suitable for black start because wind may not be available when needed. wind turbines, mini hydro or micro hydro plants are often connected to induction generators which are incapable of providing power to reenergize the network. The black start unit must also be stable when operated with the large reactive load of a long transmission line.

- often hydroelectric power plants are designated as the black start sources to restore network interconnections. certain types of combustion turbine can be configured for black start, providing another option in places without suitable hydroelectric plants.

- Black start can only be carried out by a generating station that can self start without requiring power from the grid.

2.5) c) selection of number and sizes of units : 15 IF

while selecting the size and number of units, it has to be borne in mind that:

(I) one set of highest capacity should be kept as standby unit.
(II) the units should meet the maximum demand on the station.
(III) There should be overall economy.

The number and size of the units are selected in such a way that they correctly fit the station curve. The selection of the number and sizes of the units is decided from the annual load curve of the station.

Important points in the selection of units :

(I) The number and sizes of the units should be so selected that they approximately fit the annual load curve of the station.

(ii) The units should be preferably of different capacities to meet the load requirements. Although the use of identical units ensures saving in cost, they often do not meet the load requirement.

(iii) The capacity of the plant should be made 15 – 20 % more than the maximum demand to meet the future load requirements.

(iv) There should be a spare generating unit so that repairs and over hauling of the working units can be carried out.

v). The tendency to select a large number of units of smaller capacity in order to fit the load curve very accurately should be avoided. It is because the investment cost per kW of capacity increases as the size of the units decreases.

Plant location and site selection:

i Raw material availability
ii Climate
iii Transport facilities
iv Availability of labors.
v Political & strategic considerations
vi Taxations and legal restrictions
vii Availability of suitable land
viii Location

ix Availability of utilities
x environmental impacts and effluent disposal.
xi Local community considerations.

Factors affecting the size of unit in a generating station:

- Demand of Power
- max. efficiency
- growth of demand in near future
- capacity of plant should be 15% or 21% more than the expected maximum demand.

D). Thermal pollution: 14/F, 13/F, 11/S, 10/S

- Thermal pollution is the degradation of water quality by any process that changes ambient water temperature. A common cause of thermal pollution is the use of water as a coolant by power plants and industrial manufacturers. when water is used as a coolant is returned to the natural environment at a higher temperature, the sudden change in temperature decreases oxygen supply and affects ecosystem composition.

- Fish and other organism adapted to particular temperature range can be killed by an abrupt change in water temperature (either a rapid increase or decrease) known as thermal shock.

- Causes of thermal pollution:

(I) water as cooling agent in power, manufacturing & industrial plant.

(II) soil erosion.

(iii) Deforestation

(iv) Runoff from paved surfaces

(v) Natral causes like volcano, geothermal activity under oceans, seas.

Effects of Thermal Pollution:

(i) **Decrease in dissolved oxygen levels:**
The warm temperature reduces the levels of dissolved oxygen in water. The warm water holds relatively less oxygen than cold water. warmer water allows algae to flourish on surface of water and over the long term growing algae can decrease oxygen levels, in the water.

(ii) **Increase in toxins:**
with the constant flow of high temperature discharge from industries, there is a huge increase in toxins that are being regurgitated into the natural body of water. These toxins may contain chemicals or radiations that may have harsh impact on the local ecology and make them susceptible to various diseases.

(iii) **Loss of biodiversity:**

(iv) **Ecological impact**

(v) Migration of particular species of organisms to suitable environment that would cater to its requirement for survival.

vi) Increase metabolic rate:
Thermal pollution increases the metabolic rate of organisms as increasing enzyme activity occurs that causes organisms to consume more food than what is normally required if their environment were not changed. It disrupts the stability of food chain and alter the balance of species composition.

Control of Thermal pollution:

- cooling ponds and cooling towers where the heat is released through evaporation convection, heat transfers and radiation. These are artificial structures.

- Co-generation: a process by which the heated water is recycled for domestic use or industrial heating.

- storm water basins are also in use but not as effective as these are exposed to the sun and its heat not allowing the water to cool.

The following sources contribute to thermal pollution:

i) Nuclear power plants
ii) coal fired "
iii) Domestic sewage
iv) Hydro electric power
v) Industrial effluents.

E) Discuss the balancing of power generation with load. 74/F, 73/S, 73/F
Describe how the governing action of a power plant balances generation with load. 72/S, 71/S

⇒ Load balancing, load matching or daily peak demand reserve refers to the use of various techniques by electrical power stations to store excess electrical electrical power during low demand periods for release as demand rises.

The imbalance between load and generation may arise due to uncertainities in demand forecasting, generator's inability to follow up the changes in load and generation or load trips. Regulation is the use of online generating units that are equipped with control mechanism that can change output quickly to track the moment to moment fluctuations in load and unintended fluctuations in the generation.

- speed governor is the controlling mechanism which controls the input to the prime mover automatically when there is a change in system frequency (speed). when there is a change in speed, governor responses by causing valves/gates to open/close to increase/decrease the input to the prime mover. Governors, attempts to restore load generation balance, using frequency change as a signal.

- A change in the balance between the generation of active power and the consumption of active power changes the kinetic energy of the rotating mass of the generators, and alters the system frequency. The active power balance is restored by a so called speed governor.

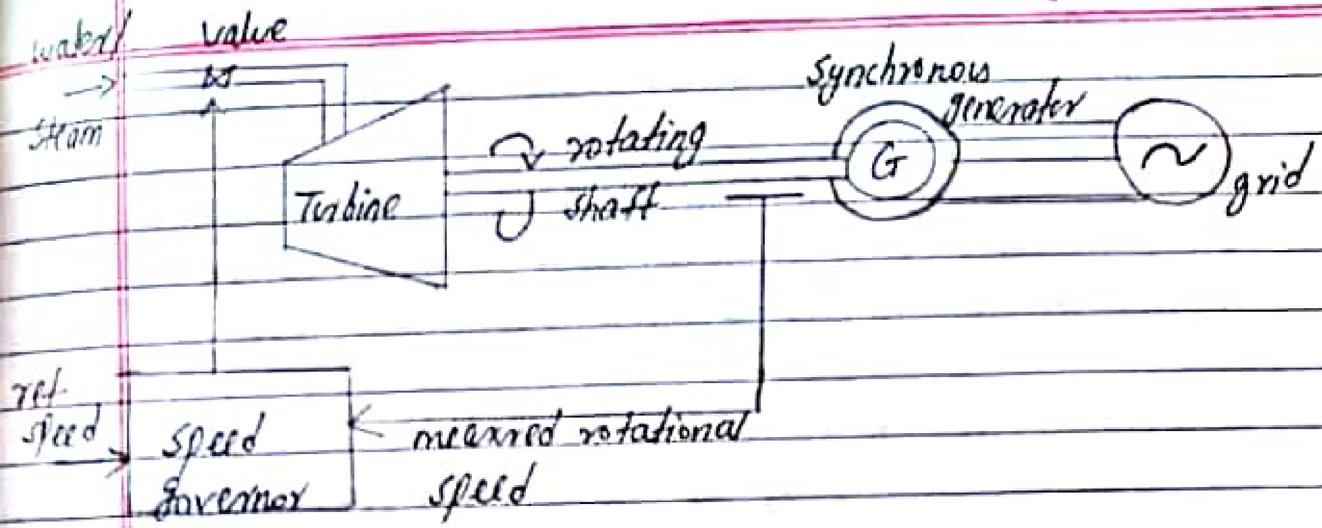

Fig: Basic principle of speed governor control system.

$$R_{gi} = -\frac{\Delta f / f_r}{\Delta P_{gi} / P_{gi,r}}$$

R_{gi} = droop or regulation of generator
Δf = frequency change in the system
f_r = nominal rated frequency
ΔP_{gi} = change in active power of generator
$P_{gi,r}$ = nominal rated power of "

F) Discuss why the following types of power plants can be used as peaking stations. 12/F

(1) Gas turbine power plants:

The thermodynamic efficiency of simple cycle gas turbine power plant ranges from 20 to 42% with between 30 and 42% being average for a new plant. This kind of power station can be used to produce limited amounts of electricity/electrical energy. A gas turbine cannot be turned on like a gasoline or diesel engine. Since the compressor is driven by the shaft of the turbine, an outside source is required to start the system. Gas turbine power plants can be started up and run at full capacity in only 10 to 20 minutes making them well suited for peak load power plants.

G. Discuss about the reliability of a supply system. What are the measures to be taken into considerations to improve the reliability of a supply system? 10/S, 15/F

⇒ Reliability is the probability of a device performing its function adequately for the intended period of the time under specified operating conditions. Reliability is the ability of the system or its components to withstand instability, uncontrolled events, cascading failures or unanticipated loss of system components.

Following are the measure to be taken into consideration to improve the reliability of supply systems:

i) average number of service interruptions per load per year.
ii) average restoration time at each load point.
iii) average total interruption time per load point per year.

iv. maximum expected no of interruption experienced by any load point.

v. maximum expected no of restoration time expected by any load point.

vi. probability that any load point will be out of service at any time longer than a specified time.

H. Give a brief account of the influence of diversity factor and of load factor upon the total cost of supply of electric energy. 12/F

=> Influence of diversity factor upon total cost of supply of electric energy:

The capacity of the power station determines the capital cost of the power station. Lower the maximum demand of the power station, the lower is the capacity required and hence lower is the capital cost of the plant. with a given number of consumers, the higher the diversity factor of their loads, the small will be the capacity of the plant required and consequently the fixed charges due to capital investment will be much reduced.

— Diversity factor gives the time diversification of the load and is used to decide the installation of sufficient generating and transmission plant.

I) Briefly discuss the factors affecting cost of generation of power in following types of power plants. 72/F
(i) Hydro power plants
(ii) Diesel " "

=> Factors affecting cost of generation of power in different power plants are: 74/F

(i) Load factor
(ii) Diversity "
(iii) Demand "
(iv) utilization "

J. A power plant has to supply loads as follow:
Determine load factor and select a suitable number and size of units to supply this load. Reliability of

supply is to be maintained. Determine the reserve capacity, plant capacity factor, plant use factor and operating schedule of plant to meet the load.

Time	Load (kW)	Time	Load (kW)
12 pm to 5 am	500	2 pm to 5 pm	2500
5 am to 10 am	800	5 pm to 8 pm	2000
10 am to 12 noon	2000	8 pm to 10 pm	1500
12 noon to 2 pm	1000	10 pm to 12 pm	1000

soln,

=> The energy generated during 24 hours is:

$= 5\times500 + 800\times5 + 2\times2000 + 2\times1000 + 2500\times3$
$+ 2\times1500 + 2\times1000 + 2000\times3$
$= 31000$ kWhr

max. demand = 2500 kW

(I) Load factor $= \dfrac{31,000}{24\times2500}\times100$
$= 51.66\ \%$

(II) Reserve capacity =

From the load variation, it can be seen that three units, two of 1000 kW and one of 500 kW will be sufficient. A reserve capacity equ to largest unit will be taken.

Total installed capacity $= 3\times1000 + 500$
$= 3500$ kW

(III) plant capacity factor $= \dfrac{31000}{3500\times24}\times100$
$= 36.90\ \%$

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(iii) Operating schedule:

12 mid – 5 am	1 unit of 500 kW
5 am – 10 am	1 " " 1000 "
10 am – 12 noon	2 " " 1000 kW each
12 noon – 2 pm	1 " " 1000 kW
2 pm – 5 pm	2 " " 1000 kW & 1 unit of 500 kW
5 pm – 8 pm	2 " " " " each
8 pm – 10 pm	1 unit of 1000 kW & one unit of 500 kW
10 pm – 12 midnight	1 " " " "

With the operating schedule listed above, energy that could have been generated by the capacity of the plant actually running for the schedule time would be,

$= 5 \times 500 + 5 \times 1000 + 2 \times 2000 + 2 \times 1000 + 3 \times 2500 + 3 \times 2000 + 2 \times 1500 + 2 \times 1000$

$= 32{,}000$ kWhr

Hence,

(iv) $\text{plant use factor} = \dfrac{31000}{32000} \times 100$

$= 96.87\ \%$

Here, we have selected the number and size of units such that they fit the load curve ideally. That is why the plant use factor is almost 100 %. In practice, this is not possible and plant use factor is much below 100 %.

K). Explain in detail the various methods of converting solar energy into electrical energy. 11k

⇒ In the solar power plant, solar energy is used to generate electricity. Sunrays are focused using concave reflectors on to copper tubes filled with water and painted black outside.

1) A power station is to design to meet following loads:

Time	demand (MW)	Time	demand (MW)
11 pm – 5 am	5	12 pm – 1 pm	21
5 am – 6 am	7	1 pm – 5 pm	17
6 am – 7 am	10	5 pm – 7 pm	15

7 am - 9 am	13	7 pm - 10 pm	12
9 am - 12 pm	18	10 pm - 11 pm	8

Draw the load curve for the power generation station & find
(i) number of generating units 17/5
ii operating schedule
iii Load factor and plant capacity factor.

Soln,

=> max demand = 21 MW

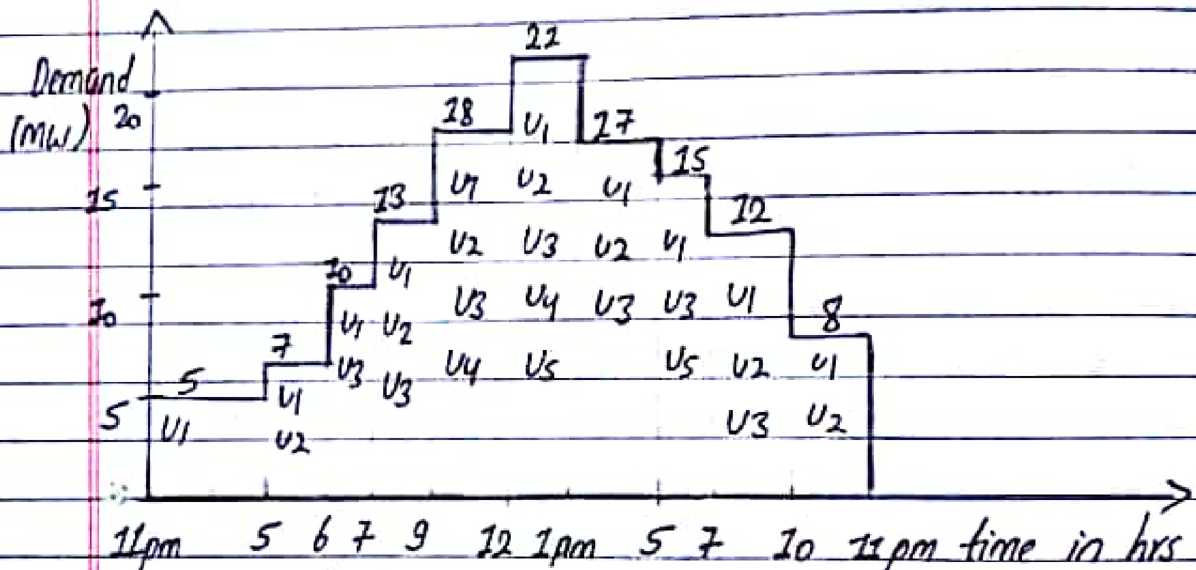

Fig: Load curve

(i) Load factor = $\frac{\text{energy consumed per day}}{\text{max demand} \times \text{hours in a day}}$

$$= \frac{6\times5+1\times7+1\times10+2\times13+18\times3+1\times21+17\times4+15\times2+12\times3+8\times1}{21\times24}$$

$$= \frac{290}{504}$$

$$= 0.5753$$

∴ L.F = 57.54 %

and,

plant capacity factor = $\frac{\text{amt of energy generated}}{\text{Installed capacity} \times \text{operation time}}$

(ii) No. and size of generating units:
5 generating units of size one 3 MW and four 5 MW is needed.

Generator 1 = 5 MW = U_1
" 2 = 3 MW = U_2
" 3 = 5 MW = U_3
" 4 = 5 MW = U_4
" 5 = 5 MW = U_5

Reserve capacity = 5 MW
Installed " = 5X4 + 3 + 5 MW
= 28 MW

Hence,
$$\text{Plant capacity factor} = \frac{290}{28 \times 24} = 0.431 = 43.15\ \%$$

(iii) operating schedule:

Time	generating plant	Time	generating plant
11 pm - 5 am	U_1	12 pm - 1 pm	U_1, U_2, U_3, U_4, U_5
5 am - 6 am	U_1, U_2	1 pm - 5 pm	U_1, U_2, U_3
6 am - 7 am	U_1, U_3	5 pm - 7 pm	U_1, U_3, U_5
7 am - 9 am	U_1, U_2, U_3	7 pm - 10 pm	U_1, U_2, U_3
9 am - 12 pm	U_1, U_2, U_3, U_4	10 pm - 11 pm	U_1, U_2

M). The daily load demand on an isolated power plant is as below.

Time	demand	Time	demand
6 am to 8 am	5 MW	5 pm to 7 pm	7.5 MW
8 am - 10 am	15 MW	7 pm to 10 pm	8.5 MW
10 am - 2 pm	8 MW	10 pm - 4 am	2 MW
2 pm - 5 pm	10 MW	4 am - 6 am	6 MW

choose the size and number of generating units. What reserve plant would be necessary? 72 IE, 71 S, 74 S

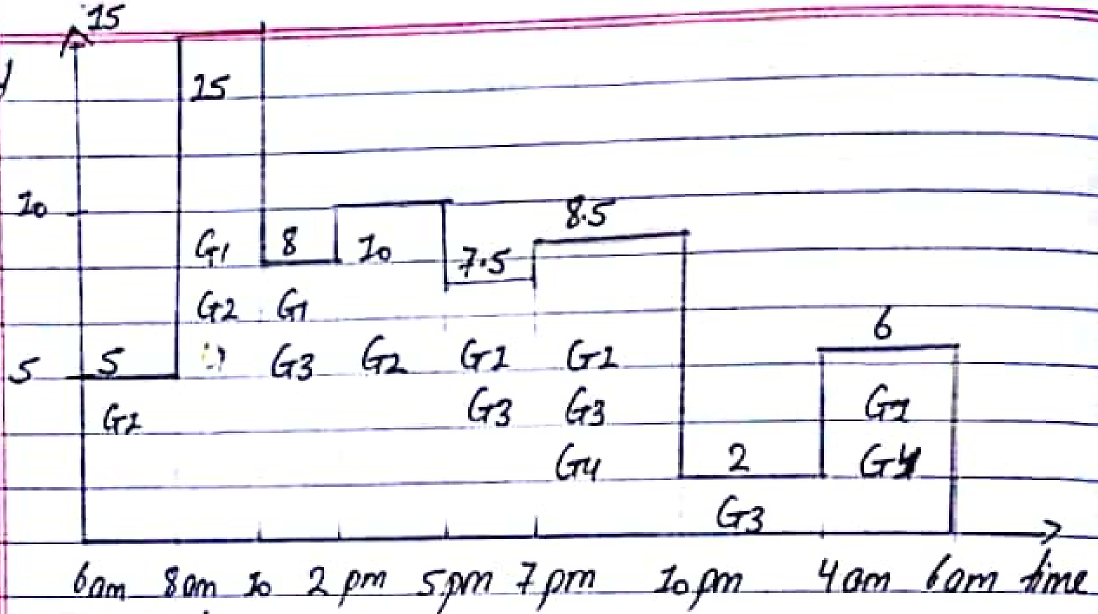

Fig : Load curve

(i) Size and generating units:

G1 = 5 MW
G2 = 10 MW
G3 = 3 MW
G4 = 1 MW

No of generating units = 4

Size of generating units are:
1 unit of 5 MW, 1 unit of 10 MW, 1 unit of 3 MW and 1 MW of 1 unit.

(ii) Reserve capacity = 10 MW

(iii) Installed capacity = 5 + 10 + 3 + 1 + 10
= 29 MW

(iv) Rated capacity = 5 + 10 + 3 + 1 = 19 MW

v) daily load factor

$$= \frac{2\times5 + 2\times15 + 4\times8 + 3\times10 + 2\times7.5 + 3\times8.5 + 6\times2 + 6\times2}{15 \times 24}$$

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$= 0.4625$

$\therefore$ L.F $= 46.25\ \%$

vi) Plant capacity factor $= \dfrac{166.5}{29 \times 24} = 0.2392 = 23.92\ \%$

vii. Average load $= \dfrac{\text{no of units generated in given time period}}{\text{Time period}}$

$= 166.5$ mwh

viii Plant use factor $= \dfrac{\text{station output in kwh}}{\text{plant capacity} \times \text{Hours of use}}$

According to operating schedule, the energy that could have been generated by the capacity of plant actually running for the schedule time would be,

$= 2\times5 + 2\times15 + 8\times4 + 10\times3 + 8\times2 + 3\times9 + 3\times6 + 6\times2$

$= 175$ mwhr

Hence,

plant use factor $= \dfrac{166.5}{175} \times 100$

$= 95.142\ \%$

ix utilization factor $= \dfrac{\text{max demand of system}}{\text{rated system capacity}}$

$= \dfrac{15}{29} \times 100$

$= 51.72\ \%$

x. min. energy that could be produced

$= \dfrac{\text{actual energy produced in a day}}{\text{plant use factor}}$

$= \dfrac{166.5}{0.5172} = 322$ mwh/day.

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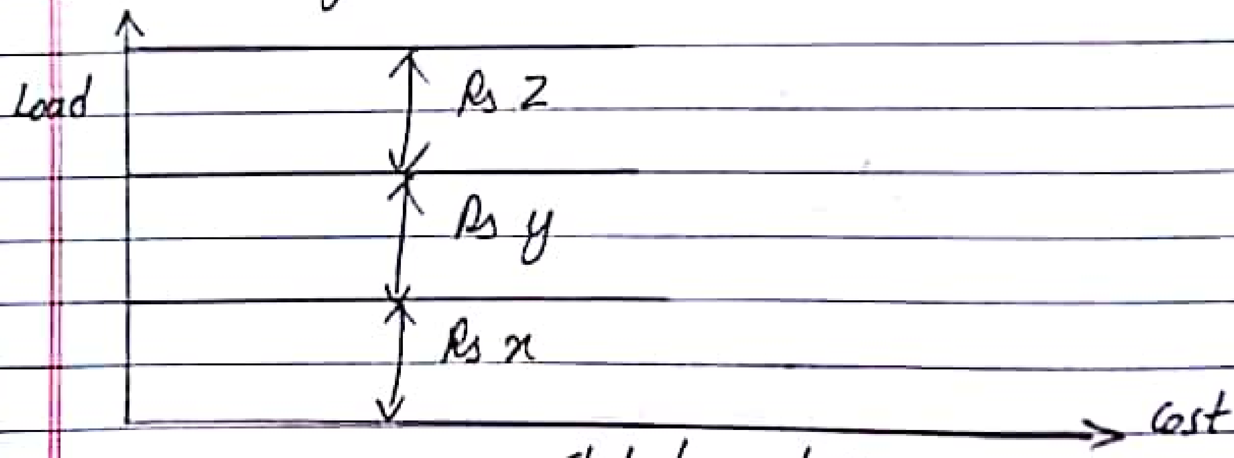
3). methods of deciding Tariff :

(i) Flat demand rate
ii straight meter "
iii Block " "
iv Two part method "
v Three " " "

(i) Flat demand rate :

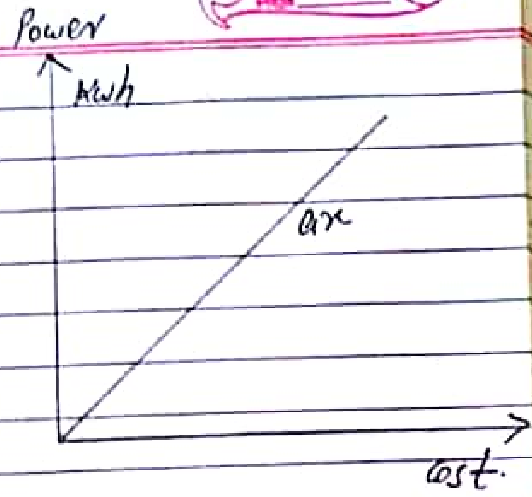
In flat demand rate, various ranges of maximum load with respect to cost is given and consumers are charged on the basis of that range. In this method, if consumers using minimum limit of power and if consumes maximum power in that given range, then both consumers have to pay same charges for different load. In this method consumers are not encouraged for using more electricity.



Flat demand curve

(ii) straight meter rate :

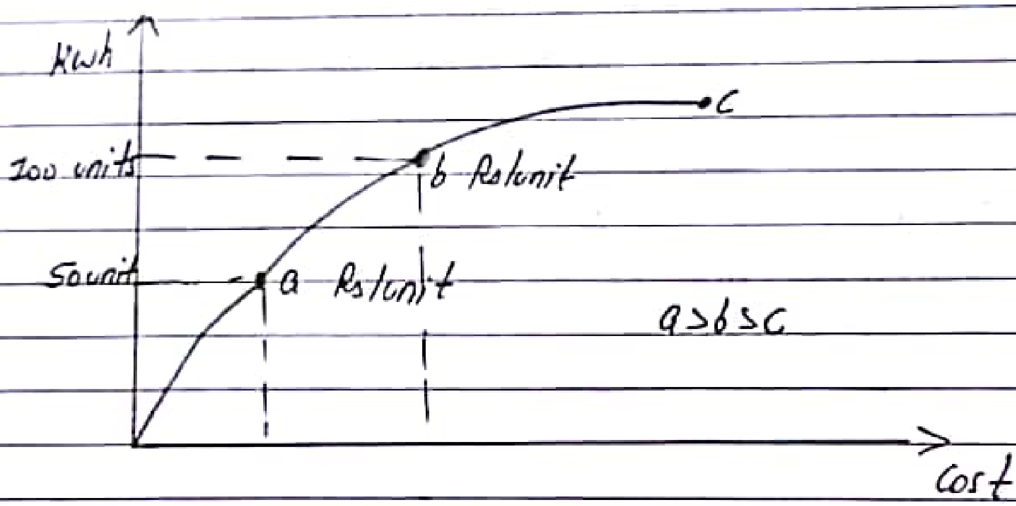
Charge = $a \cdot x$
a = fixed cost of 1 unit
x = Kwh energy.



In this method, consumer is charged for total amount of units consumed and there is one fixed cost of each unit. This method is used for domestic and residental consumer decade ago. This method doesnot encourage consumers who has large load.

iii. **Block meter Rate:**

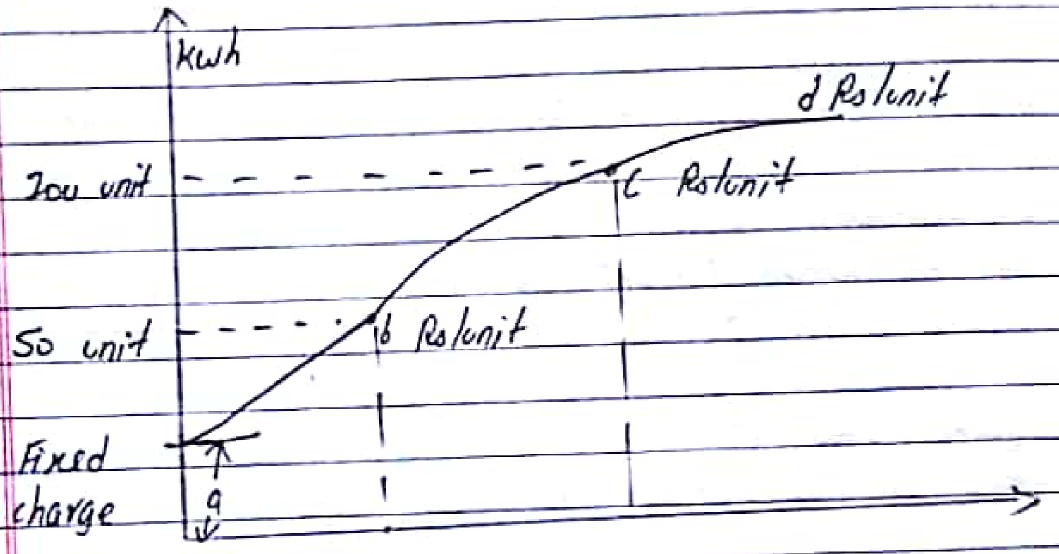
In this method, various ranges of electricity demand is fixed by utility center and each range has fixed cost per unit, as demand increases the cost of each unit decreases. This method is useful for residental or domestic purposes.



iv. **Two part method:**

$$\text{Charge} = Rs\ a + b \cdot x$$
$$= Rs\ a + Rs\ b \times x \text{ unit}$$

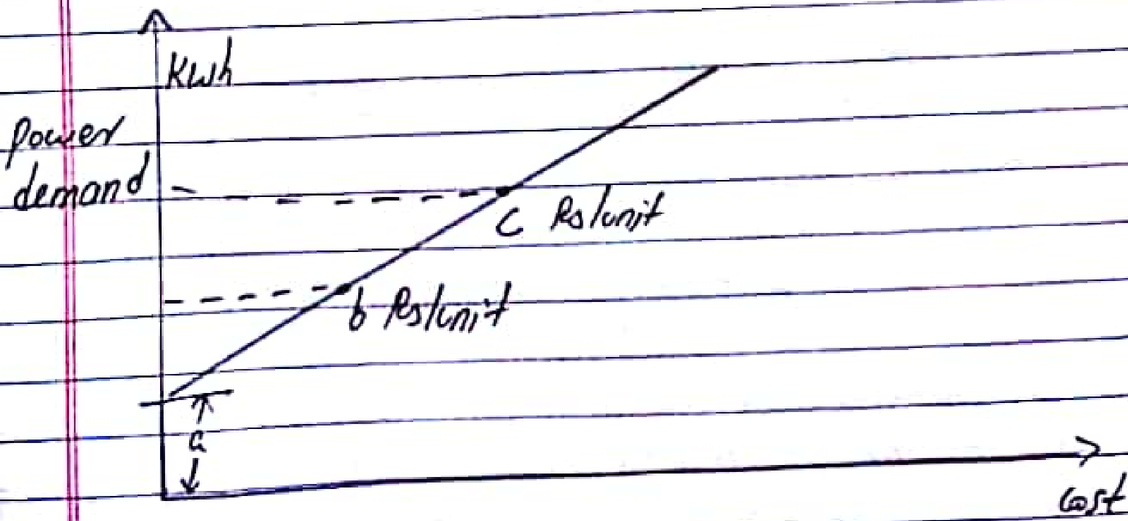
In this method, some fixed amount of money is charged to the consumer on monthly basis weather they are consuming power or not. They also pay for the amount of electricity used on the basis of block meter rate. It is applicable for both commercial as well as residential load.



v) Three part method:

In this method, utility company charge the consumer in three component.

- First is fixed charge which has to pay either electricity is used or not.
- Second, maximum power demand of consumer.
- Third, dependent on the unit of energy consumed by consumer.



This method is applied to commercial consumer. In this method, for calculating total charge of energy consumed to different meter are installed in industries, first meter is used for measuring max demand, second meter is for measuring amt of unit consumed by consumer.

charge = a Rs + b Rs/kw + c Rs/kw

Eg: For a given power plant, the cost of generation & various expenditure are given below:

① Calculate cost per unit generated by that power plant.

Installed capacity of power plant = 200 MW
Capital cost of " " = 280 lakhs.
Annual load factor = 40 %
Annual cost of fuel, oil, salaries = NRs 60 lakhs
Interest and depreciation = 13 %

$$\text{Cost of one unit} = \frac{\text{Total fixed cost} + \text{total operating cost}}{\text{total no of units generated}}$$

$$= \frac{TFC}{TNU} + \frac{TOC}{TNU}$$

= total fixed cost for 1 unit + Total operating cost of 1 unit.

① Calculation of total fixed cost incurred by generator,

Total fixed cost = interest & depreciation cost

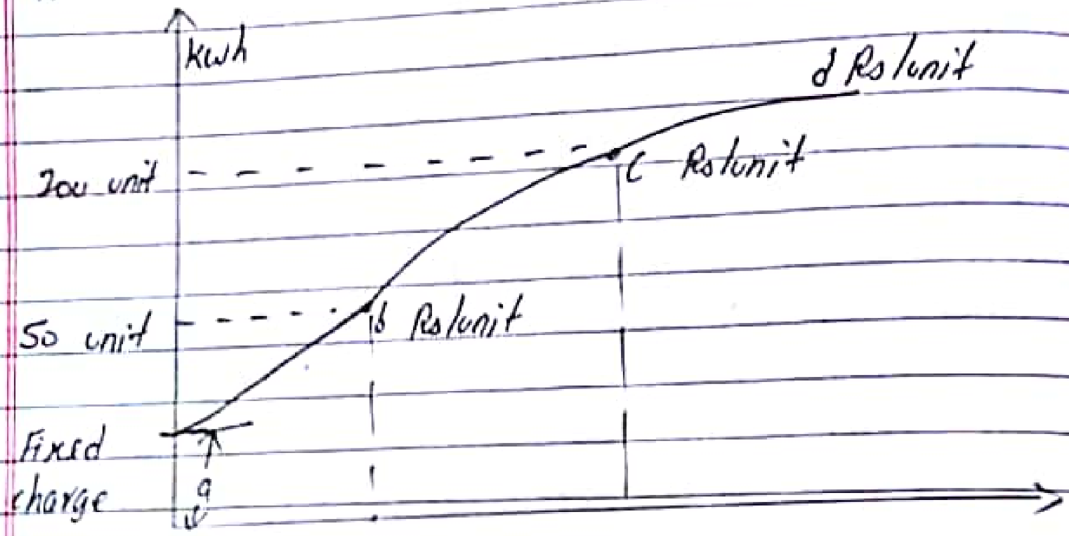
$= 13\% \times 280 \times 10^5$

$= \text{Rs } 3.64 \times 10^6 \text{ / year}$

(II) Calculation of operating cost:

Total operating cost $= \text{Rs } 60 \times 10^5 \text{ / year}$

applicable for both commercial as well as residential load.



v) Three part method:

In this method, utility company charge the consumer in three component.

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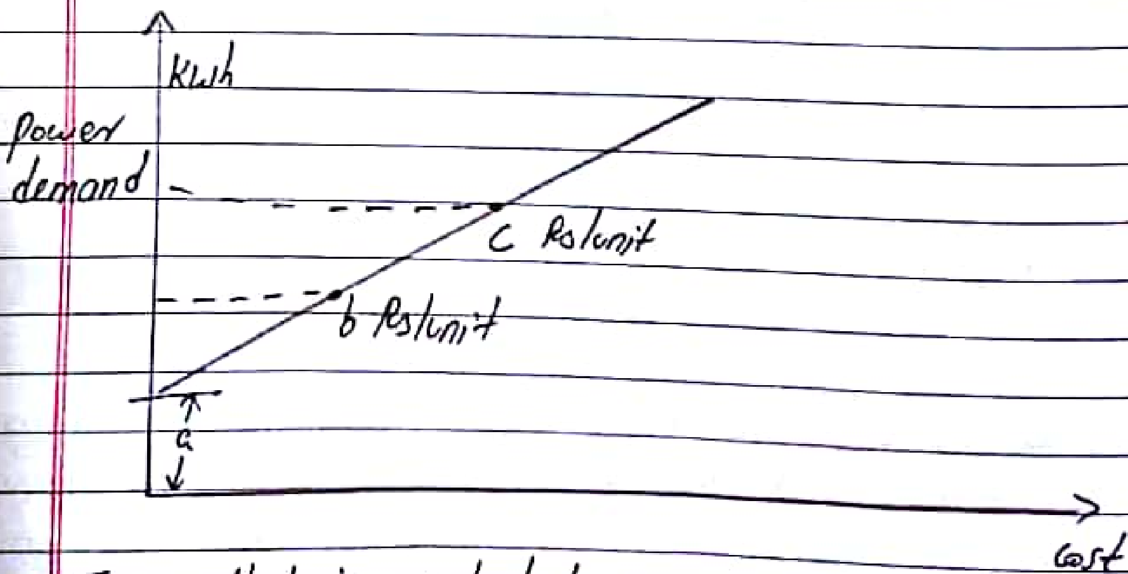

This method is applied to commercial consumer. In this method, for calculating total charge of energy consumed to different meter are installed in industries, first meter is used for measuring max demand, second meter is for measuring amt of unit consumed by consumer.

charge = a Rs + b Rs/kw + c Rs/kw

Eg: For a given power plant, the cost of generation & various expenditure are given below:
(I) Calculate cost per unit generated by that power plant.

Installed capacity of power plant = 200 MW
Capital cost of " " = 280 lakhs.
Annual load factor = 40 %
Annual cost of fuel, oil, salaries = NRs 60 lakhs
Interest and depreciation = 13 %

$$\text{Cost of one unit} = \frac{\text{Total fixed cost} + \text{total operating cost}}{\text{total no of units generated}}$$

$$= \frac{TFC}{TNU} + \frac{TOC}{TNU}$$

= total fixed cost for 1 unit + Total operating cost of 1 unit.

(I) calculation of total fixed cost incurred by generator,

Total fixed cost = interest & depreciation cost

$= 13\% \times 280 \times 10^5$

$= Rs\ 3.64 \times 10^6$ / year.

(II) calculation of operating cost:

Total operating cost $= Rs\ 60 \times 10^5$ /year

∴ Total cost of generation $= TFC + TOC$

$= 3.64 \times 10^6 + 60 \times 10^5$

$= 9640000$ Rs

Total no of units generated by power plant in a year :

$$\text{load factor} = \frac{\text{average load}}{\text{maximum load}}$$

∴ No. of units generated $= L.F \times \text{max load}$

$= 0.40 \times 200 \times 10^3 \times 365 \times 24$

$= 7.008 \times 10^8$ units

$= 7.008 \times 10^8$ kWh

$= 7.008 \times 10^8$ kWh

∴ cost of one unit $= \dfrac{\text{total cost of generation}}{\text{no of units generated}}$

$= \dfrac{9.64 \times 10^6}{7.008 \times 10^8}$

$=$ Rs 0.0137 or 1.37 P/kWh.

How to reduce Power generation cost? 15ks

i) Using a plant of simple design that doesnot need highly skilled personnel.

ii) Increasing the power stations efficiency.

iii) Running the power stations at high load factors.

iv) Keeping proper supervision, which ensures less breakdown and extended plant life.

v) Carrying out proper maintenance of power plant equipment to avoid plant breakdown.

vi) Selecting equipment of longer life & proper conditions.

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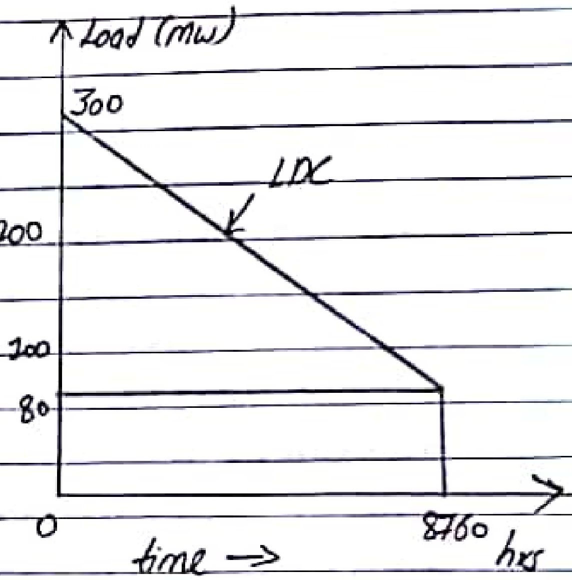
11B. The yearly duration curves of a certain power plant can be considered as a straight line from 300 MW to 80 MW. Power is supplied with one generating unit of 200 MW capacity and two units of 100 MW each. Determine:

i. Installed capacity iii) Load factor
ii. Plant factor iv) maximum demand
v. utilization factor.

Sol^n,

=> Given,



(I) Installed capacity:

$= 200 + 2 \times 100$

$= 400$ MW

(II) Load factor:

$L.F = \frac{\text{Avg load}}{\text{max demand}}$

$\text{Avg load} = \frac{\text{total energy in load curve for the period}}{\text{total number of hours in the period}}$

$= \frac{80 \times 8760 + (1/2) \times (300 - 80) \times 8760}{8760}$

$= 190$ MW

$\therefore L.F = \frac{190}{300} = 0.633$

(III) Plant factor $= \frac{\text{average load}}{\text{capacity of plant}} = \frac{190}{400} = 0.475$

(IV) maximum demand $= 300$ MW

V). Utilization factor $= \frac{\text{max load}}{\text{Rated capacity of plant}}$

$$= \frac{300}{400} = 0.75$$

B). A motor of 25 HP connected to a condensate pump has been burnt beyond economical repairs. Two alternatives have been proposed to replace it by:

	Cost	efficiency at full load	efficiency at half load
motor A	Rs 5000	90%	85%
motor B	Rs 3500	86%	80%

The life of each motor is 20 years and its salvage value is 12% of its initial cost. The rate of interest is 5% annually. The motor operates at full load for 30% of time and at half load for the remaining period. The annual maintenance cost of motor A is Rs 400 and that of motor B is Rs 200. The energy rate is 12 paisa/Kwh. Which motor will be economical? 15/s

Soln,

⇒ For motor A:

Salvage value = 12% of initial cost

$= 12\% \times 5000 = Rs\ 600$

Depreciation cost = $\frac{\text{Investment cost} - \text{salvage value}}{\text{no. of years}}$

$$= \frac{5000 - 600}{200}$$

= Rs 220 / year.

Interest = 5% of Initial cost

$= 5\% \times 5000$

= Rs 250 / year.

maintenance cost = Rs 400

energy given to motor = $\frac{\text{load on motor} \times \text{time in hours}}{\text{efficiency of the motor}}$

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∴ Energy cost =

Load on motor = 25 HP = 25 X 0.7355 kW
no. of hours = 365 X 24 hours
energy rate = 12 paisa/kwh.
motor operates at full load for 30% time and at half load for the 70% time.
Hence,

$$\text{energy cost} = \left[\left(25 \times 0.7355 \times (365 \times 24) \times \frac{30}{100} \times \frac{1}{0.90}\right) + \left((25 \times 0.7355) \times \frac{1}{2} \times (365 \times 24) \times \frac{70}{100} \times \frac{1}{0.85}\right)\right] \times \frac{12}{100}$$

$$= (53691.5 + 66324.8) \times \frac{12}{100}$$

$$= \text{Rs } 14402/\text{ year.}$$

∴ Total cost of motor A = 14402 + 250 + 220 + 400
= Rs 15,272 year.

For motor B;
Salvage value = 12% X 3500 = Rs 420

$$\text{Depreciation} = \frac{3500 - 420}{20} = \text{Rs } 154 \text{ per year}$$

Interest = 5% of 3500 = Rs 175 per year.
maintenance cost = Rs 200

$$\text{energy cost} = \left[\left(25 \times 0.7355 \times 365 \times 24 \times \frac{30}{100} \times \frac{1}{0.86}\right) + 25 \times 0.7355 \times \frac{1}{2} \times (365 \times 24) \times \frac{70}{100} \times \frac{1}{0.80}\right)\right] \times \frac{12}{100}$$

$$= \text{Rs } (56188.8 + 70470) \times \frac{12}{100}$$

$$= \text{Rs } 15199/\text{year}$$

Hence,

Date ____
Page ____

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Total cost of motor B = 154 + 175 + 200 + 15199
= Rs 15728 / year

Hence,
motor A is economical since its annual cost is less than motor B.

C. The maximum demand of a power station system is 200 MW. and the load factor is 50 %. This demand is to be met by either of the following methods.

① A steam power plant of sufficient capacity to meet the whole load.

ii). A hydro power plant of sufficient capacity to meet the whole load.

iii A nuclear power plant of sufficient capacity to meet the whole load.

iv. A combination of steam and hydro power plants. The hydro station can supply 175×10^6 units per year with a max output of 75 MW.

Estimate the total cost to generate 1 units in each case. Indicate which alternative is most economical.

	Items	steam P.P	Nuclear P.P	Hydro P.P
i)	capital cost/kw of installed capacity	Rs 1600	Rs 2700	Rs 2100
ii	Interest & depreciation of capital cost	12 %	10 %	10 %
iii	operating cost / unit	5 paisa	4 paisa	1 paisa
iv.	Transmission cost /unit	Negligible	Negligible	0.27 paisa

16/5, 15/5,

Sol^n,

⟹ Total no. of units to be generated & supplied per year:

$= \text{max. demand} \times \text{hours in a year} \times \text{load factor}$
$= 200 \times 1000 \times 8760 \times 50\%$
$= 876 \times 10^6$ units

(I) Fixed cost per year $= \text{Rs } 200 \times 1000 \times 1600 \times 12\%$
$= \text{Rs } 384 \times 10^5$
$= \text{Rs max demand} \times \text{capital cost/kw} \times \text{interest rate}$

Total cost per unit $= 5 + \dfrac{384 \times 10^5}{876 \times 10^6} \times 100$ paisa
$= 5 + 4.4$
$= 9.4$ paisa.

(II) Fixed cost per year $= \text{Rs } 200 \times 1000 \times 2100 \times 10\%$
$= \text{Rs } 42 \times 10^6$

$\therefore$ Total cost per unit $= 1 + 0.27 + \dfrac{42 \times 10^6}{876 \times 10^6} \times 100$
$= 1 + 0.27 + 4.8$
$= 6.07$ paisa.

(III) Fixed cost per year:
$= \text{Rs } 200 \times 1000 \times 2700 \times 10\%$
$= \text{Rs } 54 \times 10^6$

$\therefore$ Total cost per unit $= 4 + \dfrac{54 \times 10^6}{876 \times 10^6} \times 100$
$= 4 + 6.15$
$= 10.15$ paisa

(IV) units supplied by the hydrostation: $= 175 \times 10^6$
$\therefore$ units to be supplied by steam station
$= (876 - 175) \times 10^6$
$= 701 \times 10^6$ units.

Installed capacity of hydro station = 75 MW

" " " steam plant = 200 − 75 MW

= 125 MW

Fixed cost per year for hydrostation :

$= 75 \times 1000 \times 1600 \times 10\%$

$= Rs\ 1575 \times 10^4$

Fixed cost per year for steam station:

$= 125 \times 1000 \times 1600 \times 12\%$

$= Rs\ 2400 \times 10^4$

∴ Total fixed cost per year $= Rs\ 3975 \times 10^4$

Now,

Running cost for Hydrostation :

$= 175 \times 10^6 \times (1 + 0.27) \times \frac{1}{100}$

$= Rs\ 222 \times 10^4$

Hence, hydro power plant is most economical.

Running cost for steam station :

$= 701 \times 10^6 \times \frac{5}{100}$

$= Rs\ 3505 \times 10^4$

∴ Total running cost $= Rs\ 3727 \times 10^4$

∴ " cost per year $= Rs\ 7702 \times 10^4$

$= Rs\ (3975 \times 10^4 + 3505 \times 10^4)$

∴ Cost per unit $= \frac{7702 \times 10^4}{876 \times 10^6} \times 100$

$= 8.78$ paisa.

D. A generating plant has a maximum capacity of 100 kW & costs Rs 1,60,000. The annual fixed charges are 13%

consisting of 6% interest, 5% depreciation, 2% taxes. Find the fixed charges per kwh if load factor is 12k

i. 100%

ii) 50%

Sol^n,

⇒ plant capacity = 100 kw

capital cost = Rs 1,60,000

annual fixed cost charges = 13%

Total fixed charges = 13% of 160000

= Rs 20800 / year

Total units generated per year :

= max demand X load factor X 365 X 24

= 100 X 365 X 24 X L.F

= 876000 X L.F

For L.F = 100%

∴ Total generated units = 876000 kwh

For LF = 50%

∴ Total generated units = 438000 kwh

Hence,

① Fixed charges per kw: for 100% Load factor is:

$$= \frac{\text{Fixed cost per annum}}{\text{max demand}}$$

$$= \frac{20800}{160000}$$

= Rs 0.130/kw

Fixed charges per kwh for 100% L.F is,

$$= \frac{\text{annual fixed cost}}{\text{energy generated per year}}$$

$$= \frac{20800}{876000} = \text{Rs } 0.0238 \text{ / kwh}$$

(11) Fixed charge per kwh for 50 % L.F is,

$$= \frac{20800}{438000}$$

$= Rs\ 0.04748\ /Kwh$

E). Determine the load factor at which the cost of supplying a unit of electricity is same in diesel station as in a steam station if the respective annual fixed and running charges are given below: 15k

Diesel : Rs $(40/Kw + 0.06/Kwh)$

steam : Rs $(160/Kw + 0.015/Kwh)$.

Sol^n,

$\Rightarrow$ let, P = maximum load in kw

x = load factor

average load $= P \times x$

cost of diesel station = Cdiesel

$C_{diesel} = 40\,P + 0.06 \times P \times x \times (365 \times 24)$

Cost of steam station,

$C_{steam} = 160\,P + 0.015 \times P \times x \times (365 \times 24)$

As given in question,

unit energy cost of diesel station = steam station.

or $\dfrac{40P + 0.06\,Px \times 8760}{Px \times 365 \times 24} = \dfrac{160\,P + 0.015\,Px \times 8760}{Px \times 365 \times 24}$

or $40\,P + 525.6\,Px = 160\,P + 131.4\,Px$

or $120\,P = 394.2\,x$

or $x = \dfrac{120}{394.2}$

$\therefore x = 0.3044$

Hence, load factor needed is 0.3044

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E. A load having maximum demand of 100 MW at 40% load factor may be supplied by one of the following schemes.

i) A steam plant capable of supplying the whole load.

ii) A steam plant in conjuction with a pumped storage plant capable of supplying 130×10^6 kWh energy per year with a maximum output of 40 MW.

using the following data and assuming that no reserve capacity is needed, find economic scheme among two.

capital cost of steam plant = Rs 2000 /kW of installed capacity.

capital cost of pumped storage plant = Rs 1300 /kW of installed capacity

Annual operating cost of steam plant = Rs 6 p/kWh

" " " pump storage plant = 0.5 p /kWh.

Interest and depreciation on capital cost = 12 % p.a.

soln, 11/5, 13/5

=>

① steam station:

capital cost $= 100 \times 1000 \times 2000 = Rs\ 200 \times 10^6$

Interest and depreciation $= 12\% \times 200 \times 10^6$

$= Rs\ 24 \times 10^6$

Average load = Load factor X max. demand.

$= 0.40 \times 100 \times 10^3$

$= 40000$ kW

energy supplied per year = avg load X 365 X 24

$= 40000 \times 365 \times 24$

$= 350.4 \times 10^6$ kWh

∴ Interest and depreciation charges per unit of energy:

$$= \frac{24 \times 10^6}{350.4 \times 10^6} \times 100$$

$= 6.85$ p/kwh

$\therefore$ Total cost per unit $= 6 + 6.85$

$= 12.85$ p/kwh

steam station in conjuction with pump storage plant:

Load supplied by the steam plant $= 100 - 40$

$= 60$ MW

$\therefore$ capital cost of steam plant $= 60 \times 1000 \times 2000$

$= Rs\ 120 \times 10^6$

capital cost of pump storage plant:

$= 40 \times 1000 \times 1300$

$= Rs\ 52 \times 10^6$

$\therefore$ Total capital cost of combined station

$= 120 \times 10^6 + 52 \times 10^6$

$= Rs\ 172 \times 10^6$

Interest and depreciation charge on capital investment:

$= 12\% \times 172 \times 10^6$

$= Rs\ 20.64 \times 10^6$

$\therefore$ operating cost of pump storage plant

$= 0.5\% \times 130 \times 10^6$

$= Rs\ 0.65 \times 10^6$

unit energy supplied by steam station:

$=$ Total units required $-$ energy units supplied by pump storage plant

$= 350.4 \times 10^6 - 130 \times 10^6$

$= 220.4 \times 10^6$ Kwh.

operating cost of steam station:

$= 6\% \times 220.4 \times 10^6 = Rs\ 13.22 \times 10^6$

$\therefore$ Total cost per year $= Rs\ (20.64 \times 10^6 + 0.65 \times 10^6 + 13.22 \times 10^6)$

$= Rs\ 34.51 \times 10^6$

$\therefore$ Total cost per unit $= \dfrac{34.51 \times 10^6 \times 100}{350.4 \times 10^6}$

$= 9.85$ p/kwh.

Q- Compute the generation cost per kwh from the following data.

Installed capacity = 200 MW

capital cost = Rs 3000 per kw. 14/5

Fuel cost = Rs 7000 per 1000 kg

other operating cost = 30% of fuel cost

Load factor = 80% of peak load = 170 MW

sol^n, Taking 100% as interest & tax rate

$\Rightarrow$ Load factor = 0.80

Total capital cost = Rs $3000 \times 200 \times 1000 \times 1$

= Rs 600000000

Annual fixed cost :

$= 3000 \times 200 \times 1000 \times 1$

$= Rs\ 6.0 \times 10^8$

Annual energy output = max demand $\times$ Load factor

$= 200 \times 1000 \times 365 \times 24 \times 0.80$

$= 1.401 \times 10^9$ kwh

Annual fuel consumption $= 1.401 \times 10^9$ kg

Fuel cost $= \dfrac{7000 \times 1.401 \times 10^9}{1000}$

$= Rs\ 9.811 \times 10^9$

other operating cost = 30% of fuel cost

$= 30\% \times 9.811 \times 10^9$

$= 2.9434 \times 10^9$

$\therefore$ Annual operating cost = annual fuel cost + annual cost of operation

$= Rs\ 9.811 \times 10^9 + 2.9434 \times 10^9$

$= Rs\ 1.27543 \times 10^{10}$

Annual ~~fixed~~ Plant cost:

= annual fixed cost + annual operating cost

$= Rs\ 6 \times 10^8 + 1.27543 \times 10^{10}$

$= Rs\ 1.33543 \times 10^{10}$

$\therefore$ Generation cost $= \dfrac{\text{annual Plant cost}}{\text{annual energy output}}$

$= \dfrac{1.33543 \times 10^{10}}{1.409 \times 10^9}$

$= Rs\ 9.4778\ /Kwh.$

11. Compute the generation cost per Kwh from the following data: installed capacity = 200 MW; capital cost = Rs 3000 per KW; interest and depreciation = 12 %, Fuel consumption = 0.9 Kg/Kwh; fuel cost = Rs 7000 per 1000 Kg; other operating cost = 30% fuel costs; load factor = 80% of peak load.

18/F, 14/F

Soln,

$\Rightarrow$ Annual fixed cost = 12% of $3000 \times 200 \times 1000$

$= Rs\ 7.20 \times 10^7$

Annual fuel consumption = $0.90 \times$ annual energy output

Annual energy output = max demand $\times$ load factor $\times$ no of hours

$= 200 \times 1000 \times 0.80 \times 365 \times 24$

$= 1.402 \times 10^9$ Kwh

Annual fuel consumption $= 1.2614 \times 10^9$ Kg

Fuel cost $= \frac{7000}{1000} \times 1.2614 \times 10^9$

$= Rs\ 8.830 \times 10^9$

Annual cost of operation = annual fuel cost + annual cost of operation, labour, maintenance

$= 30\%$ of fuel cost

$= 30\% \times 8.830 \times 10^9$

$= 2.649 \times 10^9$ Rs

Annual plant cost = annual fixed + operating cost

$= 7.20 \times 10^7 + 2.649 \times 10^9$

$= Rs\ 2.721 \times 10^9$

$\therefore$ Generation cost $= \frac{\text{annual plant cost}}{\text{annual energy output}}$

$= \frac{2.721 \times 10^9}{1.401 \times 10^9}$

$= Rs\ 1.9422\ /Kwh.$

1.) A power plant of 180 MW installed capacity has following data:

capital cost = Rs 2160 /Kw installed

Interest and depreciation = 12 %

Annual load factor = 0.6

" capacity " = 0.5

" running charges = Rs 36×10^6

energy consumed by power auxiliaries = 6 %

calculate (i) Reserve capacity

(ii) generation "

Sol",

$\Rightarrow$ Load factor $= \frac{\text{avg load}}{\text{max demand}}$

capacity factor = $\frac{\text{average load}}{\text{rated capacity}}$

$\therefore$ $\frac{\text{Load factor}}{\text{capacity ''}}$ = $\frac{\text{Rated capacity}}{\text{max. demand}}$

or $\frac{0.6}{0.5} = \frac{180}{\text{max. demand}}$

$\therefore$ max demand = 150 MW

(i) Reserved capacity = Installed capacity − max demand
= 180 − 150 MW
= 30 MW

ii) Generation cost :
average load = Load factor X max. demand
= 0.6 X 150
= 90 MW

energy generated per annum = $90 \times 10^3 \times 365 \times 24$
= 788.4×10^6 Kwh

energy consumed by auxiliaries
= $\frac{6}{100} \times 788.4 \times 10^6$
= 47.3×10^6 Kwh

net energy available = $788.4 \times 10^6 - 47.3 \times 10^6$
= 741.1×10^6 Kwh

Fixed cost of generation = Interest + depreciation
= $12\% \times 2160 \times 180 \times 10^3$
= Rs 46.65×10^6

Total annual cost = Running cost + fixed cost
= $36 \times 10^6 + 46.65 \times 10^6$
= Rs 82.65×10^6

$\therefore$ Generation cost $= \dfrac{82.65 \times 10^6}{741.1 \times 10^6} \times 100$

$= 11.1$ paisa

J. What are the benefits of interconnection with of utility. 15/5

=> Distributed generation is the need of hour due to its operational benefits like system reliability, peak power requirements, ancillary services and grid security; however the operational as well as commercial issues related to system and utilities involved, need to be taken care while doing interconnection of distributed generation to the utility systems.

Benefits are:

- Better handling of two way electrical flows.
- Providing ancillary services.
- Easier deployment
- Reduced downtime
- maintaining power to local micro grids during system outages
- Higher penetration test
- Dynamic integration of variable energy generation.

K. A power station having maximum demand of 100 MW has a load factor of 30% and is to be supplied by one of the following schemes.

i) A steam station in conjuction with a hydro electric station, the latter supplying 100×10^6 kWh per annum with a maximum load output of 40 MW.

ii) A steam capable of supplying the whole load.

iii) A hydro station capable of " " " "

Compare the overall cost per kWh generated, assuming the following data:

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13.

	steam	Hydro
capital cost /kw installed	Rs 1250	Rs 2500
Interest & dep. on capital investment	12%	10%
operation cost / kwh	5 paisa	1.5 paisa
Transmission cost/kwh	negligible.	0.2 paisa

Sol^n.

⇒ units generated/annum = max demand X L.F X hours in a year

$= 100 \times 10^3 \times 0.3 \times 8760$

$= 262.80 \times 10^6$ kwh

① steam station in conjuction with hydro station:

units supplied by hydro station $= 100 \times 10^6$ kwh

" " " steam " $= (262.8 - 100) \times 10^6$

$= 162.8$ kwh

Since, the max. output of hydro station is 40 MW, the balance 100 - 40 = 60 MW shall be supplied by steam station.

ⓐ steam station:

capital cost = Rs $60 \times 10^3 \times 1250$ = Rs 75×10^6

Annual dep. and interest = Rs $0.12 \times 75 \times 10^6$

= Rs 9×10^6

operating cost = Rs $0.05 \times 162.8 \times 10^6$ = Rs 8.14×10^6

Transmission cost = negligible.

∴ Total annual cost = Rs $(9 + 8.14) \times 10^6$

= Rs 17.4×10^6

ⓑ Hydro station:

capital cost = Rs $2500 \times 40 \times 10^3$ = Rs 100×10^6

Annual interest and dept = Rs $0.1 \times 100 \times 10^6$ = Rs 10×10^6

operating cost = Rs $0.015 \times 100 \times 10^6$ = Rs 1.5×10^6

Transmission cost = Rs $0.002 \times 100 \times 10^6$ = Rs 0.2×10^6

Total annual cost = Rs $(10 + 1.5 + 0.2) \times 10^6$

$= Rs\ 11.7 \times 10^6$

Total annual charges for both steam and hydro stations,

$= Rs\ (11.7 + 17.14) \times 10^6$

$= Rs\ 28.84 \times 10^6$

$\therefore$ overall cost/Kwh $= Rs\ \dfrac{28.84 \times 10^6}{262.8 \times 10^6}$

$= Rs\ 0.1097$

$= 10.97$ paisa

ii) steam station:

capital cost $= Rs\ 1250 \times 100 \times 10^3 = Rs\ 125 \times 10^6$

Annual interest & dept $= Rs\ 0.12 \times 125 \times 10^6 = Rs\ 15 \times 10^6$

Fixed charges /Kwh $= Rs\ \dfrac{15 \times 10^6}{262.8 \times 10^6}$

$= Rs\ 0.0571 = 5.71$ paisa.

operating cost / Kwh $= 5$ paisa

Transmission cost/Kwh = negligible.

$\therefore$ overall cost /Kwh $= 5.71 + 5 =$ i.e. 10.71 paisa.

(iii) Hydro station:

capital cost $= Rs\ 2500 \times 100 \times 10^3 = Rs\ 250 \times 10^6$

Annual interest and dep $= Rs\ 0.1 \times 250 \times 10^6 = Rs\ 25 \times 10^6$

$\therefore$ Fixed charge/Kwh $= Rs\ \dfrac{25 \times 10^6}{262.8 \times 10^6}$

$= Rs\ 0.0951$

$= 9.51$ paisa.

$\therefore$ overall cost /Kwh $= 9.51 + 1.5 + 0.2$

$= 11.21$ paisa.

1) Explain the need for the co-ordination of different types of power plants connected to an interconnected power system. 15S, 13F

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What are the major problems that involves during coordination? 75/F

⇒ Coordination of Power plant means interconnected power plant system to maintain the minimum cost of generation for the consumer during given operating duration.

Advantages of coordinated system :
Same as advantages of interconnected system.
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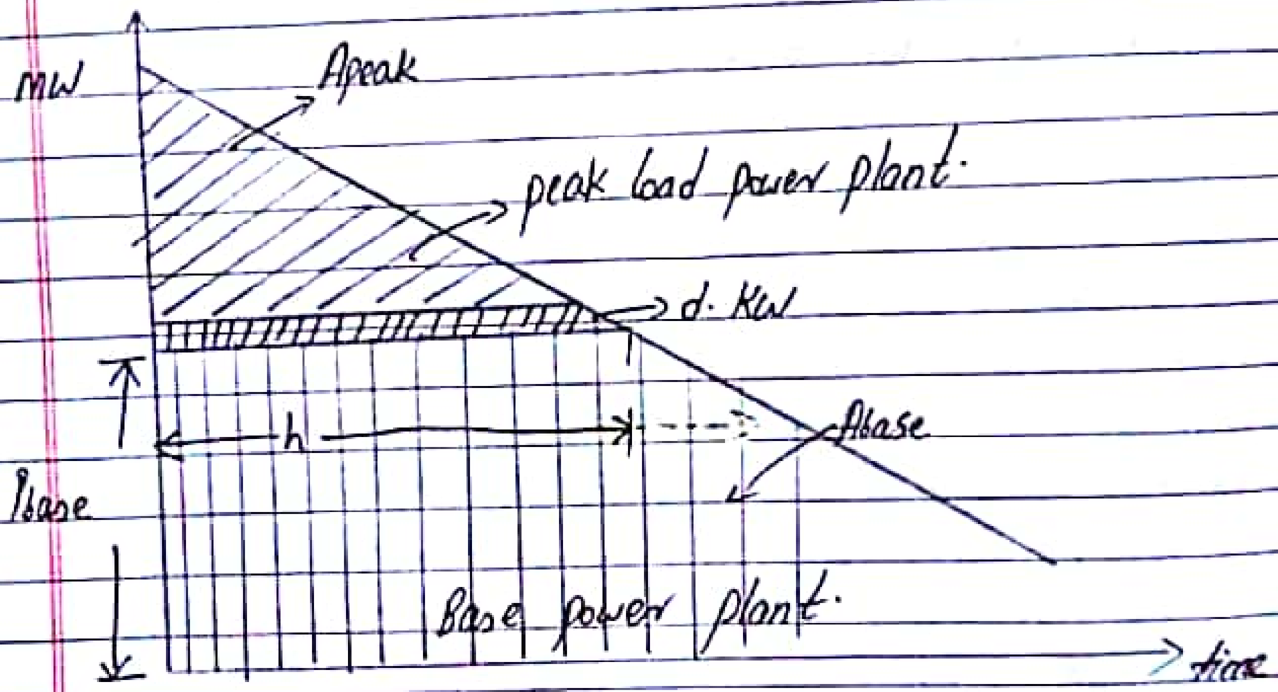
m. Cost analysis of Coordinated Power Plants:



let,
Cost function for peak load power plant is given by,
$C_{peak} = a_1$ Rs $+ b_1$ Rs/Kw $+ C_1$ Rs/Kwh
$C_{base} = a_2$ Rs $+ b_2$ Rs/Kw $+ C_2$ Rs/Kwh.

Assume, the differential change in max load of base p. plant is dKw. Assume initial condition, max load on base p. plant was P_{base} and max load on peak. p. plant was P_{peak}.

Total cost of generation for base P.plant in initial condition i.e. when there was no increment in max load.

Cost of generation for base P. plant:

$Cost_b = Rs\ (a_2 + b_2 \times P_b + c_2 \times A_b)$

Cost of generation for peak P. plant:

$Cost_p = Rs\ (a_1 + b_1 \times P_p + c_1 \times A_p)$

Total cost of gen if both P.P are operating simultaneously:

$= Cost_b + Cost_p$

$C = Rs\ (a_1 + a_2 + b_1 \times P_p + b_2 \times P_b + c_1 \times A_p + c_2 \times A_b)$

Suppose dkW amount of load is increased on base load, then new cost of generation for base P.P

$Cost_{bn} = a_2 + b_2 \times (P_b + dkW) + c_2 \times (A_b + h \times dkW)$

new cost of generation for peak P.P:

$Cost_{pn} = a_1 + b_1 (P_p - dkW) + c_1 \times (A_p - h\,dkW)$

Total cost of generation when P.P are working simultaneously in new condition will be,

$C_n = Rs[(a_1 + a_2 + b_2 (P_b + dkW) + b_1 (P_p - dkW) + c_2 (A_b + h\,dkW) + c_1 (A_p - h\,dkW)]$

Change in cost when there is increase in load on base load P.P is,

$C_n - C = a_1 + a_2 - a_1 - a_2 + b_2 P_b - b_2 P_b + b_2 dkW + b_1 P_p - b_1 P_p - b_1 dkW + c_2 A_b - c_2 A_b + c_2 h\,dkW + c_1 A_p - c_1 A_p - c_1 h\,dkW$

$= b_2 dkW - b_1 dkW + c_2 h\,dkW - c_1 h\,dkW$

$= dkW (b_2 - b_1) + h\,dkW (c_2 - c_1)$

For maintaining minimum cost during changes in load, the

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difference in both cost is 0.

Hence,

or $0 = (b_2 - b_1) + h\,(C_2 - C_1)$

or $h\,(C_2 - C_1) = -(b_2 - b_1)$

$\therefore\ h = \dfrac{b_1 - b_2}{C_2 - C_1}$

Here,

a. = constant amount charged to the consumer during each billing period.

b = energy rate per kW of max. demand

c = energy rate per kWh.

N). It is necessary to choose a power transformer for a new power station. The expected load on the transformer is as follows:

500 kVA for 4 hrs

1000 kVA for 6 hrs

1500 kVA for 14 hrs

Two transformer each rated 2000 kVA with 0.8 pf lagging have been quoted as:

Particulars	Transformer I	Transformer II
Full load efficiency	98.5 %	99 %
Core loss	2.7 kW	2.5 kW
Price	Rs 4,00,000	Rs, 4,50,000

Determine: which transformer should be chosen. If the annual charges of interest and depreciation are 10% and the energy cost is NRs 5.00 per kWh. 2415, 241F, 10ds

Soln,

⇒ annual charges for interest and depreciation = %

annual energy cost per kWh = 5 Rs

Rating = 2000 kVA

power factor = 0.8 lag.

We know,

$$\text{efficiency} = \frac{\text{output}}{\text{output} + \text{copper loss} + \text{iron loss}}$$

For Transformer : 1 :

Iron loss = 2.7 kW

efficiency, η = 98.5 %

output = 1500

So,

$$\text{or, } 0.985 = \frac{2000 \times 0.8}{2000 \times 0.8 + Cu + 2.7}$$

$\therefore$ copper loss = 21.665 kW at full load

We have,

$$\frac{\text{Cu loss at any load}}{\text{Cu loss at full load}} = \left(\frac{\text{VI at any load}}{\text{VI at any load}}\right)^2$$

So,

$$\text{Cu loss at 500 kVA} = \left(\frac{500}{2000}\right)^2 \times 21.665$$

$$= 1.354 \text{ kW}$$

$$\text{Cu loss at 1000 kVA} = \left(\frac{1000}{2000}\right)^2 \times 21.665$$

$$= 5.41625 \text{ kW}$$

$$\text{Cu loss at 1500 kVA} = \left(\frac{1500}{2000}\right)^2 \times 21.665$$

$$= 12.186 \text{ kW}$$

Total copper loss = 12.18 + 5.42 + 1.354
= 18.96 kW

Total copper loss in a day = 1.354 × 4 + 5.42 × 6 + 14 × 12.18
= 208.45 kWh

Annual copper loss = 208.45 × 365
= 76084.25 kWh

Annual iron loss = 2.7 × 365
= 985.5 kWh.

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$\therefore$ Total iron loss cost = Rs 5 X 985.5
= Rs 4927.50

$\therefore$ Total copper loss cost = Rs 5 X 76084.25
= Rs 380,421.25

Depreciation and interest on Transformer – 1:
= 10 % of capital cost
= 10 % X Rs 4,00,000
= Rs 40,000

Hence,
Total cost annually = Rs 40,000 + 380,421 + 4927
= Rs 4,25,348

For Transformer II :

efficiency = 99 %
Core loss = 2.5 kW
capital cost = Rs 4,50,000
interest and depreciation cost = 450000 X 10%
= 45000 Rs

or $0.99 = \dfrac{2000 \times 0.8}{2000 \times 0.8 + 2.5 + Cu\ loss}$

$\therefore$ Cu loss at full load = 13.66 kW

For various loads,

Cu loss at 500 kVA $= \left(\dfrac{500}{2000}\right)^2 \times 13.66 = 0.85$ kW

" " " 1000 kVA $= \left(\dfrac{1000}{2000}\right)^2 \times 13.66 = 3.42$ kW

" " " 1500 " $= \left(\dfrac{1500}{2000}\right)^2 \times 13.66 = 7.69$ kW

Total copper loss in a day
$= 0.85 \times 4 + 6 \times 3.42 + 14 \times 7.69$

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$= 131.58$ kwh

Total copper loss in a year $= 131.58 \times 365$

$= 48026.7$ kwh

$\therefore$ Total copper loss cost $=$ Rs 5×48026.7

$=$ Rs 240133.5

Total iron loss $= 2.5 \times 365$ in a year

$= 912.5$ kwh

Total iron loss cost $= 5 \times 912.5$

$=$ Rs 4562.5

Depreciation and interest on Transformer 2:

$= 10\%$ of $450,000$

$=$ Rs 45000

Hence,

$\therefore$ Total annual cost $=$ Rs $45000 + 4562.5 + 240133.5$

$=$ Rs $289,696$

Since, annual cost for transformer 2 is Rs 2,89,696 which is less than that annual cost for transformer 1 (Rs 425,348) Hence, Transformer-2 should be chosen.

Q. The fixed cost for a thermal station is Rs 2600 per kw of installed capacity per year, the fuel and operating costs can be taken as Rs 2 per kwh generated. Find the costs of the electrical energy generated per kwh at station load factors of 100 %, 75 %, 50 % and 25 %. 121F, 131F

Plot the curves showing the variation of the cost of energy per kwh generated.

Sol^n,

$\Rightarrow$ Fixed costs per year per kw $=$ Rs 2600.

" " " hour " " $=$ Rs $\frac{2600}{8760} = 0.2968$ Rs

Thus, 1-kW capacity of the plant is available at a cost of Rs 0.296 per hour whether the plant is in use or not; this charge is compulsory. The fuel and operating costs depend on the number of kWh produced, the rate is Rs 2 per kWh.

The energy produced is, however, dependent on the load factor. If a 1 kW plant runs for 1 hour at 100% load factor, it can produce 1 kWh; if run at 75% load factor, it can produce only 0.75 kWh and so on. The cost per kWh at different load factors can hence be found as follows:

Load factor %	Energy produced in 1 hour with 1 kW plant (kWh)	Fixed cost per hour (Rs)	Fuel & ope. cost per hour (Rs)	Total cost per hour (Rs)	Cost per kWh produced per hour (Rs)
100	1	0.296	2	2.296	2.296
75	0.75	0.296	1.5	1.796	2.394
50	0.50	0.296	1	1.296	2.592
25	0.25	0.296	0.50	0.796	3.184

$$\text{Cost per kWh produced per hour} = \frac{\text{total cost / hour}}{\text{energy produced in 1 hr with 1 kW}}$$

As the load factor decreases, the cost per kWh increases.

If the fixed costs form a large proportion of the costs even at 100% load factor, this variation and increase in the cost per kWh will be more pronounced.

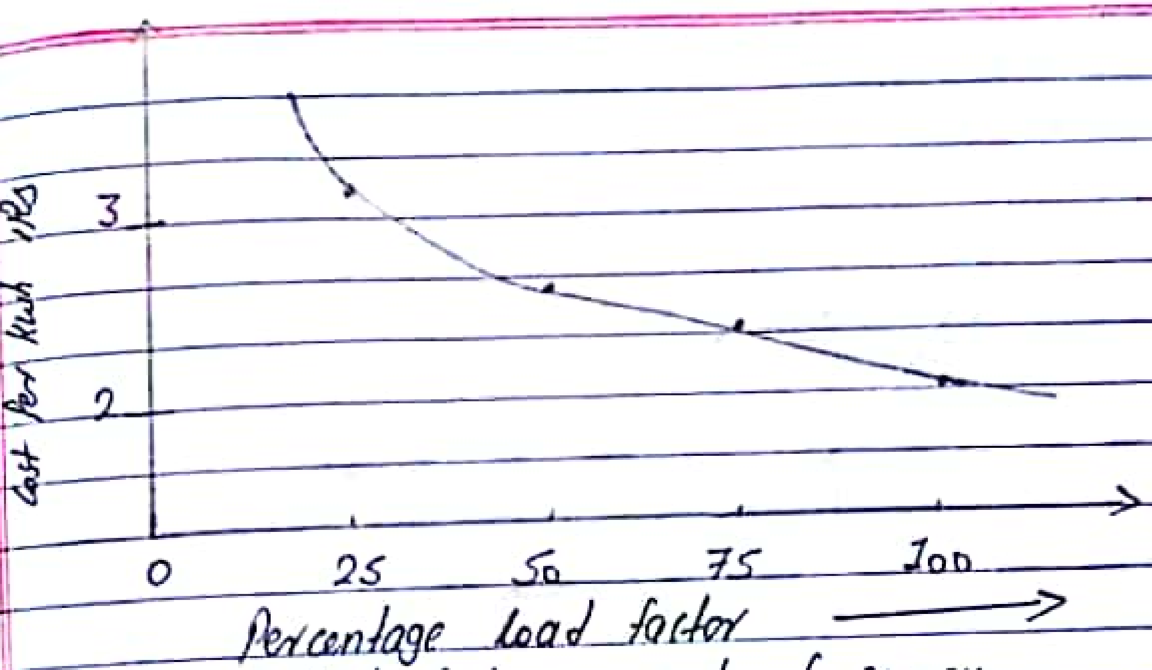

Fig: effect of load factor on cost of energy.

P. From the load duration curve, the following data are available: The maximum demand on the system is 25 MW. The load is supplied by two generating units, unit I is of 15 MW and unit II of 12.5 MW. The unit I acts as a base load unit and the unit II as a peak load. The base load unit operates for 100% of the time while the peak load unit operates for 40% of the time. The energy generated by the unit I is 91×10^6 units and that by the unit II is 1×10^7 units. Find,

(I) load factor, plant capacity factor and the plant use factor for unit I.

(II) load factor, plant capacity factor and the plant use factor for unit II.

16/F

soln,

$\Rightarrow$ max demand = 25 MW

Base load unit – I = 15 MW

Peak " " – II = 12.5 MW

energy generated by base load = 91×10^6 units

" " " Peak " = 1×10^7 "

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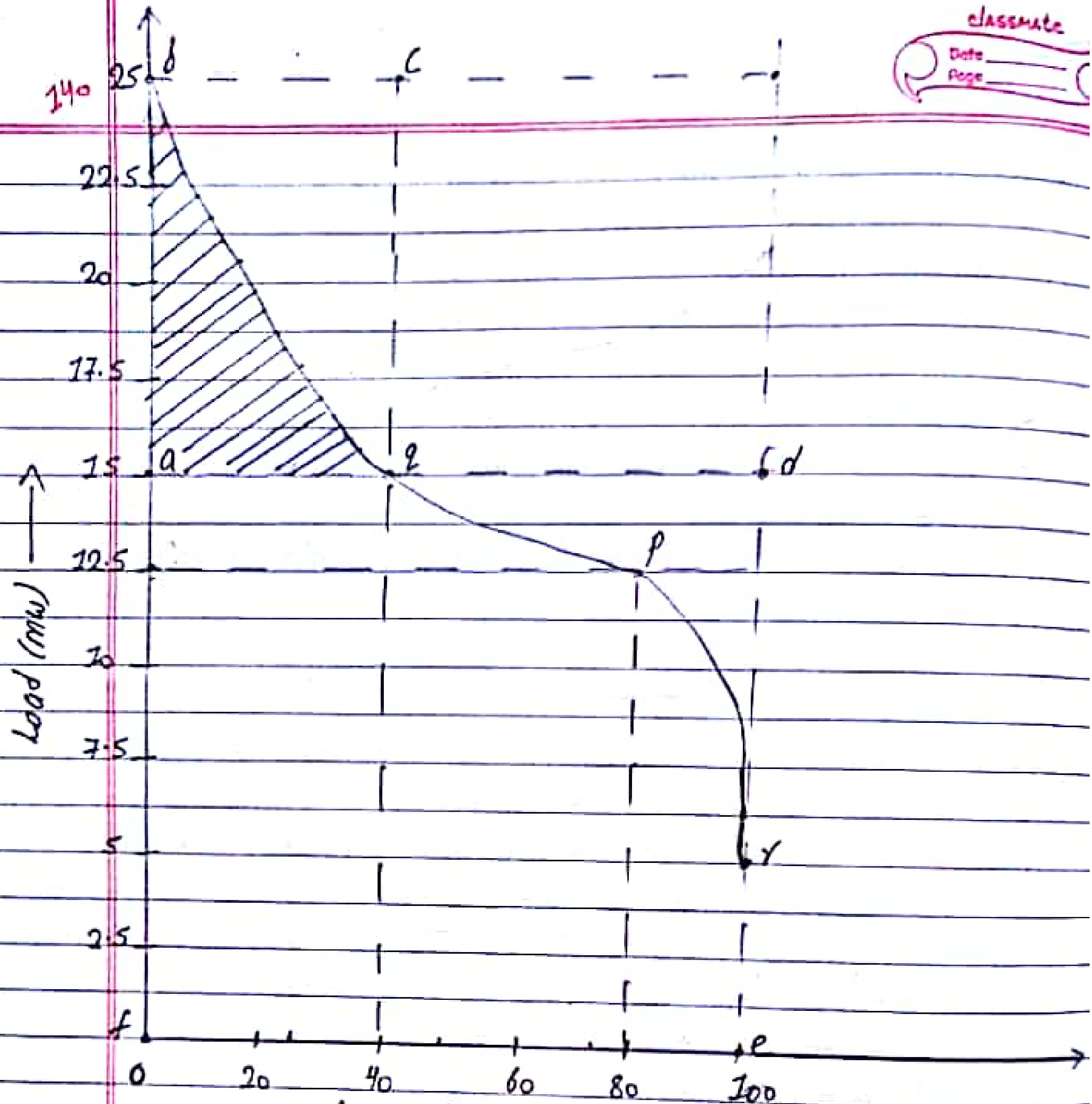


Fig: annual duration curve

The line aq is the line of demarcation of load, as the max load supplied by base load plant is 15 MW. The remaining load above this line is supplied by unit no II.

Plant no 1 is run for all the time, namely, 100% of the year and the max load that it can supply is 15 MW. It has no reserve capacity. The curve area aqprefa under the load duration curve denotes the energy produced by plant no 1 during the year.

∴ Load factor of plant 1 =

$$= \frac{\text{energy produced during the year}}{\text{max. demand} \times 8760}$$

$$= \frac{91 \times 10^6}{15 \times 10^3 \times 8760}$$

$$= 0.6926$$

$$= 69.26\ \%$$

since, there is no reserve capacity for plant no 1, hence

∴ capacity factor = Load factor

$$= 0.6926$$

$$= 69.26\ \%$$

since the plant has been running for the whole year - 8760 hours - continuously, the plant use factor, hence, is the same as the plant capacity factor or load factor.

∴ Plant use factor = plant capacity factor

$$= 69.26\ \%$$

For Plant II :

Plant 2 supplies the remaining load ; the maximum demand on it is $(25-15) = 10$ MW and it runs for 40 % of the year ; its capacity is 12.5 MW. The area under area under this curve represents the energy it produces.

∴ Load factor $= \dfrac{1 \times 10^7}{10 \times 1000 \times 0.40 \times 8760}$

$$= 0.2853$$

$$= 28.53\ \%$$

If taken on the whole year basis ie, 100% utilization,

∴ $L.F = \dfrac{1 \times 10^7}{10 \times 1000 \times 8760} = 0.1145$

Annual plant capacity factor

$$= \frac{1 \times 10^7}{12.5 \times 1000 \times 8760}$$

$= 0.0913$

$= 9.14\ \%$

Plant use factor $= \dfrac{1 \times 10^7}{12.5 \times 1000 \times 0.4 \times 8760}$

$= 0.2284$

$= 22.84\ \%$

and,

$\therefore$ annual load factor of the whole system:

$$= \frac{91 \times 10^6 + 1 \times 10^7}{8760 \times 25 \times 10^3}$$

$= 0.4612$

$= 46.12\ \%$

Q. The two power station X and Y supply to a system whose maximum load is 120 MW and minimum load is 12 MW. during the year. The estimated cost of these stations are as follow:

$C_x =$ Rs $120/KW + 0.028/Kwh$

$C_y =$ Rs $115/Kw + 0.032/Kwh$

If the load varies as a straight line, find

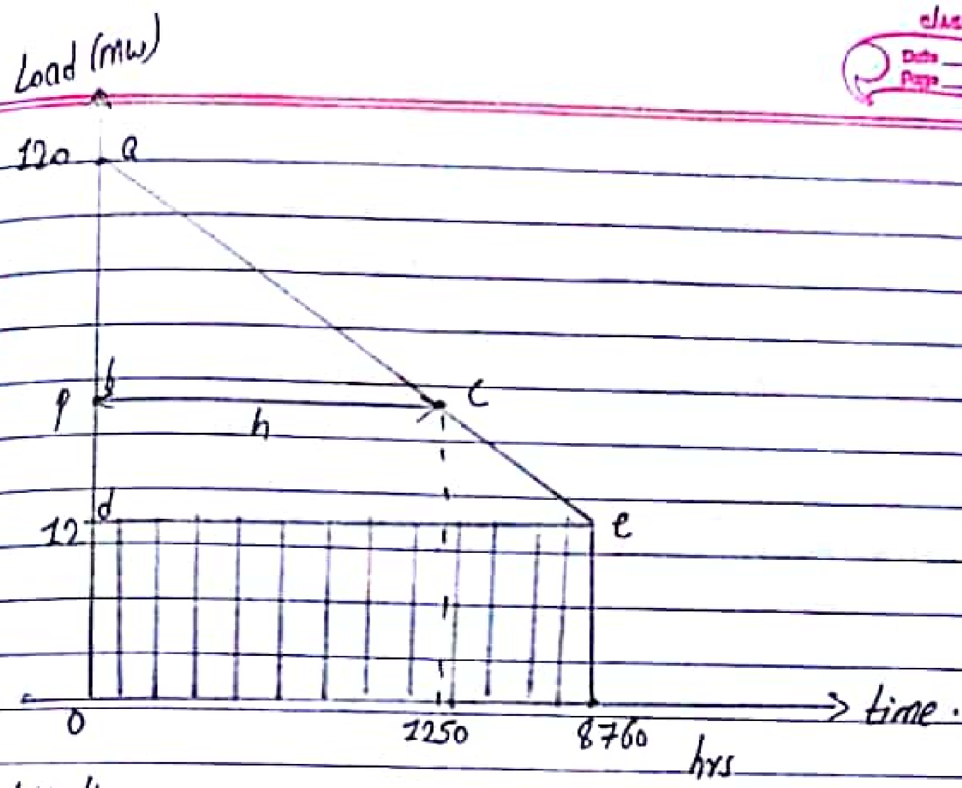
(I) installed capacity of each plant.

(II) annual load factor, capacity factor, average cost of production per kw for each plant and for entire system also.

Assume reserve capacity of Plant y is 22 %.

Soln,

$\Rightarrow$ Plant x acts as Base load Power Plant and
" y " " Peak " " "



We know,

$$h = \frac{b_1 - b_2}{C_2 - C_1}$$

C_1 = Coeff of base load P.P ie, 1Kwh value
C_2 = " " Peak " P.P ie, 1Kwh value.
P = max load on base power plant.

Here,

$$\Delta abc \sim \Delta ade$$

or $$\frac{ab}{ad} = \frac{bc}{de}$$

or $$\frac{120-P}{120-12} = \frac{h}{8760}$$

or, $$\frac{120-P}{} = \frac{h}{81.11} \quad \text{— ①}$$

By using cost function of x and y Power plant,

$$h = \frac{b_1 - b_2}{C_2 - C_1}$$

$$= \frac{120 - 115}{0.032 - 0.028}$$

$\therefore$ h = 1250 hours

From eqn ①,

or $120 - P = \frac{1250}{81.11}$

or, $P = 120 - 15.41$

$\therefore P = 105$ MW

① Installed capacity:

of Base power plant ie, Plant x

$= 105$ MW

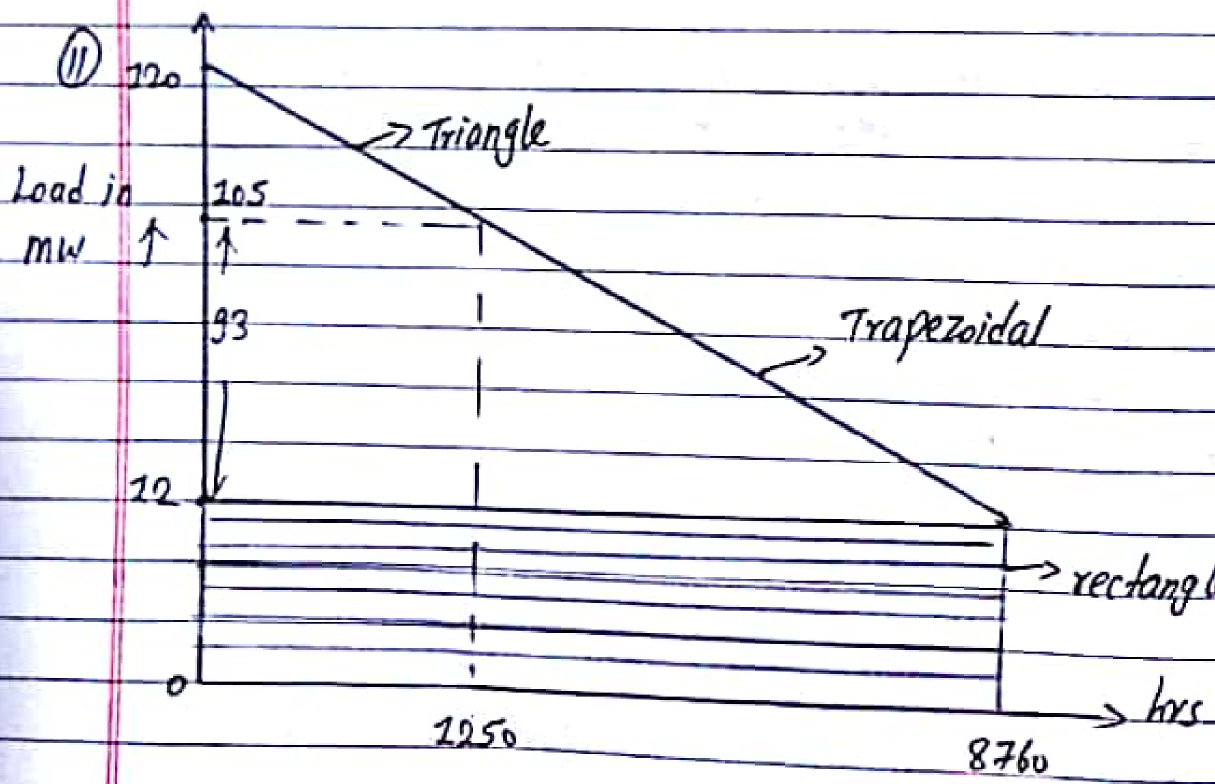
of peak power plant ie, Plant y,

$= 15 +$ reserve capacity

$= 15 + 22\%$ of 15

$= 18.32$ MW

⑪



Load factor $= \frac{\text{avg load}}{\text{max load}}$

$= \frac{\text{no. of units generated}}{\text{max load} \times \text{time}}$

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no. of units generated = area of (rectangle + trapezoidal)
$= [(1/2) \times (\text{sum of parallel side}) \times \text{distance between parallel side}] + \text{length} \times \text{breadth of rectangle}.$

$= [(1/2) \times [1250 + 8760] \times 93 + 12 \times 8760] \times 10^3$
$= 5.70 \times 10^8$ Kwh

Hence,
$$L.F \text{ of Base P.P} = \frac{5.70 \times 10^8}{105 \times 10^3 \times 8760} = 0.621$$

$\therefore$ L.F for Peak P.P i.e. Y P.P
$$= \frac{(1/2) \times 1250 \times 15 \times 10^3}{15 \times 10^3 \times 8760} = \frac{\text{area of triangle}}{\text{max load} \times \text{time}}$$
$= 0.0713$

$\therefore$ capacity factor of X P.P = load factor of X P.P
$= 0.621$
$= 62.10\ \%$

$\therefore$ capacity factor of Y P.P $= \dfrac{\text{no of units generated}}{\text{capacity of P.P} \times \text{time}}$
$$= \frac{(1/2) \times 15 \times 1250 \times 10^3}{18.3 \times 1000 \times 8760}$$
$= 0.058$
$= 5.8\ \%$

$\therefore$ Calculation of cost of generation for X P.P:
= Rs 120/Kw + 0.028 /Kwh
$= 120 \times \text{peak load} + 0.028 \times \text{no of units generated}$
$= 120 \times 105 \times 10^3 + 0.028 \times 5.70 \times 10^8$
$=$ Rs 2.85×10^7

Cost of Y. P.P:

$= Rs\ 115 \times 15 \times 10^3 + 0.032 \times 9.37 \times 10^6$

$= Rs\ 2.02 \times 10^6$

$\therefore$ Total cost of system $= Rs\ 2.02 \times 10^6 + 2.85 \times 10^7$

$= Rs\ 3.052 \times 10^7$

$\therefore$ whole system load factor

$= \frac{\text{total no of units generated}}{\text{max load} \times \text{time}}$

$= \frac{5.70 \times 10^8 + 9.37 \times 10^6}{8760 \times 120 \times 10^3}$

$= 0.5511$

$= 55.12\ \%$

$\therefore$ average cost $= \frac{30.59 \times 10^6}{580 \times 10^6}$

$= Rs\ 0.0527/kWh$

$\therefore$ whole system plant factor

$= \frac{\text{total no of units generated}}{\text{total plant capacity} \times \text{time}}$

$= \frac{5.70 \times 10^8 + 9.37 \times 10^6}{8760 \times 123.3 \times 10^3}$

$= 0.5364$

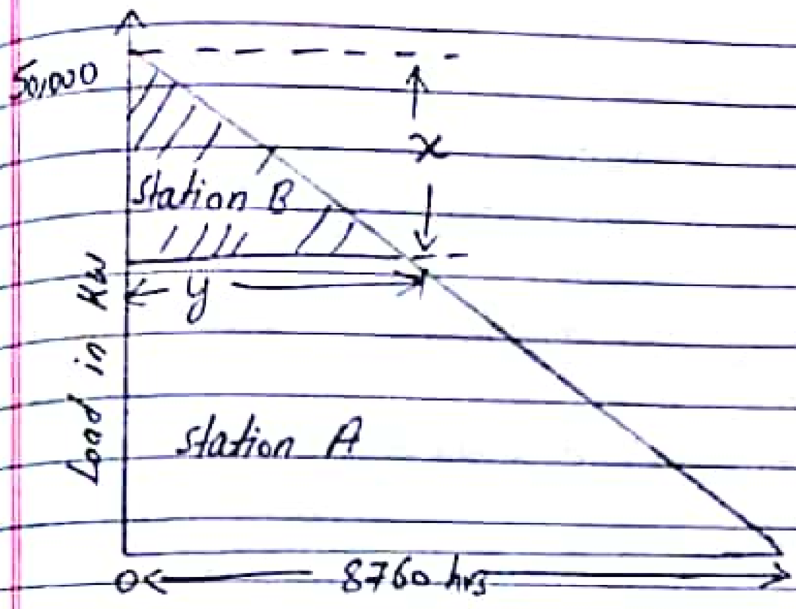
$= 53.64\ \%$

R. The load duration curve of a system for the whole year of 8760 hours is as shown in fig. The system is supplied by two stations A and B having the following annual costs:

station A = Rs $75000 + 80 \times kW + 0.02 \times kWh$

" B = Rs $50000 + 50 \times kW + 0.03 \times kWh$

Determine the installed capacity required for each station and for how many hours per year peak load station should be operated to give the minimum cost per unit generated.



Soln,

$\Rightarrow$ As station A has the lower operating cost, it should be used as the base load station. on the other hand, station B should be used as the peak load station.

let,

x = installed capacity of station B in kW

y = operation hours of station B.

$\therefore$ Installed capacity of station A = $(50000 - x)$ kW

units generated / annum by station B $= \frac{1}{2} \times x \times y$

$$= \frac{1}{2} \times x \times \frac{8760 \times x}{50,000}$$

$$= 0.0876\, x^2$$

units generated / annum by station A

$$= \frac{1}{2} \times 50000 \times 8760 - 0.0876\, x^2$$

$$= 219 \times 10^6 - 0.0876\, x^2$$

Annual cost of station B, CB = Rs $50000 + 50x + 0.03 \times 0.0876\, x^2$

$= Rs\ 50{,}000 + 50x + 0.00262\, x^2$

Annual cost of station A, C_A:

$= Rs\ 75000 + 80 \times (50000 - x) + 0.02 \times (219 \times 10^6 - 0.0876 x^2)$

$= Rs\ 8.455 \times 10^6 - 80x - 0.00175\, x^2$

∴ Total annual operating cost of stations A and B

$C = C_A + C_B$

$= Rs\ 8505{,}000 - 30x + 0.00087\, x^2$

For minimum annual operating costs, $\frac{dC}{dx} = 0$,

∴ $\frac{dC}{dx} = 0 - 30 + 2 \times 0.00087\, x$

or $0 = -30 + 0.00174\, x$

∴ $x = 17{,}241$ kW

∴ Capacity of station $B = 17{,}241$ kW

∴ " " " $A = 50000 - 17{,}241$

$= 32{,}758$ kW

∴ No of hours of operation of station B is,

or $y = \frac{8760\, x}{50000}$

$= \frac{8760 \times 17241}{50{,}000}$

∴ $y = 3020$ hours

5. A generating station has the following data:
Installed capacity = 300 MW, capacity factor = 50 %, annual load factor = 60 %, annual cost of fuel etc = Rs 9×10^7, capital cost = Rs 10^9, annual interest & depreciation = 10 %,

calculate (i) minimum reserve capacity of the station (ii) the cost per kwh generated.

Soln.

⇒ capacity factor = $\frac{\text{average demand}}{\text{Installed capacity}}$ = C.F — (i)

Load factor = $\frac{\text{avg demand}}{\text{max. demand}}$ = L.F — (ii)

dividing (i) by (ii),

or $\frac{C.F}{L.F} = \frac{\text{max. demand}}{\text{Installed capacity}}$

or max demand = Installed capacity × $\frac{C.F}{L.F}$

$= 300 \times \frac{0.5}{0.6}$

∴ max demand = 250 MW

and,

(i) Reserve capacity = 300 − 250 = 50 MW

(ii) units generated/annum = max demand × L.F × hours in a year

$= 250 \times 10^3 \times 0.6 \times 8760$ kwh

$= 1314 \times 10^6$ kwh

annual fixed charges = annual interest & depreciation

$=$ Rs 0.1×10^9

$=$ Rs 10^8

Annual running charges = Rs 9×10^7

∴ Total annual charges = Rs $(10^8 + 9 \times 10^7)$

$=$ Rs 19×10^7

∴ Cost per kwh = Rs $\frac{19 \times 10^7}{1314 \times 10^6}$ = Rs 0.14/kwh

T. Importance of High load factor: 15/s, 17/s, 12/F, 16/F, 16/s, 22/s

The load factor plays a vital role in determining the cost of energy. Some major advantages of high load factor are listed below:

(I) Reduces cost per unit generated:
A high load factor reduces the overall cost per unit generated. The higher the load factor, the lower is the generation cost. It is because higher load factor means that for a maximum demand, the number of units generated is more. This reduces cost of generation.

(II) Reduces variable load problems:
A higher load factor means comparatively less variations in the load demands at various times. This avoids the frequent use of regulating devices installed to meet the variable load on the station. So, a high load factor reduces the variable load problems on the power station.

U. What is the advantages of high diversity factor in a power system. Prove that the load factor of a power system is improved by an increase in diversity of load.

⇒ A high value of diversity factor is always welcomed in power system because it indicates the conservation of energy ie, there is less wastage of energy. Higher the value of diversity factor, lower will be the overall cost of per unit generated.

The capital cost of the power station depends upon the capacity of the power station. Lower the maximum demand of the power station, the lower is the capacity required and hence lower is the capital cost of the plant. with a given number of consumers the higher the diversity factor of their loads, the smaller will be capacity of the plant required and consequently the fixed charges due to capital investment will be much reduced.

Diversity factor helps in obtaining better conditions for power supply; diversity is a silver lining to the dark cloud of the load factor.

$$\text{Diversity factor} = \frac{\text{sum of individual max demand}}{\text{simultaneous maximum demand}}$$

As the total maximum demand required at any time during the day is less than the sum of the maximum demands, owing to diversity; the total load factor improves, which is a desirable result. There would be greater diversity between different types of loads occuring at different times of the day. It will always be the aim of a power engineer to persuade the commercial dept. to encourage loads in some places and to discourage them in others in such a way that the total maximum demand is reduced, so that, with lower plant capacity installed at the source of generation, more energy can be supplied, the cost of electrical energy being less at higher load factors.

V. Effect of variable load on Power Plant operation & design:

The equipment to be used for variable load conditions should be designed so that it operates at lower loads (half loads or less) with nearly the same efficiency as at full load. The efficiency curve should not drop too much with changes in load. when it is necessary to cope with a variation in load, the prime movers and generators have to act fairly, quickly and take up or shed load without causing variations in the voltage or frequency of the system. An important requirement is therefore, the control of the supply of fuel to the prime mover by the action of the governor. When the load on generator increases suddenly, the first effect is to slow down the rotor and hence reduce the frequency. The speed of the prime mover drops. The governor acts, admitting more fuel - enough to bring the speed back to normal and pick up the load. The governor may be set for such operation at the desired load.

To suit variable load conditions, the generator units should have characteristics which enable them to run parallel without load shedding i.e, without switching off part of the load. Variable load conditions also create operating problems. There are numerous, starting with the allotment of units to proper portions of the load curve, preparing operating schedules for the best use of the generator units and trying to operate the plant to produce electrical energy as cheaply as possible.

The rate for electricity supply to the consumers - the tariff - largely depends on the variable load conditions. To cope with variable load conditions/operation, it is necessary for the utility undertaking to keep the reserve plant ready for taking load at any time the demand is made because reliability without interruption is an essential feature of power supply. This reserve is necessary for an individual or an isolated plant and is known as the spinning reserve.

The variable load problem can be solved in some cases by partly generating and partly buying power, particularly for the peak load portion of the curve, if supply from a grid is available and if economics demands it.

14. The daily load curve for a power plant is given by the following eq^n:

$$L = 350 + 10t - t^2$$

where, t is the time in hours from 0 to 24 hours and L is in MW. calculate:

i). Load factor of the plant.

ii) value of maximum load and when it occurs.

Sol^n,

⇒ Given,

$$L = 350 + 10t - t^2$$

(i) value of maximum load and when it occurs:

Condition for finding the value of maximum load is $\frac{dL}{dt} = 0$

$\therefore \frac{d}{dt}(350 + 10t - t^2) = 0$

or $10 - 2t = 0$

$\therefore t = 5$ hours

Thus, the maximum load occurs at the 5th hour during the day.

$\therefore L_{max} = 350 + 10 \times 5 - 5^2$

$= 375$ MW

(ii) Load factor:

average load, $L_{av} = \frac{1}{24}\int_0^{24} L \cdot dt$

$= \frac{1}{24}\int_0^{24} (350 + 10t - t^2)\,dt$

$= \frac{1}{24}\left[350t + 10 \times \frac{t^2}{2} - \frac{t^3}{3}\right]_0^{24}$

$= \frac{1}{24}\left[350 \times 24 + 10 \times \frac{24^2}{2} - \frac{24^3}{3}\right]$

$= 278$ MW

hence,

Load factor, L.F = $\frac{I_{av}}{I_{max}}$

$= \frac{278}{375}$

$= 0.7413$

∴ Load factor = 74.13 %

X). Characteristics of the Grid:

— The grid can absorb all produced energy and make it available whereever it is required.
- The SHP runs permanently at maximum possible capacity.

— Voltage and frequency are defined by the grid and cannot be influenced by the SHP.
- The SHP needs to 'form' its produced energy in a way that it is possible to feed it into the grid.

— Faulty equipment can cause black outs of large extend.
- Higher requirements to the installed equipment.
- Application of standards.

Advantages of decentralized Power Production:
— Reduced dependency on single large power plants.
— Backing up the voltage level in remote areas.
— Reduction of transmission losses in the national grid.

Y.

3) Some major components used in HV switchyards and Power Plants : 3 Hrs

1.

1A) Discuss the merits and demerits of SF_6 circuit Breaker.

=> Merits of SF_6 circuit Breaker :

(i) It is simple, less costly and maintenance free compact.

(ii) The gas is inflammable and chemically stable. The decomposition products are not explosive. Hence, there is no danger of fire or explosions.

(iii) The breaker is silent and doesnot sound, like ABCB during operation.

iv. No cost for compressed air system as in ABCB.

v. low noise level.

vi. Reliability and availability

vii. Integrated closing resistors or synchronized operations to reduce switching overvoltages.

viii. Possible compact solutions when used for GIS or hybrid switchgear.

ix. short break time of 2 to 2.5 cycles.

x. High electrical endurance, allowing atleast 25 years of operation without reconditioning.

xi. Autonomy provided by the puffer technique.

xii. No frequent contact replacement. Contact corrosion is very small due to inertness of SF_6 gases. Hence, contacts donot suffer oxidation.

xiii. Excellent insulating, arc extinguishing, physical and chemical properties of SF_6 gases is the greatest advantage of SF_6 breaker.

xiv. Simplicity of the interrupter chamber which doesnot need an auxiliary chamber for breaking.

2

xv. No overvoltage problems. Due to particular properties of SF6 gas, the arc is extinguished at natural current zero without current chopping and associated over voltage originating in circuit breakers.

xvi maintenance required is minimum.

xvii Ability to interrupt low and high fault currents, magnetizing currents, capacitive currents, without excessive over voltage.

Demerits :

(I) Sealing problems arise due to the type of construction used. special materials are necessary in construction. Imperfect joints leads to leakage of gas.

(II) Arced SF6 gas is poisonous and should not be inhaled or let out.

(III) The double pressure SF6 CB is relatively costly.

iv. Influx of moisture in the system is very dangerous to SF6 gas ckt breakers.

v) The internal parts should be cleaned thoroughly during periodic maintenance, under clean, dry environment.

vi) special facilities are needed for transporting the gas, transferring the gas and maintaining the quality of the gas. The deterioration of quality of the gas affects the reliability of the SF6 circuit breaker.

vii) Continuous monitoring devices are required.

3

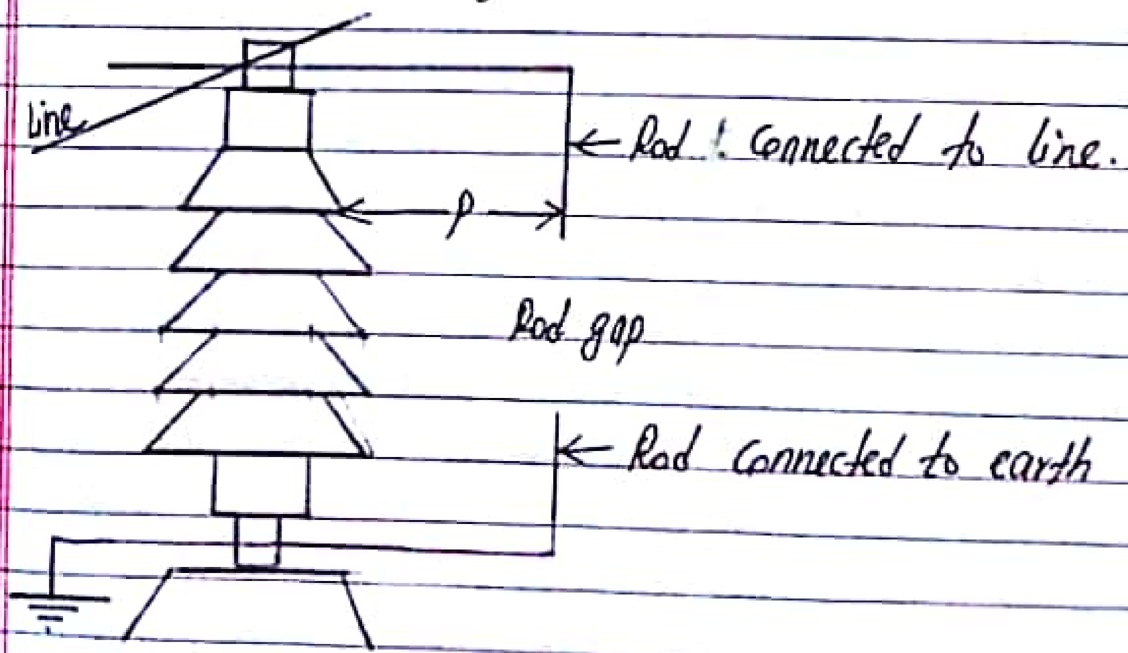
B). Describe different types of lightning arrestors used for outdoor applications. 16/F, 17/F, 17/S

⇒ Different types of lightning arrestors used for outdoor applications are:

① Rod gap arrestor:

It is a very simple type of arrester and consists of two 1.5 cm rods, which are bent at right angles with a gap in between. one rod is connected at the line circuit and the other rod is connected to earth. The length distance between gap and insulator must not be less than one third of the gap length so that the arc may not reach the insulator & damage it.

Generally, the gap length is so adjusted that breakdown should occur at 80% of spark voltage in order to avoid cascading of very steep wave fronts across the insulators.



— under normal operating conditions, the gap remains non conducting. on the occurrence of a high voltage surge on the line, the gap sparks over and the surge current is conducted to earth, in this way, excess charge on the line due to the surge is harmlessly

4

conducted to earth.

- They are used in insulators, equipment & bushings.

Limitations:

(I) The climatic condition affect the performance of rod gap arrestor.

(II) The polarity of the surge also effects the performance of this arrestor.

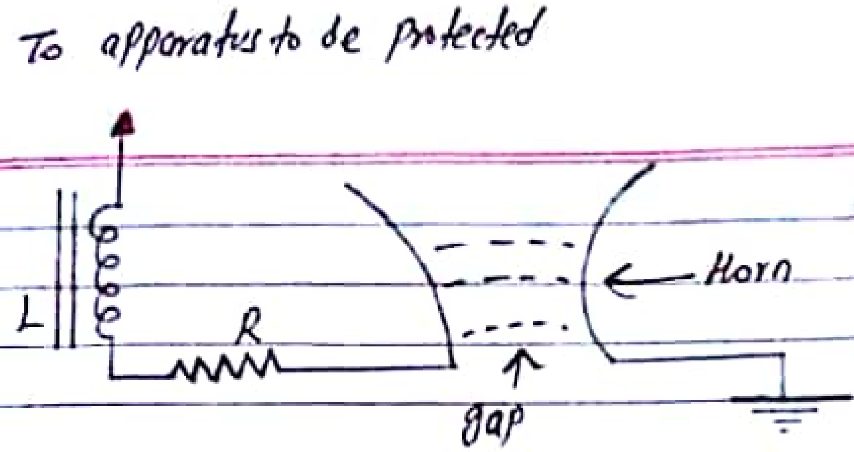
(III) The rods may melt or get damaged due to excessive heat produced by the arc.

Due to the above limitations, the rod gap type arrestor is only used as a Back up protection in case of main arrestor.

(II) Horn gap arrestor:

It consists of a horn shaped metal rods A and B separated by a small air gap. The horns are so constructed that distance between them gradually increases towards the top. The horns are mounted on porcelain insulators. one end of horn is connected to the line through a resistance and choke coil L while the other end is effectively grounded. The resistance R helps in the limiting the follow current to small value. The choke coil is so designed that it offers small reactance at normal power frequency but a very high reactance at transient frequency. Thus, the choke doesnot allow the transients to enter the apparatus to be protected.

The gap between the horns is so adjusted that normal supply voltage is not enough to cause an arc across the gap.



Advantages:

i) Series resistance helps in limiting the follow-current to a small value.

ii) In case of rod gap arrester, arc may continue when the system attains normal frequency. But in this arrestor, there is no such problem.

Disadvantages:

i) The gap can be bridged by some external agency such as birds.

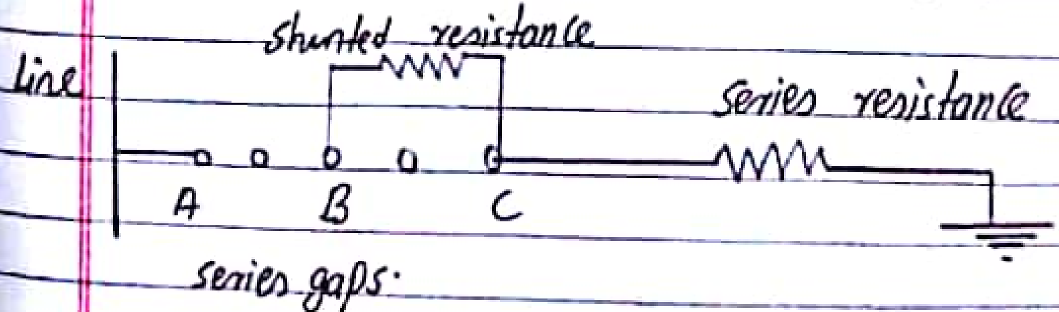
ii) Breakdown voltage value is affected by atmospheric conditions.

iii) At different frequencies, the gap breaks at different voltages.

iv) The setting of horn gap is likely to change due to corrosion which affects the performance of the lightning arrester.

(III) multigap arrester:

It consists of a series of metallic cylinders insulated from one another and separated by small intervals of air gaps. The first cylinder in the series is connected to the line and the others to the ground through a series resistance. The series resistance limits the power arc.



Such arrester can be employed where system voltage does

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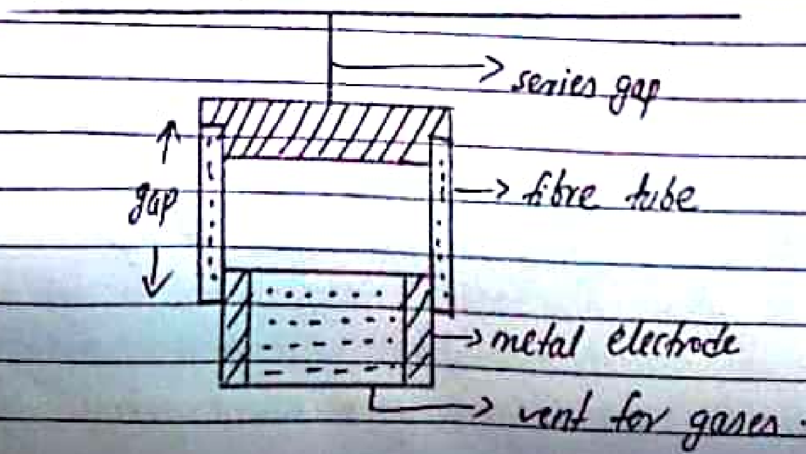
not exceed 33 kV. By the inclusion of series resistance the degree of protection against traveling wave is reduced.

In order to overcome this difficulty, some of the gaps (B to C) are shunted by resistance. Under normal conditions the point B is at earth potential and the normal supply voltage is unable to break down the series gaps. On the occurrence of an overvoltage, the breakdown of series gaps A to B occurs. The heavy current after breakdown will choose the straight-through path to earth via the shunted gaps B and C, instead of the alternative path through the shunt resistance.

Hence, the surge is over, the arcs B to C go out & any power current following the surge is limited by the two resistances (shunt and series resistance) which are now in series. The current is too small to maintain the arcs in the gaps A to B and normal conditions are restored.

(iv) Explosion type Arrestor:

This type of arrestor is also called as protector tube and is commonly used on system operating at voltages upto 33 kV.



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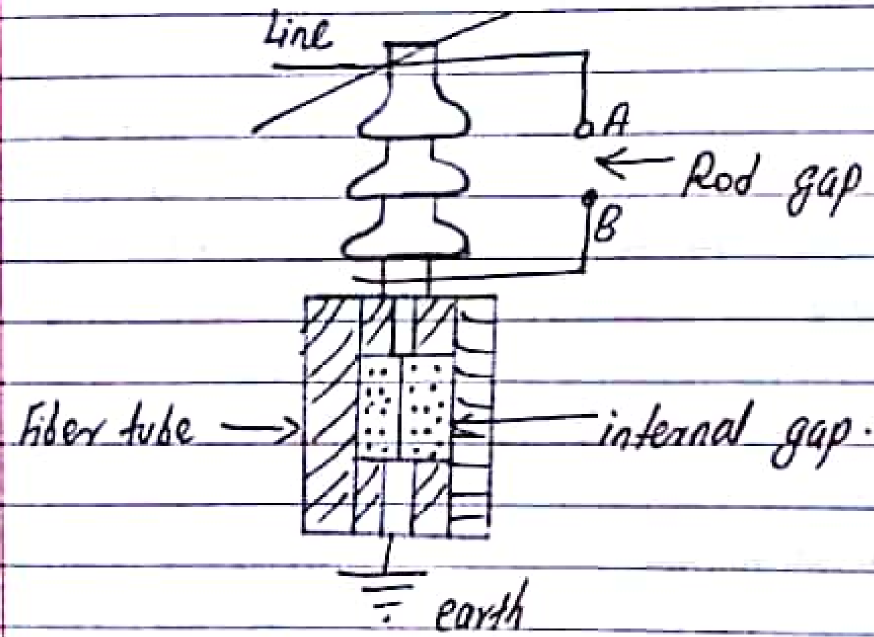
Advantages:

- Not very expensive.
- can be easily installed.
- They are improved form of rod gaps arrestors as they block the flow of power frequency follow currents.

Limitations:

- Due to poor volt/amp characteristics of the arrestor, it is not suitable for protection of expensive equipment.
- cannot be mounted on enclosed equipment due to discharge of gases during operation.



It essentially consists of a rod AB in series with a second gap enclosed within the fiber tube. The gap in the fiber tube is formed by two electrodes. The upper electrode is connected to rod gap and the lower electrode to the earth. One explosion arrestor is placed under each line conductor.

v) Valve type arrestor:

valve type arrestor incorporate non linear resistor and are extensively used on systems, operating at high voltages. It consists of two assemblies ① series

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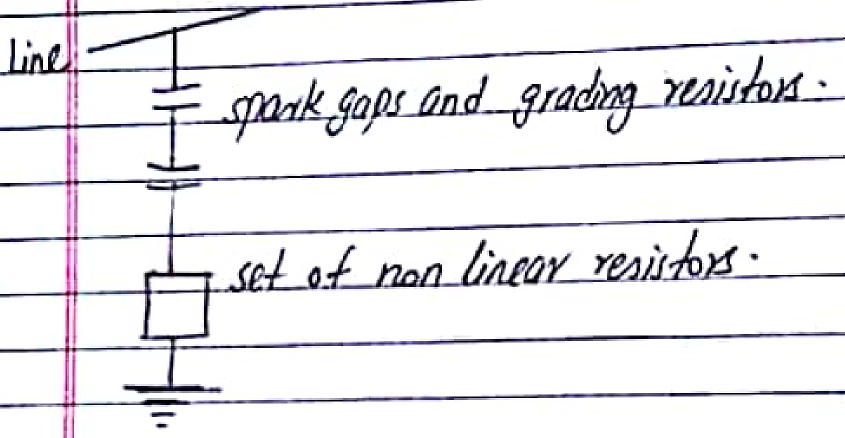
spark gaps (ii) non-linear resister discs in series.



The non linear elements are connected in series with the spark gaps and earth.

Under normal working conditions, when system voltage is normal, there is no effect on the spark air gap at this time, air gap remains non conducting state. on the occurrence of an overvoltage or voltage surge the breakdown of the series spark gap takes place and the surge current starts flow through the non linear resistor to earth.

Since, magnitude of surge current is very large so than non linear resistors will offer a very low resistance path to the passages of surge. when the surge is over, the value of non linear resistance become high and stops the flow of current through them.

Advantages:

- low maintenance cost
- donot require daily supervision.
- provide Effective protection against surges.
- operation of the arrester is fast.
- impulse ration is practically unity.

3

Disadvantages:

- If moisture enters with enclosures, it affects the performance of arrester.

Applications:

- power station operating on voltage upto 220 kv.

vi) silicon carbon arrestors:

The silicon-carbide arrester has some unusual electrical characteristics. It has a very high resistance to low voltage, but a very low resistance to high voltage.

When lightning strikes or transient voltage occurs on the system, there is a sudden rise in voltage and current. The silicon carbide resistance breaks down allowing the current to be conducted to ground. After the surge has passed, the resistance of silicon carbide blocks increases allowing normal operation. The silicon carbide arrestor uses non linear resistors made of bonded silicon carbide placed in series with gaps. The function of the gaps is to isolate the resistors from the normal steady state system voltage.

Advantages:

- Due to the presence of gaps, the normal power frequency voltage during normal operation is negligibly less compared to gapless arrestors. Hence, no leakage current flow between the line & earth in SIC arrestor.

Disadvantages:

- Probability of sparking between the gaps.
- Decrease in energy absorption capability compared to ZnO arrestors.
- Silicon carbide arrestors have inferior VI characteristics compared to ZnO (metal oxide arrestor).

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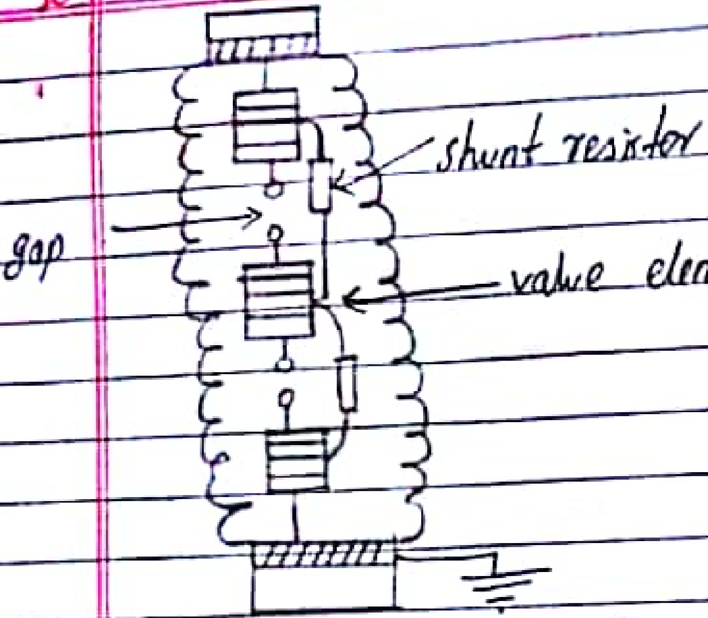


The VI characteristics of SiC type arrester is given by,

$$I = KV^5$$

vii) metal oxide arrester:

The metal oxide arresters are without gaps, unlike the SIC arrester. This gap less design eliminates the high heat associated with the arcing discharges. A metal oxide surge arrester utilizing zinc oxide blocks provides the best performance as surge voltage conduction starts and stops promptly at a precisely voltage level, thereby improving the system protection. Failure is reduced, as there is no air gap contamination possibility; but there is always a small value of leakage current present at operating frequency.

Advantages:

i) Eliminates the risk of spark over and also the risk of shock to the system when the gaps breakdown.

ii. Eliminates the need of voltage grading system.

iii There is no power follow current in ZnO diverter.

iv. It has high energy absorbing capability.

v. ZnO diverter passes high stability during & after prolonged discharged.

vi) It is possible to control the dynamic overvoltages in addition to switching surges. This results in economic insulation coordination.

vii) The leakage current in the ZnO is very low as compared to other diverters.

- It is mainly used for overvoltage protection at all voltage levels in a power system.

Disadvantages:

i) Voltage is continually resident across the metal oxide & produces a current of about 1 milli Amp. while this low magnitude current is not detrimental.

ii) Higher currents, resulting from excursions of the normal power frequency voltage or from temporary overvoltages such as from faults or ferroresonance, produce heating in the metal oxide.

The static characteristics of metal oxide arrestor is,

$$I = KV^x$$

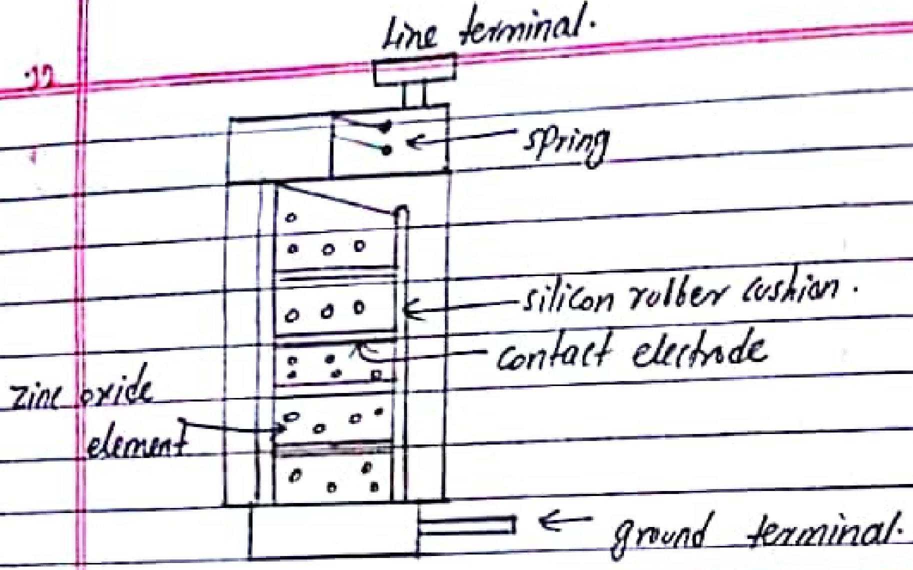
where, $x = 40$,

$$\therefore \quad I = KV^{40}$$

- As $V^{40} > V^5$, the characteristics curve of ZnO arrester is above the characteristics of SiC arrestor.
- V-I characteristics of ZnO arrestor is flat.
- metal oxide arrestor have superior characteristics.

The oxides which are used as;

- Zinc oxide (ZnO)
- Cobalt oxide
- Bismuth oxide



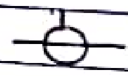
c. <u>Location of current & voltage transformers in substations:</u>

15/S, 17/F

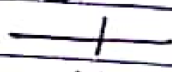
⇒ Instruments transformer are used to supply measured quantities of current and voltage in an appropriate form to controlling and protective apparatus such as energy meters, indicating instruments, protective relays, fault recorders and synchronizers. Instrument transformers are thus installed when it is necessary to obtain measuring quantities for the above mentioned purposes.

Typical points of installations are switch bays for lines, feeders, transformers, bus couplers etc at transformer neutral connections and at the busbars.

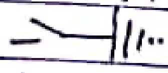
Voltage transformer = 

current " = 

power " = 

Disconnector = 

circuit breaker = 

Earthing switch = 

disconnecting circuit breaker = 

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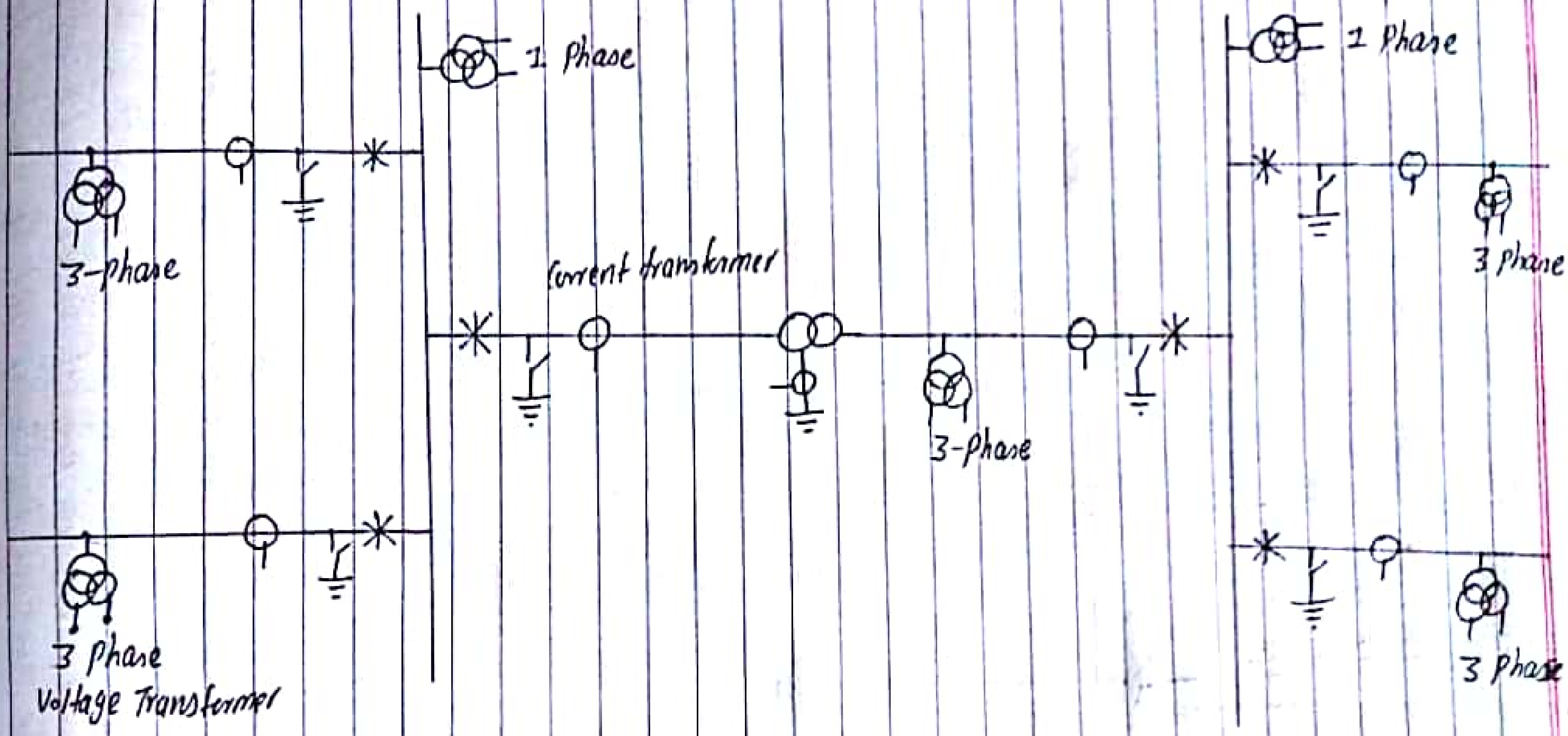

Fig: current and voltage transformer in a substation.

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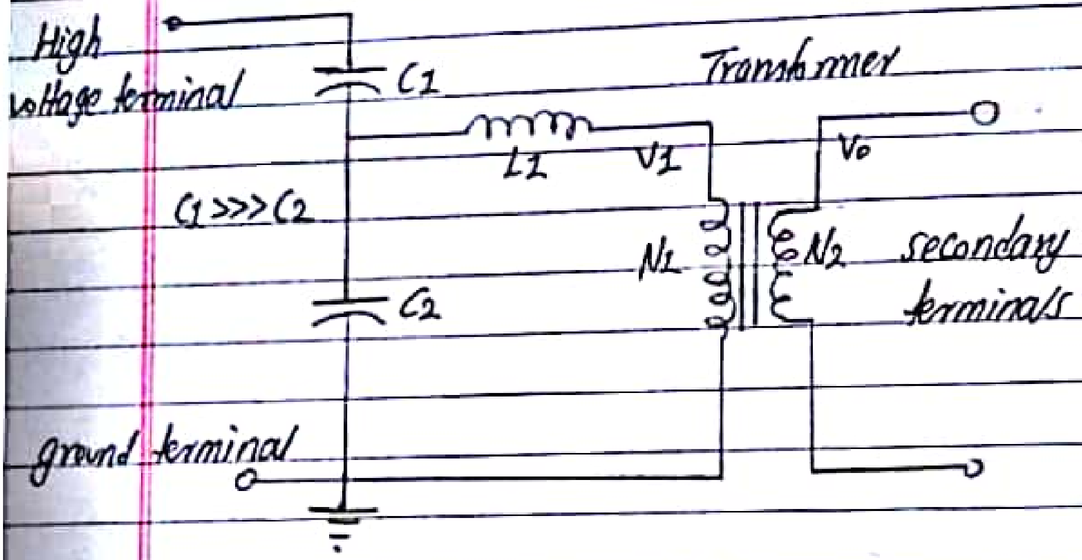
D. capacitor voltage Transformer: 16/5, 15/5

A capacitor voltage transformer (CVT or CCVT) is a transformer used in power systems to step down extra high voltage signals and provide a low voltage signal for metering or operating a protective relay.



The capacitive potential divider, inductive element & the auxiliary transformer are the three main parts of the capacitive potential transformer.

Need of CVT:

For measuring high voltage (above 100kV) the high insulated transformer is required. The highly insulated transformer is quite expensive as compared to normal transformer. For reducing the cost, the CTV is used in the system. The CVT is cheap & their performance is not much inferior to the highly insulated transformer.

Working:

The capacitive potential divider is used in combination with the auxiliary transformer and the inductive element.

25

The capacitive potential divider step down the extra high voltage signals into a low voltage signal. The output voltage of the capacitive potential transformer is further step down by the help of the auxiliary transformer. The capacitor or potential divider is placed across the line whose voltage is used to be measured or controlled. The output of the potential divider acts as an input to the auxiliary transformer. The capacitor placed near to the ground have high capacitance as compared to that placed near the transmission line.

The voltage turn ratio of the transformer is given as.

$$\frac{V_0}{V_1} = \left[\frac{C_2}{C_1+C_2}\right] \times \frac{N_2}{N_1}$$

Applications:

(i) The CVT is also used in communication systems. CVTs in combination with wave traps are used for filtering high frequency communication signals from power frequency.

(ii) HF transmissions: They can be used for power line carrier (PLC) coupling.

(iii) Transient recovery voltage: when installed in close proximity to HV/EHV ckt Breakers, CVT's own high capacitive enchance C/B short line fault / TRV performance.

iv) measuring of voltage:
They accurately transform transmission voltages down to useable levels for revenue metering, protection and control purposes.

Advantages:

i) simple design and easy installation.
ii) provides isolation between the high voltage terminal and low voltage metering.
iii) can be used both as a voltage measuring device for meter and relaying purposes and also as a coupling condenser for power line carrier communication and relaying.

Disadvantages:

i) Problem of inducing ferroresonance in power systems.
ii) voltage ratio is susceptible to temperature variations.

3.2) E. What is the purpose of isolators? Describe its types that is used in HV switchyard. 15/S, 16/F

⇒ Isolator or disconnecting switches are mechanical switch which isolates a part of electric circuit from system as when required.

Purposes:
i) It completely disconnects the system from the source.
ii) Isolators are used for safety purpose for maintenance work of the system.

iii) A C.B in off condition also disconnects the system but still there remains a chance of arc if there is any external fault. An isolator completely disconnects system and prevents arc quenching also.

Types:

on the basis of system requirement:

- Double break isolator
- single " "
- Pantograph " "

on the basis of position in power system,

- Bus side isolater:

  The isolator is directly connected with main Bus.

- Line side isolator:

  The isolator is situated at line side of any feeder.

- Transfer Bus side isolator:

  The isolator is directly connected with Transfer bus.

(I) Double break isolators:

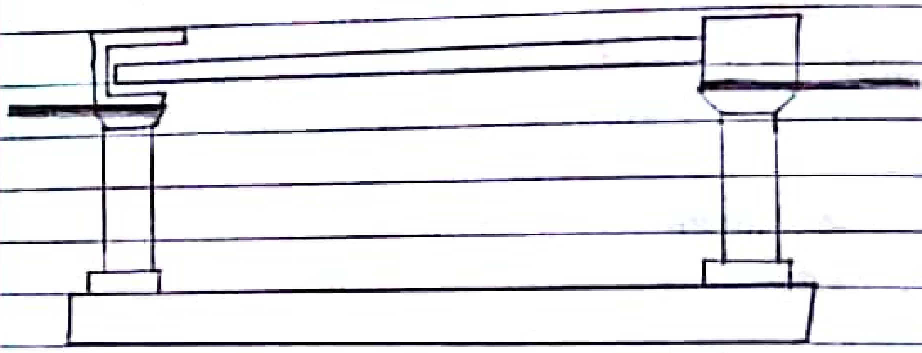
- Low contact resistance through the life of switch.
- sturdy design of current carrying parts.
- smooth and trouble free operation.

The isolator is designed to suit overhead systems used in high density urban situations or high load centers, where the load is much higher and the need of improved and steady quality power supply is much greater. main function of this isolator is to isolate the Transformer, overhead lines, system or cables from distribution network.

(II) Single Break Isolators:

- suitable for lower voltage applications ie, 11 KV and below. Two insulators post support each pole. one pole is fixed while other is kept free to rotate. Fixed insulators carries fixed contact and rotating insulator carries switchblade and contact plate. contact plate : closes and opens the isolator. single break isolators are applied to :

- Neutral ckt isolator of the transformer
- Bus switching of the station earthing.
- switching of the earth resister etc.



(III) Pantograph isolator :

A pantograph isolator assembly consists of :

- Pantograph isolator
- Conducting joints
- scissors shaped copper tube linkage.

The pantograph isolator is built using light tubes. The special profile tubes are made up of aluminium magnesium allow. This alloy has high mechanical strength and very good conductivity. Due to high elastic characteristics of this material, the pantograph construction is made flexible.

The pantograph isolator covers less floor area. Each pole can be located at a suitable point and the 3 poles need not be in one line, can be located in a line at the desired angle with the bus axis. This type of isolators are used at ultra high voltage substations.

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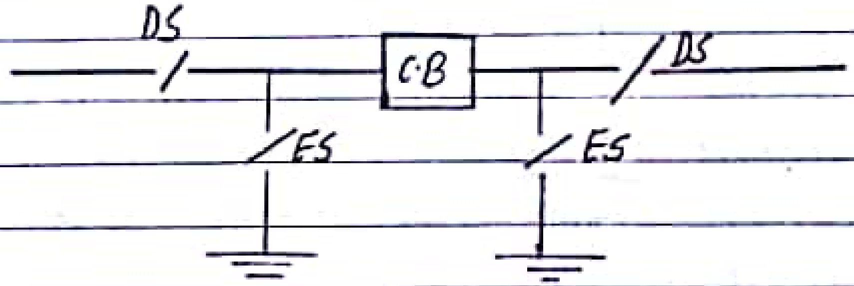
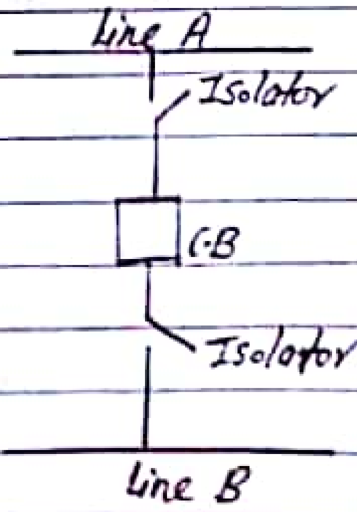
5). Distinguish between circuit breaker and isolator : 15/5

=>

Isolator	Circuit Breaker
(i) operated manually	operated automatically.
ii) Isolator is an off load device.	C.B is an on load device.
iii It is a mechanical device which acts as a switch.	It is an electronic device made by using BJT or MOSFET.
iv They have low withstand capacity as compared to C.B.	They have high withstand capability at the on load condition.
v. No arc quenching technique is provided.	Arc quenching technique is provided.
vi Primarily, isolators are used to disconnect a portion of the circuit from source for maintenance.	A C.B is typically connected in series with apparatus to be protected from overcurrent or overload or short circuit.



DS = Disconnecting switch / Isolator
ES = earth switch
C.B = circuit Breaker.



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Q: Discuss in briefs the following types of switch gears:
① SF6 insulated switchgear : 14/F, 23/S, 23/F, 22/S, 24/S

Sulphur Hexafluoride circuit breaker protect electrical power stations and distribution systems by interrupting electric currents, when tripped by a protective relay. Instead of oil, air or a vacuum, a sulfur hexafluoride circuit breaker uses sulphur hexafluoride (SF_6) gas to cool and quench the arc on opening a circuit.

Properties of SF6 gas:

i) The gas is colourless, odourless, non toxic & nonharmful to health.
ii) The gas is non inflammable.
iii) It is heavy gas having high density.
iv) Liquidification starts at low temperature which depends on pressure.
v) The heat transferability is high as compared to air at same pressure.
vi) Gas is electronegative.
vii) The metallic fluorides are good dielectric metals. Hence, are safe for electrical equipment.
viii) The gas is inert and stable upto 500°C. The life of metallic part, contacts is longer in SF6 gas.

Types:

There are mainly 3 types of SF6 C.B depending upon the voltage level of applications:

① Single interruptors SF6 C.B applied for upto 245 kV
② Two " " " " " " 420 kV

iii) 4 " " " " " " 800 KV

Operating Principle:

Current interruption in a high voltage C.B is obtained by separating two contacts in a medium, such as sulpher hexafluoride (SF6) having excellent dielectric & arc quenching properties. After contact separation, current is carried through an arc and is interrupted when this arc is cooled by a gas blast of sufficient intensity.

- The SF6 gas is an electronegative gas and has a strong tendency to absorb free electrons.
- The contacts of the breaker are opened in a high pressure flow of SF6 gas and an arc is struck between them.
- The gas captures the conducting free electrons in the arc to form relatively immobile negative ions. This loss of conducting electrons in the arc quickly builds up enough insulation strength to extinguish the arc.

- A gas blast applied to the arc must be able to cool it rapidly so that gas temperature between the contacts is reduced from 20,000 K to less than 2000 K in a few hundred microseconds so that it is able to withstand the transient recovery voltage that is applied across the contacts after current interruption.

Applications:

i) Power ratings 10 MVA to 20 MVA and interrupting time less than 3 cycles.
ii) A typical SF6 C.B consists of interruptor units each capable of dealing with currents upto 60 KA and voltages upto the range of 50 – 80 KV.

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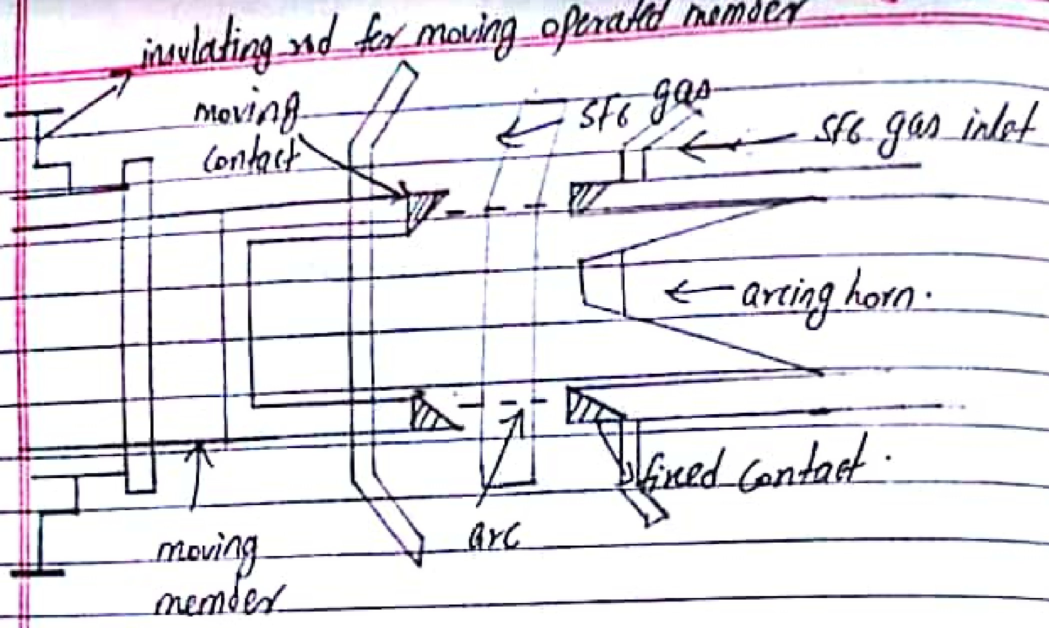
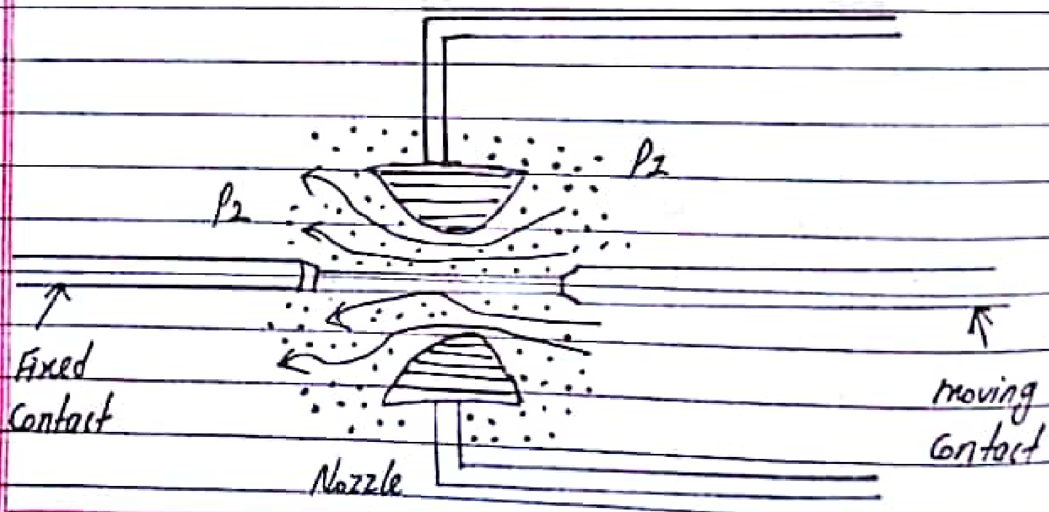


Fig: Interrupter unit of SF6 circuit breaker

Fig: Double pressure Type SF6 C.B



H) Discuss on the overvoltages due to lightning & switching and explain methods to suppress voltage surge. 15k

⇒ The switching surges may include high natral frequencies of the system, a damped normal frequency voltage component, or the restriking & recovery voltage of the system with successive reflected waves.

characteristics of switching surges:

i) De-energizing of transmission lines, cables, shunt capacitor banks.
ii. Disconnection of unloaded transformers, reactors etc.
iii. Energization or reclosing of lines and reactive loads.
iv. short circuits and fault clearances.
v. sudden switching of off loads.
vi) Resonance phenomenon like ferro resonance, arcing grounds etc.

— Protection against lightning overvoltages and switching surges of short duration:

(i) shielding the overhead lines by using ground wires above the phase wires.
ii. Using ground rods and counter poise wires.
iii. Including protective devices like expulsion gaps, protector tubes on the lines and surge diverters at the line terminations and substations.

— Switching overvoltages are rather short time and strongly damped. mainly occurred by breaker switching.

— lightning overvoltages are shorter than the other overvoltage and very strongly damped. They are mainly due to lightning strokes on overhead lines and vicinity.

—

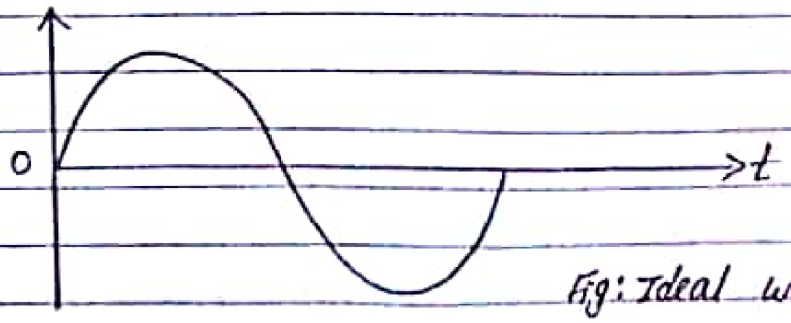


Fig: Ideal wave

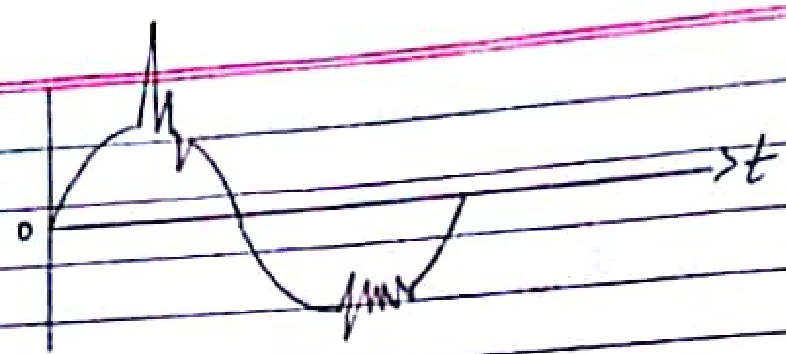


Fig: surges/Transients:

Remedies of switching surges:
- Use of opening resister with C.B.
- " " restrike free C.B
- " preinsertion resister with C.B.

Remedies of lightning surges:
- Using surge diverters
- Use of ground wire
- lightning masts
- Earthing of towers.

I) Discuss the merits and demerits of SF6 insulated switch gear. 74/F, 74/S, 72/F, 72/S, 73/S, 73/F, 77/S,

=> Merits :

(i) Compactness :
The space occupied by SF6 installation is only about 10% of that of a conventional outdoor substation. High cost is partly compensated by saving in cost of space.

(ii) Protection from pollution:
The moisture, pollution, dust etc have little influence on SF6 insulated substations. However, to facilitate installations and maintenance, such substation

25 are generally housed inside a small building. The construction of the building need not be very strong like conventional power houses.

(iii) Reduced switching overvoltages:

The overvoltage while closing and opening line, cables motors capacitors etc are low.

(iv) The gas pressure is relatively low and doesnot pose serious leakage problems.

v. Increased safety:

As the enclosure are at earth potential, there is no possibility of accidental contact by service personnel to live parts.

vi. Superior Arc Interruption:

SF6 gas is used in the circuit breaker unit for arc quenching. This type of breaker can interrupt current without overvoltages and with minimum arcing time. Contacts have long life and the breaker is maintenance free.

vii) Reduced Installation time:

The principle of building block construction reduces the installation time to a few weeks. conventional substations requires a few months for installation.

Demerits:

i) High cost compared to conventional outdoor substations.
ii) Excessive damage in case of internal fault. Long outage periods as repair of damage at site may be difficult.

iii Procurement of gas and supply of gas to site is problematic.

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Adequate stock of gas must be maintained.

iv. Such substations are generally indoor. They need a separate building. This is generally not required for conventional outdoor substations.

v. Requirements of cleanliness are very stringent. Dust or moisture can cause internal flashovers.

J). Rated short circuit breaking of C.B : 781F

①

This is the maximum short circuit current which a circuit breaker can withstand before it, finally cleared by opening its contacts.

It is the rms value of highest short circuit current which the circuit breaker is capable of breaking under specified conditions of Transient recovery voltage and power frequency voltage and expressed in KA rms at contact separation.

When a short circuit current flows through a circuit breaker, there would be thermal and mechanical stresses in the current carrying part of the breaker. If the contacts area and cross section of the conducting parts of the C.B are not sufficiently large, there may be a chance of permanent insulation damage as well as conducting parts of the C.B. As the thermal stress in the C.B is proportional to the period of short circuit, the breaking capacity of electrical C.B depends upon the operating time.

Hence, short circuit breaking capacity or short ckt breaking current of C.B is defined as maximum current

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can flow through the breaker from time of occuring short ckt to the time of clearing the short ckt without any permanent damage in the C.B.

The breaking current is expressed by two values:

- The rms value of ac component at the instant of contact separation given by $\frac{I_{AC}}{\sqrt{2}}$

- The percentage dc component at the instant of contact separation given by $\frac{I_{dc} \times 100}{I_{AC}}$

(ii) Rated short circuit making capacity:

The short ckt making current capacity of C.B is expressed in peak value not in rms value like breaking capacity. As the rated short ckt making current of C.B is expressed in maximum peak value, it is always more than rated short circuit breaking current of C.B.

This is defined as the peak value of first current loop of short circuit current which the C.B is capable of making at its rated voltage. There are certain cases under which the C.B may close when fault is existing. Under such cases current reaches to maximum value at peak of first current loop. The C.B should be able to close without difficulty and withstand the mechanical forces developed during a closure. This is checked by carrying out making current test.

Rated making current $= 1.8 \times \sqrt{2} \times$ rated short ckt breaking
$= 2.5 \times$ rated short ckt breaking current.

$\sqrt{2}$ in above exp converts rms value to peak value while

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factor 1.8 is considered for doubling effect of short ckt current.

(iii) Rated short operating of C.B : 18/F

It represents the sequence of opening & closing operations which circuit breaker can perform under specified conditions. As per specifications the C.B should be able to perform the operating sequence as per one of the ways:

- O − t − CO − T − CO
- CO − t' − CO

where,

O = operation of operating
CO = closing followed by operating
T = 3 minutes
t = 0.3 min for C.B not to be used for rapid auto reclosure
t' = 15 sec " " " " " " " "

ie,

- O − 0.3 sec − CO − 3 min − CO

iv) Rated short time current : 18/F

This is the current limit which a C.B can carry safely for certain specific time without any damage in it. The C.B donot clear the short circuit current as soon as any fault occurs in the system. There always exist some intentional and an intentional time delays present between the instant of occurrence of fault and istant of clearing the fault by C.B. This delay is because of time of operation of protection relays, time of operation of C.B and also there may be

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some intentional time delay imposed in relay for proper co-ordination of power system protection. Even a C.B fails to trip the fault will be cleared by next higher positioned C.B. In this case, the fault clearing time is longer. Hence, after fault, a C.B has to carry the short circuit for certain time. The summation of all time delays should not be more than 3 sec; hence, a C.B should be capable of carrying a maximum faulty current for at-least this short period of time.

The rated short time current of a C.B is at least equal to rated short breaking current of the C.B.

B) Circuit Breaker:

- The modern power system deals with huge power network and huge numbers of associated electrical equipment. During short circuit fault or any other types of electrical fault, these equipments as well as the power network suffer a high stress of fault current in them which may damage the equipment and networks permanently. For saving these equipments and the power networks, the fault current should be cleared from the system as quickly as possible.

- A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit.

- Its basic function is to detect a fault condition & by interrupting continuity, to immediately discontinue electrical flow.

- The circuit breaker mainly consists of fixed contacts & moving contacts. In normal "on" conditions of C.B, these two contacts are physically connected to each other due to applied mechanical pressure on the moving contacts. The potential energy can be stored in the circuit breaker by different ways like by deforming metal spring, by compressed air or by hydrolic pressure.

- But whatever the source of potential energy, it must be released during operation. Release of potential energy makes sliding of the moving contact ... at extremely fast manner.

Types of C.B:

- Oil C.B
- Vacuum C.B
- Air blast "
- SF6 "
- miniature "

How to choose a circuit Breaker?

- Making capacity
- Breaking "
- Short time "
- Rated Voltage, current and frequency.

∘ Voltage rating:

- The overall voltage rating is calculated by the highest voltage that can be applied across all end ports.
- It is important to select a C.B with enough voltage capacity to meet the end applications.
- The specified voltage is the maximum voltage at which the operation of the C.B is guaranteed.

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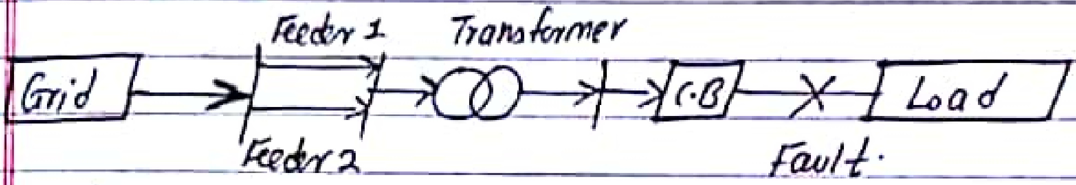
- The specified voltage is somewhat higher than the rated nominal voltage.

1). Determine the short circuit rating of the CB for the system shown below, consider the grid as infinite bus and 6 MVA as Base MVA.
Transformer : 3 Ø, 33/11 kV, 6 MVA, 0.01 + j0.08 pu
Load = 3 Ø, 11 kV, 5800 kVA, 0.8 lag, 0.2j pu
Impedance of each feeder = 9 + 18j   17/F, 18/F



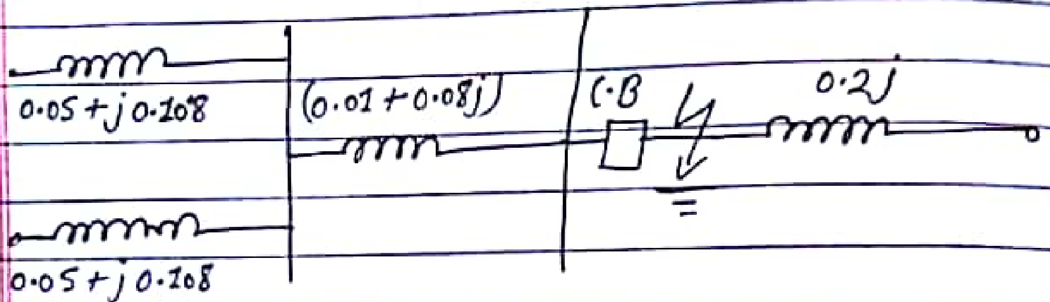
Soln,
⇒ Base MVA = 6 MVA
Base voltage = 33 kV for transformer.
= 33 " " feeder
= 11 kV " Load
For Transformer:
PU impedance = (0.01 + 0.08j) pu
For load,
pu impedance = j0.2 pu

For each feeder :
actual impedance = 9 + 18j
Now,

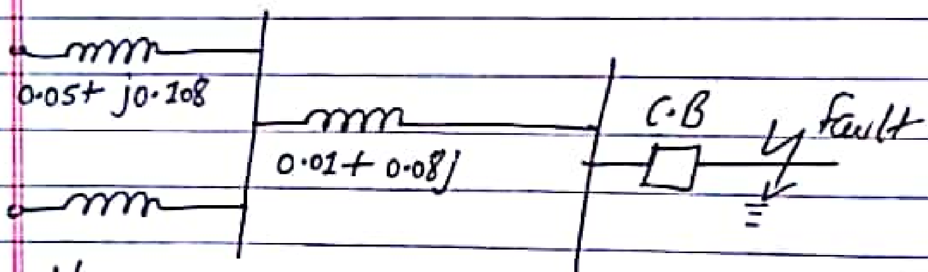
$$\text{PU impedance} = \frac{\text{actual impedance}}{\text{Base impedance}} = \frac{9 + j18}{\frac{(\text{Base kV})^2}{\text{Base MVA}}} = \frac{(9 + 18j) \times 6}{33^2}$$

$= (9 + j18) \times 0.06$
$= (0.05 + 0.108j)$ pu

Reactance diagram:



Now, if the fault occurs at the right side of the C.B, then the impedance diagram will be,



Now,

$(X_{pu})_{eq} = [(0.05 + j0.108) \,||\, (0.05 + j0.108)] \,||\, (0.01 + j0.08)]$

$= \left(\frac{1097}{46472} + j\,0.040\right) \,||\, (0.01 + j0.08)$

$= (0.024 + j0.040) \,||\, (0.01 + j0.0\,)$

$= \frac{538}{19225} + j\frac{1249}{19225}$

$= 0.071 \angle 66.7°$

$\therefore (I_{fault})_{pu} = \frac{1 \angle 0°}{0.071 \angle 66.7°} = 14.08 \angle -66.7°$ pu

$\therefore I_{CB} = \frac{14.08 \angle -66.7°}{\sqrt{3} \times 11}$

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$= 4.41 \angle -66.7$ KA

$\therefore$ Fault MVA $= \dfrac{\text{Base MVA}}{(X_{pu})_{eq}} = \dfrac{6}{0.071 \angle -66.7}$

$= 84.51 \angle 66.7^\circ$ MVA

$\therefore$ Breaking current of C.B $= 4.41 \angle -66.7$ KA

$\therefore$ making current " " $= 2.55 \times (4.41 \angle -66.7)$

$= 11.24 \angle -66.7^\circ$

Since, making current = 2.55 X breaking current of C.B

$\therefore$ Breaker ratings, $I_n = \dfrac{6 \times 10^3}{\sqrt{3} \times 11}$

$= 315$ KA

M) Explain the following terms related to the selection of C.B,

i) DC offset current

ii) Rated symmetrical interrupting current of C.B. 11/s

$\Rightarrow$ DC offset current:

DC offset occurs as a result of two natural laws:

- current cannot change instantaneously in an inductance.
- " must lag the applied voltage by the natural power factor.

DC offset is necessary to maintain the basic laws of electricity at the initial moment when the current in the system makes a sudden change like what happens during a fault. However, the generators will be able to react to the new system conditions and the DC offset will decrease over a few cycles until the waveform is back to its normal symmetrical condition.

The size and duration of DC offset depends upon:

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(i) The ability of the generator(s) to react to the fault and time necessary to stabilize the system.

(ii) The voltage magnitude at the exact moment of the fault. The maximum DC offset occurs when the voltage is zero.

(iii) The ratio of reactance and resistance (X/R) of the circuit during a fault. This includes the generator coils and the equipment connecting the generator to the fault.

DC offsets are instances where direct current overlaps an alternating current distribution system.

- The faster the C.B operates the higher the dc component it sees ie, a breaker with fast operating time and high speed differential protection can be at risk.

(ii) Rated symmetrical interrupting current of C.B:
- current without any decaying dc component.
- This value refers the maximum rms symmetrical short circuit current that can be safely interrupted by the breaker.

IV. Calculate the fault current (KA) and fault level (MVA) at medium voltage bus and high voltage bus for 3-Ø fault at bus 1 and bus 3 respectively. Determine the fault current, level, breaking and making current capacity of the C.Bs used in the power plant that has been designed for the sequence of fault at position 1 and position 2 as shown in the fig below.

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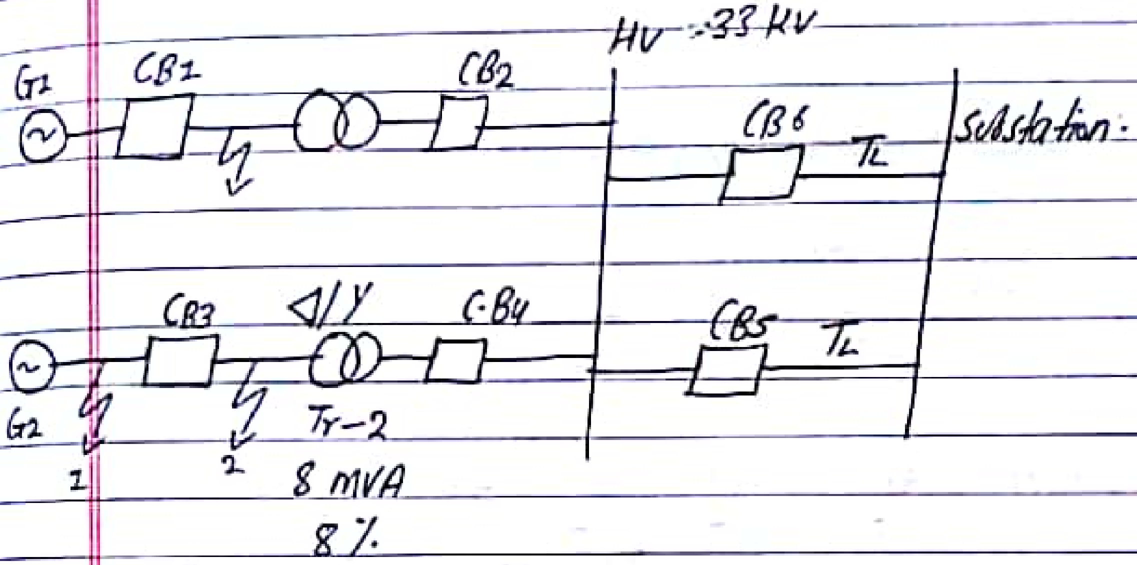
All generators = 7 MVA, 11 kV, $x = 24\%$
All transformers = 8 MVA, 11/33 kV, $x = 8\%$
All transmission lines = 33 kV, $x = 5.485$ ohm



17/5

Sol^n,

⇒ Base kV on LV side of transformer = 11 kV
" " " HV " " " = 33 kV
Base MVA = 7 MVA

∴ Base reactance on HV side $= \frac{\text{Base kV}^2}{\text{Base MVA}} = \frac{33^2}{7}$
$= 155.57\ \Omega$

Pu reactance of transmission line (T_L) $= \frac{\text{actual reactance}}{\text{base reactance}}$
$= \frac{5.485}{155.57}$
$= 0.035$ pu

Pu reactance of Transformer (Pu_{new})
$= Pu_{old} \times \left(\frac{\text{Base kV}_{old}}{\text{Base kV}_{new}}\right)^2 \times \frac{\text{Base MVA}_{new}}{\text{Base MVA}_{old}}$
$= 0.08 \times \left(\frac{11}{11}\right)^2 \times \frac{7}{8}$

$= 0.07\ pu$

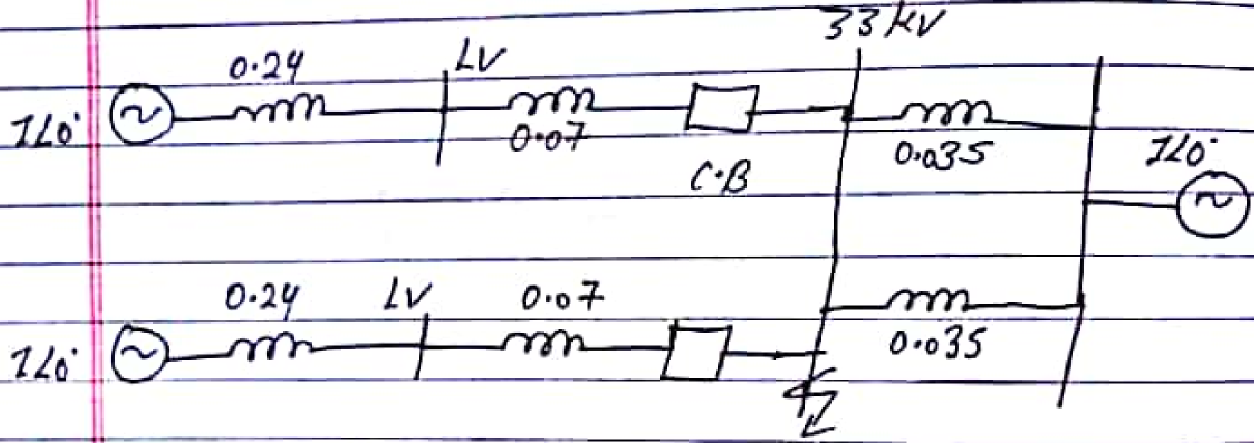
Now,

X_{pu}, generator $= 0.14\ pu$

X_{pu}, transformer $= 0.07\ pu$

X_{pu}, line $= 0.035\ pu$.

Fault at HV Bus (33 kV).



$$(X_{pu})_{eq} = \left(\frac{0.24}{2} + \frac{0.07}{2}\right) // \left(\frac{0.035}{2}\right)$$

$$= (0.155) // (0.018)$$

$$= 0.016\ pu$$

$$I_{fault,pu} = \frac{1\angle 0^\circ}{0.016} = 62.5\ pu$$

$$I_{fault,actual} = \frac{62.5 \times 7}{\sqrt{3} \times 33} = 7.65\ kA$$

$$\text{Fault MVA} = \frac{\text{Base MVA}}{(X_{pu})_{eq}} = \frac{7}{0.016} = 437.5\ MVA$$

$\therefore$ making current $= 2.5 \times$ breaking current (I_{fault})

$= 2.5 \times 7.65$

$= 19.13\ kA$.

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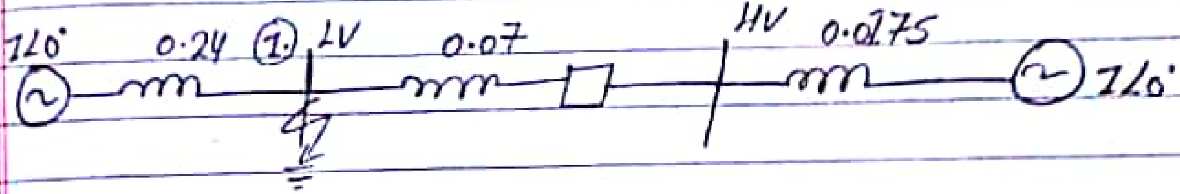
Fault at medium voltage bus (11 kV)



$(X_{pu})_{eq} = (0.07 + 0.0175) \parallel (0.24)$
$= (0.087) \parallel (0.24)$
$= 0.064$ pu

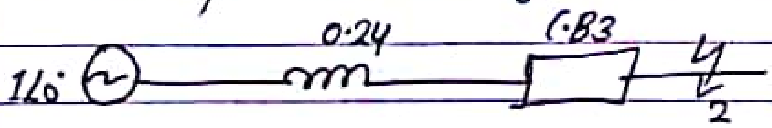
$I_{fault}(pu) = \frac{1\angle 0°}{0.064} = 15.625$ pu

$I_{fault, actual} = \frac{15.625 \times 7}{\sqrt{3} \times 11} = 5.741$ kA

Fault MVA $= \frac{\text{Base MVA}}{X_{pu,eq}} = \frac{7}{0.064} = 109.37$ MVA

$\therefore$ making current $= 2.5 \times$ Breaking current
$= 2.5 \times 5.741$
$= 14.353$ kA.

Fault at point 2 (at generator breaker):



$(X_{pu})_{eq} = 0.24$ pu

$I_{fault,pu} = \frac{1\angle 0°}{0.24} = 4.167$ pu

$I_{CB3(2)} = \frac{4.167 \times 7}{\sqrt{3} \times 11} = 1.53$ kA

Fault MVA $= \frac{\text{Base MVA}}{(X_{pu})_{eq}} = \frac{7}{0.24} = 29.16$ MVA.

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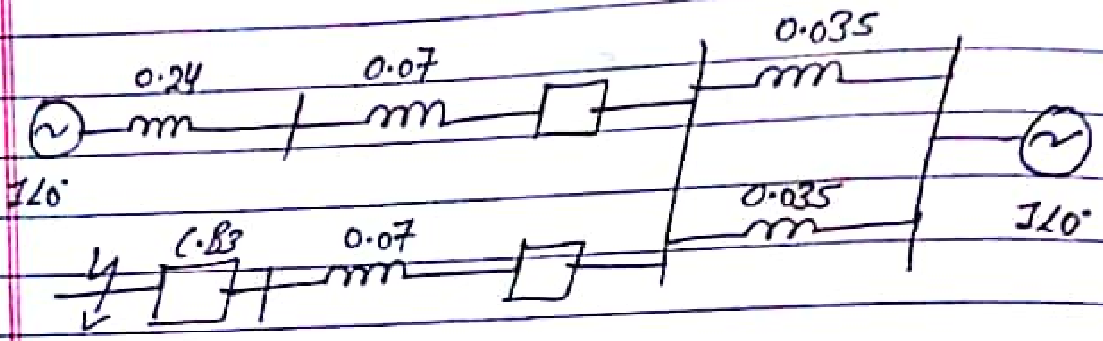
Fault at point 1:



$X_{pu,eq} = [(0.24+0.07) \parallel (0.035/2)] + 0.07$
$= 0.0866 \ pu$

$I_{fault,pu} = \frac{1\angle 0°}{0.0866} = 11.55 \ pu$

$I_{CB3}(1) = \frac{11.55 \times 7}{\sqrt{3} \times 11} = 4.24 \ kA$

$\text{Fault MVA} = \frac{7}{0.0866} = 80.87 \ MVA.$

since, $I_{CB3}(1) > I_{CB3}(2)$

∴ Breaking current of CB3 = 4.24 kA

∴ making " " " $= 2.5 \times 4.24$
$= 10.6 \ kA$

∴ Fault MVA $= 80.87 \ MVA.$

Q. Current Transformer:

– A current transformer (CT) is a type of transformer that is used to measure AC current. It produces an AC in its secondary which is proportional to the AC current in its primary. CT, together with voltage transformer (VT) which are designed for measurement are known as an instrument transformer.

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- The main task of instrument transformer are:

i) To transform currents or voltages from a usually high value to a value easy to handle for relays and instruments.

ii) To insulate the metering ckt from the primary high voltage system.

iii) To avoid possibilities of standardizing the instruments & relays to a few rated currents and voltages.

- Current transformers typically consists of a silicon steel ring core wound with many turns of copper. The conductor carrying primary current is passed through the ring. The CT's primary therefore consists of a single turn. The primary winding may be permanent part of the current transformer ie, a heavy copper bar to carry current through the core.

- CTs are specified by their current ratio from primary to secondary. The rated secondary current is normally standardized at 1 or 5 Amp.

Applications:

i) For measuring current and monitoring the operation of the power grid.

ii) Along with voltage loads, revenue grade CTs drive the electrical utility's watt hour meter on virtually every building with 3-Ø service and single phase services greater than 200 Amp.

iii) often, multiple CTs are installed as a stack for various uses.

- The secondary load of a current transformer is termed the 'burden' to distinguish it from the primary load. The burden in a CT metering ckt is the largely resistive impedance presented to its secondary winding.

- The phenomena of the CT core unable to produce the flux in proportion to the primary current is called saturation of CT or CT core. This will give wrong readings.

P. Voltage Transformers:

- VT also called potential transformer (PT) are a parallel connected type of transformer. They are designed to present negligible load to the supply being measured & have an accurate voltage ratio and phase relationship to enable accurate secondary connected metering.

- The PT is typically described by its voltage ratio from primary to secondary.

- PT is inductive step down transformer used for measurement and protection.

- $$\text{line voltage} = \frac{\text{deflection}}{\text{transformation ratio}} = (V_2/V_1)$$

Circuit Breakers

10.1 Introduction

As already seen in the last chapter, whenever any fault occurs in the power system then that part of the system must be isolated from the remaining healthy part of the system. This function is accomplished by circuit breakers. Thus a circuit breaker will make or break a circuit either manually or automatically under different conditions such as no load, full load or short circuit. Thus it proves to be an effective device for switching and protection of different parts of a power system.

In earlier days fuse was included in the protective system. But due to some limitations they are not used in practice now a days. The main difference between a fuse and circuit breaker is that under fault condition the fuse melts and it is to be replaced whereas the circuit breaker can close or break the circuit without replacement.

10.2 Requirements of Circuit Breaker

The power associated with the circuit breakers is large and it forms the link between the consumers and suppliers. The necessary requirements of circuit breakers are as follows,

1. The normal working current and the short circuit current must be safely interrupted by the circuit breaker.
2. The faulty section of the system must be isolated by circuit breaker as quickly as possible keeping minimum delay.
3. It should not operate with flow of overcurrent during healthy conditions.
4. The faulty circuit only must be isolated without affecting the healthy one.

10.3 Basic Action of a Circuit Breaker

The Fig. 10.1 shows the elementary diagram of a circuit breaker. It consists of two contacts a fixed contact and a moving contact. A handle is attached at the end of the moving contact. It can be operated manually or automatically. The automatic operation needs a separate mechanism which consists of a trip coil. The trip coil is energized by secondary of the current transformer. The terminals of circuit breaker are brought to power supply.

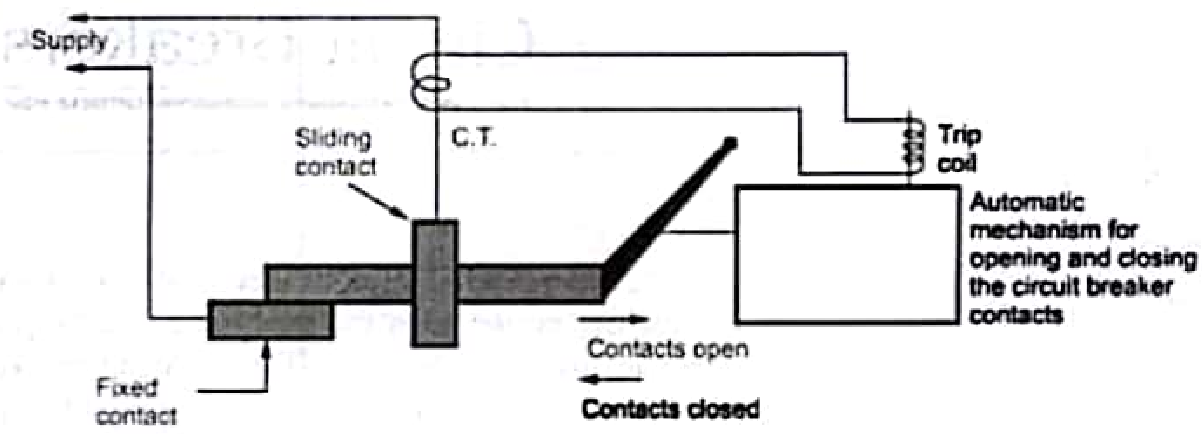


Fig. 10.1 Basic action of circuit breaker

Under normal working conditions the e.m.f. produced in the secondary winding of the transformer is insufficient to energize the trip coil completely for its operation. Thus the contacts remain in closed position carrying the normal working current. The contacts can be opened manually also by the handle.

Under abnormal or faulty conditions high current in the primary winding of the current transformer induces sufficiently high e.m.f. in the secondary winding so that the trip coil is energized. This will start opening motion of the contacts. This action will not be instantaneous as there is always a time lag between the energization of the trip circuit and the actual opening of the contacts. The contacts are moved towards right away from fixed contact.

As we have seen already the separation of contacts will not lead to breaking or interruption of circuit as an arc is struck between the contacts. The production of arc delays the current interruption and in addition to this it produces large amount of heat which may damage the system or the breaker. Thus it becomes necessary to extinguish the arc as early as possible in minimum time, so that heat produced will lie within the allowable limit. This will also ensure that the mechanical stresses produced on the parts of circuit breaker are less.

The time interval which is passed in between the energization of the trip coil to the instant of contact separation is called the opening time. It is dependent on fault current level.

The time interval from the contact separation to the extinction of arc is called arcing time. It depends not only on fault current but also on availability of voltage for maintenance of arc and mechanism used for extinction of arc.

10.4 Classification of Circuit Breakers

The circuit breakers are classified by various ways. The different criteria for classification of circuit breakers are as follows,

i) Interrupting medium
ii) According to service
iii) Way of operation
iv) Action
v) Method of control
vi) Way of mounting
vii) Tank construction
viii) Contacts

According to the interrupting medium the circuit breakers are classified as air circuit breaker, air blast circuit breaker, oil circuit breaker and magnetic blast circuit breaker.

According to service there are two types of circuit breakers viz indoor circuit breaker and outdoor circuit breaker.

Depending on the operation, the types of circuit breakers are gravity opened, gravity closed and horizontal break circuit breaker.

On the basis of action, the circuit breakers are classified as automatic and non-automatic circuit breaker.

According to method of control, the circuit breaker may be controlled directly or it may be operated remotely. The remote control may be manual, pneumatic or electrical.

The way of mounting classifies the circuit breakers into panel mounted, rear of panel or remote from panel type.

Depending on the tank construction, the circuit breakers are classified as separate tank for each pole type or one tank for all poles type.

On the basis of contacts, the different types of circuit breakers are Butt, Wedge, Laminated flat contact, Explosion chamber etc.

Out of the various ways of classification of circuit breakers the general way of classification is on the basis of medium used for arc extinction which is normally oil, air, Sulphur Hexa Flouride (SF_6) or vacuum.

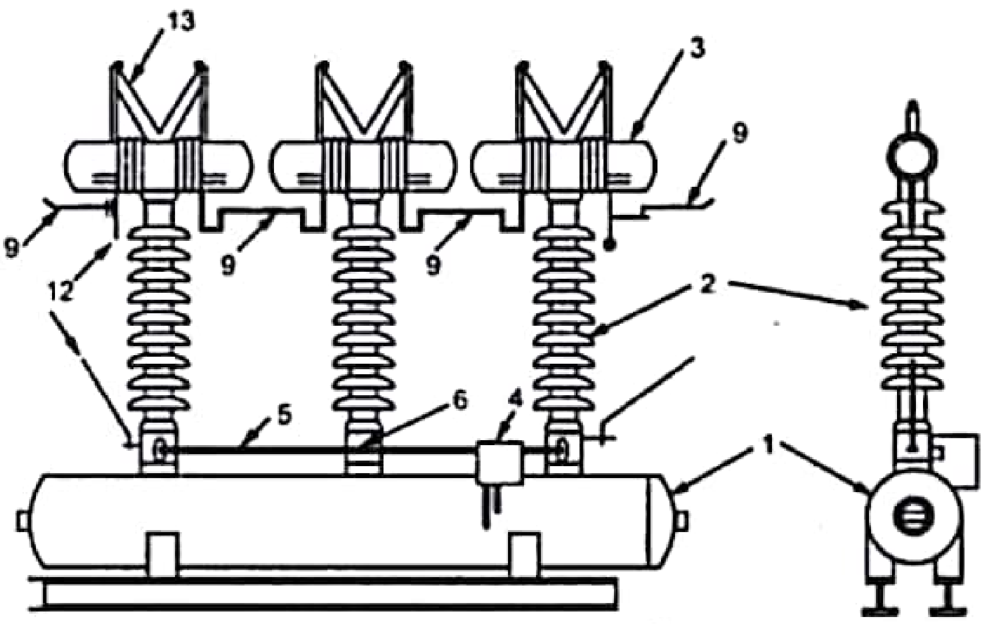
Each type of circuit breaker is associated with its own advnatages and disadvantages. We will now consider some types of circuit breakers in detail.

10.5 Air Blast Circuit Breakers

These type of circuit breakers were employed in earlier days for voltages ranging from 11 to 1100 kV. At high voltages this type of circuit breakers are most suitable. In this type of circuit breakers the compressed air is used for the arc extinction. Hence it is called compressed air circuit breaker.

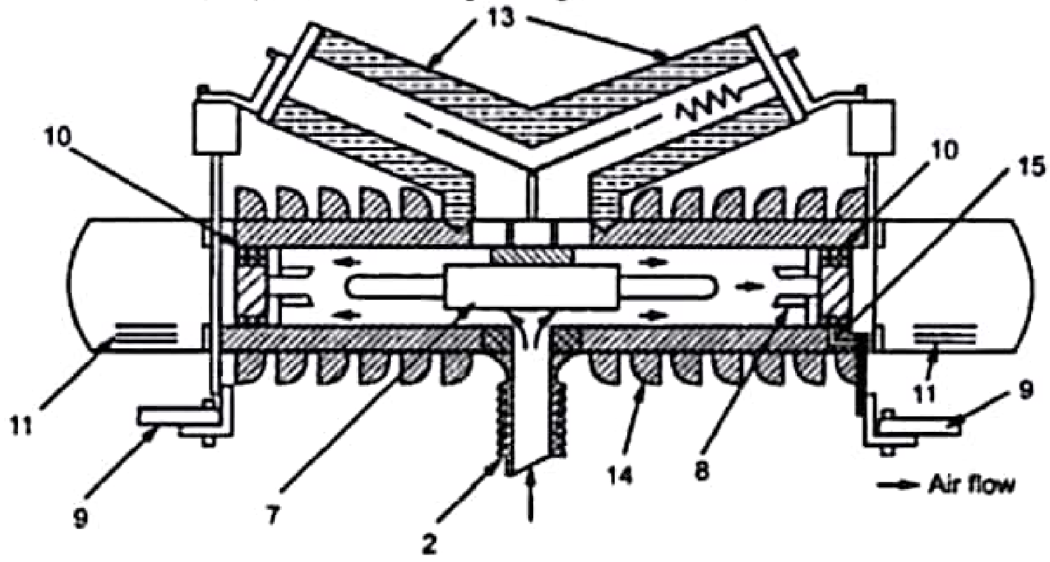
10.5.1 Construction of an Air Blast Circuit Breaker

The Fig. 10.2 shows the constructional details of air blast circuit breaker.



ELEVATION END-VIEW

One pole of an extra high voltage air blast circuit-breaker



Details of double arc extinction chamber

1. Tank air reservior (receiver)
2. Hollow insulator assembly
3. Double arc extinction chamber
4. Pneumatic operating mechanism
5. Operating rod
6. Pneumatic value
7. Fixed contact (in 3)
8. Moving contact (in 3)
9. Connection for current
10. Compression springs
11. Openings for air outlet
12. Arcing horns Optional
13. Resistance switching unit
14. Enclosure
15. Port

Fig. 10.2 Construction of air blast circuit breaker

At the bottom there is a tank which is called air reservoir with the valves. On this reservoir there are three hollow insulator columns. On the top of each insulator column there is double arc extinguishing chamber. The current carrying parts are connected to the arc extinction chambers in series. The assembly of entire arc extinction chamber is mounted on insulators as there exists large voltage between the conductors and air reservoir.

The double arc extinction chamber is shown separately in the Fig. 10.2 (b). It can be seen that for each circuit breaker pole there are six breaks as there are three double arc extinction poles in series. Each arc extinction chamber consists of two fixed and two moving contacts. These contacts can move axially so as to open or close. The position depends on air pressure and spring pressure. The opening rod is operated by the opening mechanism when it gets control signal (may be electrical or pneumatic). This will lead to flow of high pressure air by opening the valve. The high pressure air enters the double arc extinction chamber rapidly. Due to the flow of air the pressure on moving contacts increases than spring pressure and contacts open. The contacts travel through a small distance against the spring pressure. Due to the motion of moving contacts the port for outgoing air is closed and the whole arc extinction chamber is filled with high pressure air. But during the arcing period the air passes through the openings shown and takes away ionized air of arc. In case of making operation the valve is turned which connects hollow column of insulator and the reservoir. The air is passed to the atmosphere due to which pressure of air in the chamber is dropped to atmospheric pressure and closing of moving contacts is achieved against spring pressure.

10.5.2 Working

An auxiliary compressed air system is required by this type of circuit breaker. This will supply air to the air reservior of the breaker. During the opening operation, the air is allowed to enter in the extinction chamber which pushes away moving contacts. The contacts are separated and the blast of air will take ionized gases with it and helps in extinguishing the arc. This will require only one or two cycles. There are two major types - cross blast and axial blast.

In cross blast type, the blast of air cuts across the arc. It is less frequently used in the practice. In axial blast type, the blast of air is along the arc. This type of design is common in use.

10.5.2.1 Cross Blast Type

The Fig. 10.3 shows the schematic arrangement of a cross blast type.

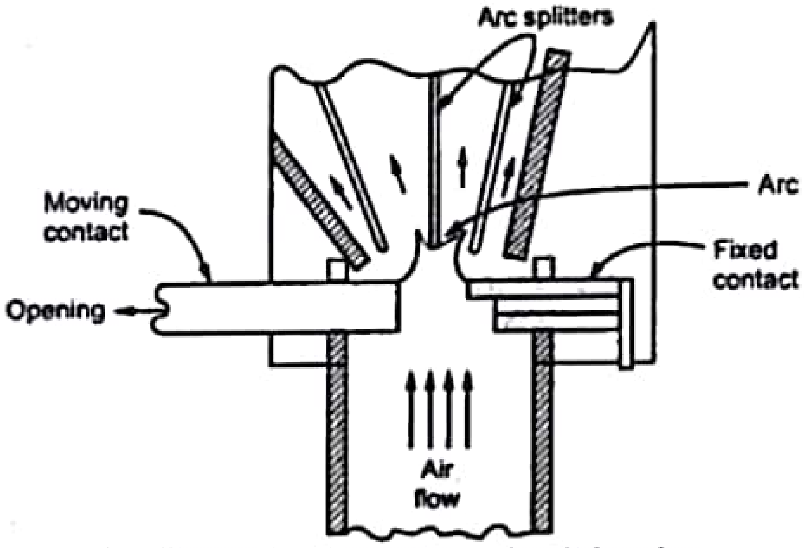


Fig. 10.3 Cross blast type circuit breaker

The flow of air is across the arc. The moving contact is near to the arc splitter assembly. The air blast forces the arc on to the arc splitter plates. These plates will lengthen the arc. Depending upon the breaking capacity of the breaker, the size and number of plates are decided. The fixed contact is mounted at the base between the two insulating blocks. It consists of a number of silver surfaced spring loaded copper fingers. The arcing portion is surfaced with a silver tungsten alloy. The moving contact consists of flat copper silver faced blade. Resistance switching is not required as sufficient resistance is automatically introduced in the arc to control the restriking transient. The cross blast breakers are commonly used in indoor circuit breakers of medium high voltage class.

10.5.2.2 Axial Blast Type

In this type the flow of blast of air is along the line of arc. This is shown in the Fig. 10.4.

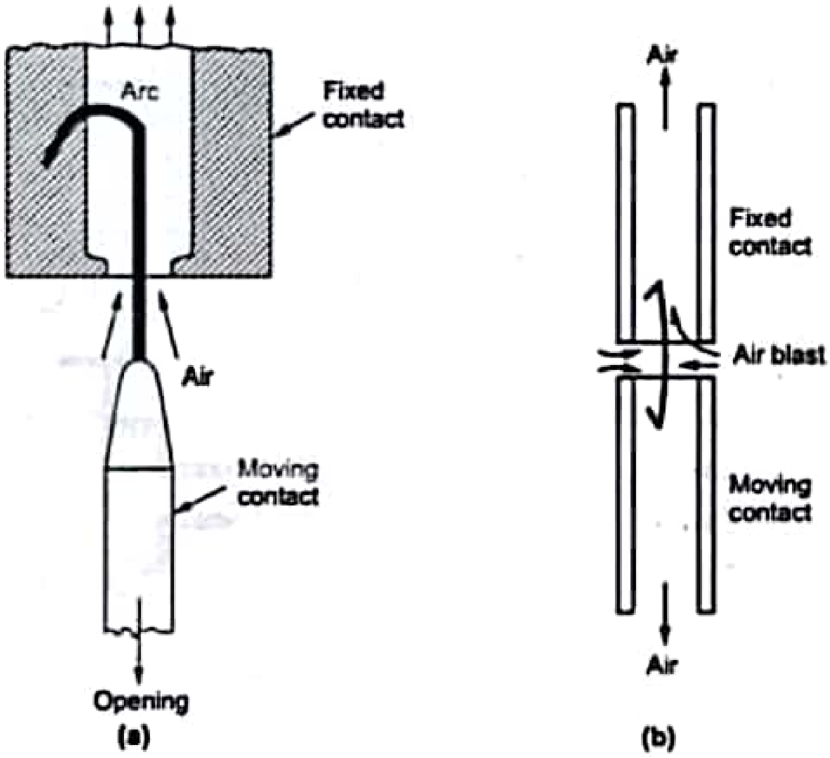


Fig. 10.4 Axial blast type circuit breaker

There are two subtypes which are shown in the Fig. 10.4 (a) and (b) viz single blast type and double blast type. The double blast arrangement is also called radial blast type due to the fact that the blast flows radially into the space between the contacts.

In this type air flows from high pressure reservior to the atmosphere through a nozzle, whose design makes air to expand in the low pressure zone. It will attain high velocity. The high speed air flowing axially along the arc will cause removal of heat from the periphery of the arc. The diameter of arc reduces to a low value at current zero. At this instant of the arc interruption the contact space is filled with the fresh air. This will make possible to remove the hot gases and fast building up of the dielectric strength of the medium.

As already seen during the contact closing, the air from the extinction chamber is allowed to pass to the atmosphere. This will reduce the pressure on the moving contacts and will assist the closing operation. The total operation is represented in the Fig. 10.5.

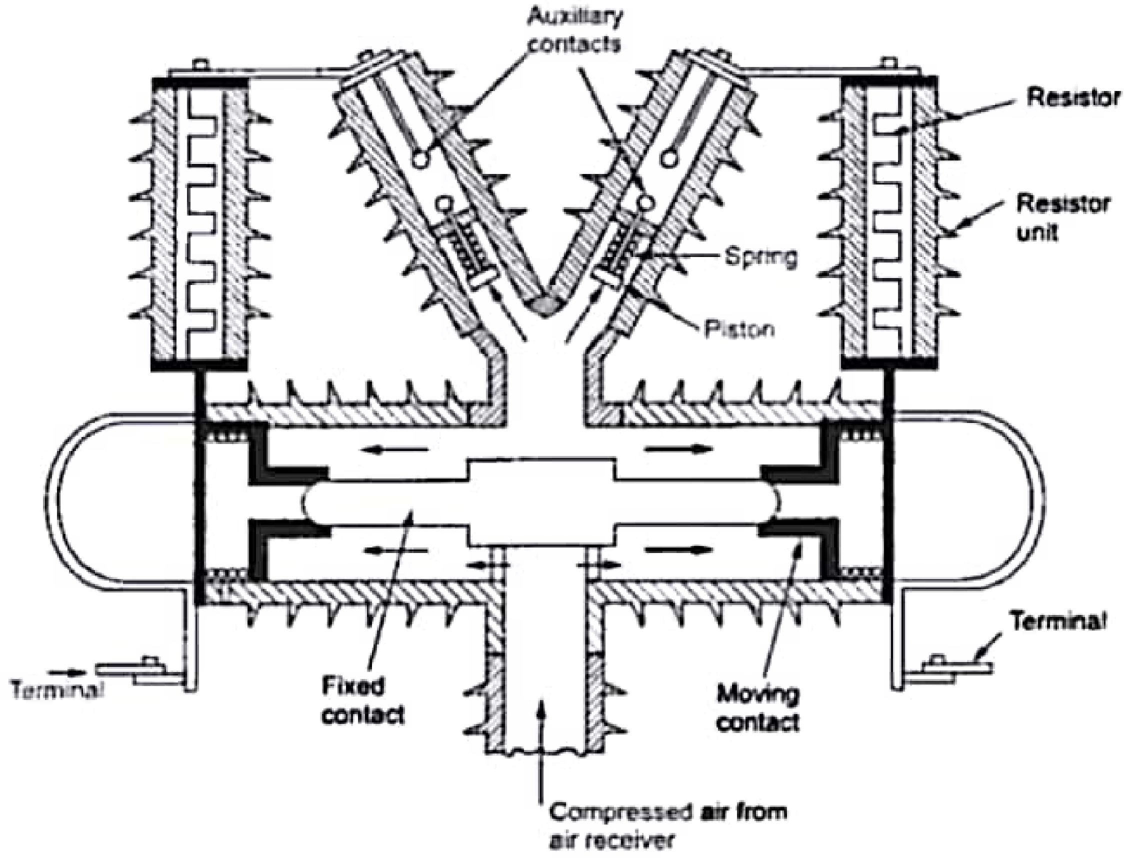


Fig. 10.5 Modification in air blast circuit breaker

In air blast circuit breaker, the pressure generated in the extinction chamber is independent of arc current the circuit breaker is said to be of external energy source. The air pressure in this type of breaker is constant which is sufficient enough to break the rated breaking current. In this type of circuit breakers the breaking capacity is found by pressure of extinguishing medium.

For low values of currents, the arcing time does not change appreaciably since air pressure is independent of arc current. For breaking low current, high pressure air will be required. Due to this the current gets chopped before reaching natural zero. This will give rise to high restriking voltage and the contact space is not likely to break down. Therefore these high voltages must be allowed to discharge to avoid breakdown of insulation of circuit breaker. Thus resistance switching is commonly employed in these breakers.

The Fig. 10.5 shows the modified arrangement for a double arc extinguishing chamber. When the contacts are opened the air flows in the arc extinguishing chamber. The separating of main contacts lead to closing of auxiliary contacts which will connect resistance across the arc for a short time. The auxiliary contacts are mounted in inclined V shaped insulators.

After the arc extinction the pressure on either side of auxiliary contacts is adjusted in such away that auxiliary contacts open and resistor circuit is interrupted. Ceramic resistances of non-linear characteristics are used for resistance switching.

10.5.3 Compressed Air System for Air Blast Circuit Breaker

The schematic arrangement shown in the Fig. 10.6 represents compressed air system.

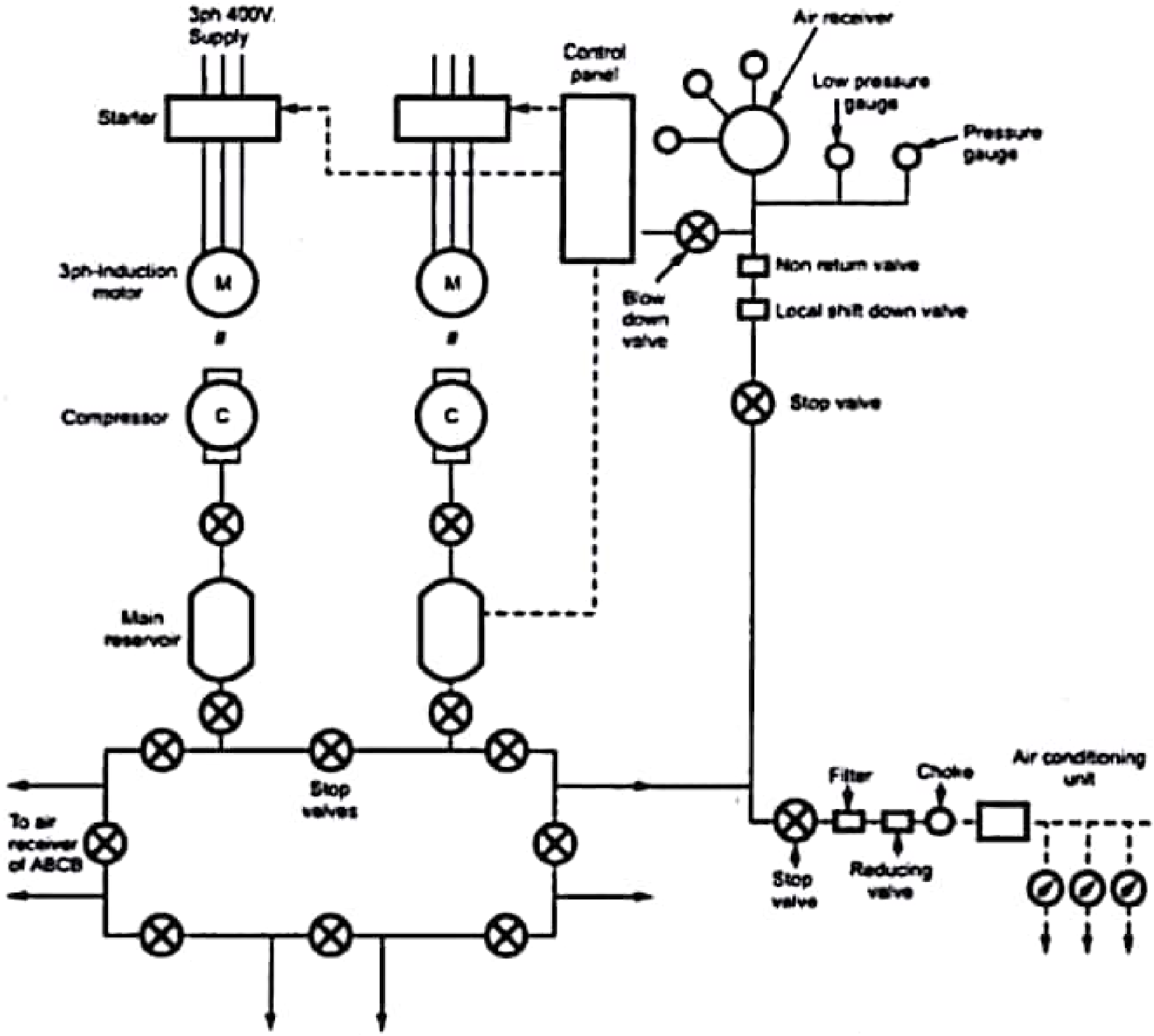


Fig. 10.6 Diagram of compressed air system

The air reservoir in the air blast circuit breaker contains air of pressure of the order of 20-30 kg force/cm^2. This air pressure is maintained by these reservoirs for 4 to 12 repeated operations.

When the pressure in the air reservoir of the circuit breaker reduces below a certain value say 20 kgf/cm^2, the pneumatic valve opens automatically and air is allowed to enter in the air reservoir from compressed air system at high pressure. The pressure in the air reservoir is then maintained at a desired value.

The size of compressor depends upon the number of circuit breakers, the number of makes and breaks expected and amount of air to be used in each make and break. The compressor feeds the air at high pressure into the main receiver through oil filters and water filters.

10.5.4 Advantages

The various advantages of air blast circuit breakers are,

i) No fire hazards are possible with this type of circuit breaker.

ii) The high speed operation is achieved.

iii) The time for which arc persists is short. Thus the arc gets extinguished early.

iv) As arc duration is short and consistent, the amount of heat released is less and the contact points are burnt to a less extent. So life of circuit breaker is increased.

v) The extinguishing medium in this type of circuit breaker is compressed air which is supplied fresh at each operation. The arc energy at each operation is less than that compared with oil circuit breaker. So air blast circuit breaker is most suitable where frequent operation is required.

vi) This type of circuit breaker is almost maintenance free.

vii) It provides facility of high speed reclosure.

viii) The stability of the system can be well maintained.

10.5.5 Disadvantages

The various disadvantages of air blast circuit breakers are,

i) If air blast circuit breaker is to be used for frequent operation it is necessary to have a compressor with sufficient capacity of high pressure air.

ii) The maintenance of compressor and other related equipments is required.

iii) There is possibility of air leakages at the pipe fittings.

iv) It is very sensitive to restriking voltage. Thus current chopping may occur which may be avoided by employing resistance switching.

10.5.6 Applications

The air blast circuit breakers are preferred for arc furnace duty and traction system because they are suitable for repeated duty. These type of circuit breakers are finding their best application in systems operating in range of 132 kV to 400 kV with breaking capacities upto 7000 MVA.

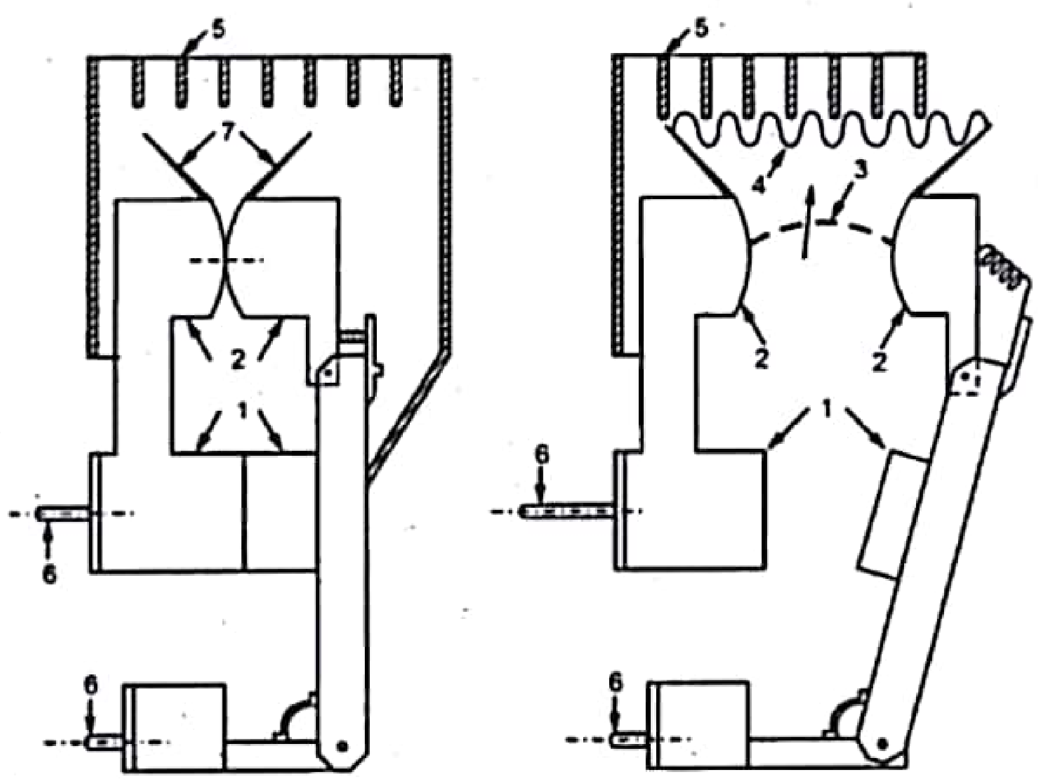
10.6 Air Break Circuit Breaker

In air circuit breakers the atmospheric pressure air is used as an arc extinguishing medium. The principle of high resistance interruption is employed for such type of breakers. The length of the arc is increased using arc runners which will increase its resistance in such a way that the voltage drop across the arc becomes more than the supply voltage and the arc will be extinguished.

This type of circuit breaker is employed in both a.c. and d.c. type of circuits upto 12 kV. These are normally indoor type and installed on vertical panels. The lengthening of arc is done with the help of mangetic fields. Some typical ratings of this type of circuit breaker are 460V – 3.3 kV with current range 400 - 3500 A or 6.6 kV with current range 400-2400 A etc.

10.6.1 Construction

The Fig. 10.7 shows the constructional details of air break circuit breaker.



(I) Contact closed

(II) Contacts open

Principle of air-break circuit-breaker

1. Main contacts
2. Arcing contacts
3. Arc rising in the direction of the arrow
4. Arc getting split
5. Arc splitter plates
6. Current carrying terminals
7. Arc runners

Fig. 10.7 Construction of air break circuit breaker

It consists of two sets of contacts.

1) Main contacts

2) Arcing contacts

During the normal operation the main contacts are closed. They are having low resistance with silver plating. The arcing contacts are very hard, heat resistant. They are made up of copper alloy. Arc runners are provided at the one end of arcing contact. On the upper side arc splitter plates are provided.

10.6.2 Working

As seen from the Fig. 10.8 the contacts remain in closed position during normal condition. Whenever fault occurs, the tripping signal makes the circuit breaker contacts to open. The arc is drawn in between the contacts

Whenever the arc is struck between the contacts, the surrounding air gets ionised. The arc is then cooled to reduce the diameter of arc core. While separating, the main contacts are separated first. The current is then shifted to arcing contains. Later on the arcing contacts also start separating and arc between them is forced upwards by the electromagnetic forces and thermal action. The arc travels through the arc runners. Further it moves upwards and split by arc splitter plates. Due to all this finally the arc gets extinguished as the resistance of the arc is increased.

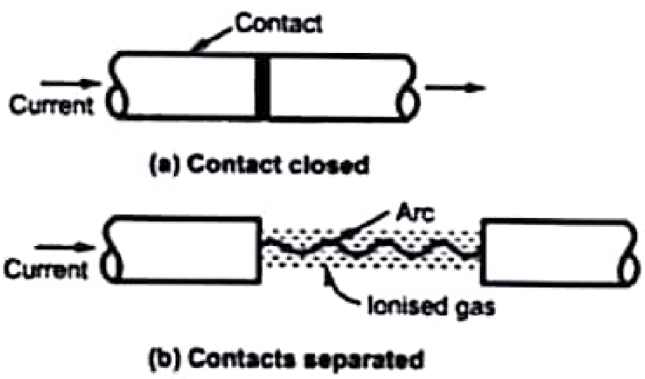


Fig. 10.8 Working of air break circuit breaker

Due to lengthening and cooling, arc resistance increases which will reduce the fault current and will not allow to reach at high value. The current zero points in the a.c. wave will help the arc extinction. With increase in arc resistance the drop across it will go on increasing.

Whenever arc leaves the contacts it is passed through arc runners with the help of blow out coils which provide a magnetic field due to which it will experience a force as given by electromagnetic theory ($F = BIl$). This force will assist in moving the arc upwards. The magnetic field produced is insufficient to extinguish the arc. For systems having low inductances arc gets extinguished before reaching extremity of runners because lengthening of arc will increase the voltage drop which is insufficient to maintain the arc.

For high inductance circuits if it is not extinguished while travelling through ar runners then it is passed through arc splitters where it is cooled. This will make th effective deionization by removing the heat from arc.

10.6.3 Applications

This type of circuit breakers are commonly employed for industrial switchgea auxiliary swithgear in generating stations.

10.7.7 Applications

A typical SF_6 circuit breaker consists of interrupter units. Each unit is capable of interrupting currents upto 60 kA and voltages in the range 50-80 kV. A number of units are connected in series according to system voltage. SF_6 breakers are developed for voltage ranges from 115 to 500 kV and power of 10 MVA to 20 MVA ratings and with interrupting time of 3 cycles and less.