Module 2: DIESEL ENGINE POWER SYSTEM, HYDRO ELECTRIC ENERGY

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Objectives
After studying this unit, student should be able to

☐ Know about layout diesel engine power plant,
☐ Understand about cooling and lubrication system in diesel engine plant
☐ Know about intake and exhaust system in diesel engine power plant
2.1 Introduction

We know that, all types of automobiles including tractors, trucks and buses use internal combustion engines. These internal combustion engines can also be used for power generation where the supply of coal and water is not available in abundant quantity. These plants are suitable for small and medium outputs and can be used as standby to hydro electric power plants and thermal power plants. These can also be used to meet peak load demand in some powerplants and can be used to supply the seasonal electric loads. Low capacity plants use petrol engines and are meant primarily for emergency service. A large capacity plant uses diesel engines for power generation. The capacity of these plants ranges from 2 to 50 MW and are used as standby sets in hospitals, cinemas, telephone exchanges, radio station etc. It is one of the most economic means of generating electricity in a small scale where cheap fuels are not available and load factors are considerably high.

In a steam plant, one or more diesel generating units may be installed to serve as stand by or to supply peak loads of small duration. As stand bys, these units may provide for the total residential load of the power plant. In thermal plant, the diesel generators supply power for auxiliaries in case of failure of main working units. In industrial plant where the steam is used for process work, diesel engines supplies power during seasons when steam for process work is not required.

2.2 Advantages and disadvantages of diesel Power Plants;
Advantages
1. Very simple in design and easy to install
2. The plant can be located very near to the load centre.
3. The overall capital cost per unit of installed capacity is lesser than thermal or hydel plant.
4. The plant requires lesser operating and supervising staff.
5. Fuel handling is easier and no ash disposal problem.
6. The cooling water requirement is less.
7. It can be quickly installed and commissioned and can be put on load quickly.
8. It can meet sudden changes in the load without much difficulty.

Disadvantages
1. The size of the unit is limited and very large capacity plants are not possible.
2. The operating cost is high.
3. Lubricating cost and maintenance costs are high.
4. The plant cost per KW is comparatively more.
5. Noise from the exhaust is a serious problem.
6. Life of the plant is limited to 2 to 5 years when compared to thermal plants.

Applications of diesel Power Plants
1. It can be used as peak load or stand by unit for hydel plants.
2. It can be used as mobile plants for temporary or emergency purposes (for large civil engineering works etc.)
3. These can be used in emergency cases where power interruption would result in financial loss or danger, in key industrial processes, tunnel lighting and operating rooms of hospitals.
4. It can be used as a Nursery station. The plant supplies power to a small town in absence of main grid and can be moved to another area which needs power in a small scale when the main grid is available is known as "Nursery station".
5. It can also be used as starting station. The plant runs the auxiliaries for starting the large thermal plants.

2.3 Layout of a diesel power plant
2.4 Engine Intake System

A large diesel engine requires 0.076 to 0.114 m³/min of air per kW of power developed, the air intake system supplies required quantity of air for combustion. The system consists of a pipe line which connects source of fresh air and engine manifold. Filters are provided to remove dust from the air, otherwise dust particles may cause wear and tear of the engine. These filters may be of dry type (made up of cloth, felt, glass, wool etc.,) or oil bath type. Electrostatic Precipitator filters can also be used. In oil bath type of filters, the air is swept over or through a bath of oil, so that the dust particles are coated. The intake ducts are made up of light weight steel. Some
times, a silencer may be used between the engine and intake since the noise may be transmitted back to the outside air via the air intake system. In the air intake system, pressure loss should be minimum. If pressure loss is high, it reduces engine capacity and increases specific fuel consumption. Therefore in total, the functions of the air intake system are:

i) To clean the air supplied to the engine
ii) To silence the intake air.
iii) To supply air for supercharging.

### 2.5 Engine exhaust system

Engine exhaust system including ducts, mufflers, water heaters, silencers etc.,
The exhaust system is used to convey the exhaust gases to the atmosphere outside the building. It also consists of a silencer to reduce the noise level. A muffler provided in the exhaust pipe reduces the pressure in the exhaust line and reduces the noise. Sometimes, a device may be used in the path of exhaust gases to recover heat. The exhaust pipe coming out of the building should have one or two flexible tubing sections in order to isolate the system from vibration by taking the effect of vibration. Its length should be shorter and should have minimum number of bends. Every engine should be provided with an independent exhaust system.

The points to be considered in the design of the exhaust system are:

1. The noise level should be minimum.
2. The system should discharge the exhausts sufficiently above the ground level.
3. The duct should take up the effect of expansion and contraction due to temperature variation.
4. As back pressure is imposed on the engine, it reduces engine power, it should be kept minimum.
5. The flexible tubing sections are to be used in the exhaust pipe in order to isolate the system from vibration.

### 2.6 Fuel System

The fuel system includes fuel storage tanks, fuel transfer pumps, strainers, heaters and connecting pipes. The trucks, rail road tank cars, or barge and tankers are used to deliver the fuel oil to the plant site. Then, fuel oil is delivered to main storage tanks through unloading facility. Then, the transfer pumps are used to deliver fuel oil to smaller service storage tanks (day tanks). For the main flow, piping arrangement is made with necessary heaters, by-passes, shut offs, drain lines, relief valves, strainers, filters, flowmeters, and temperature indicators. The minimum...
rages of maintenance should satisfy at least a month's requirement of fuel. But in order to avail the advantage of price fluctuations of the fuel, it is essential to provide storage or few months requirement. The capacity of the daily consumption tank should be at least the 8 hours requirement of the plant. Usually these tanks are relocated above the engine level so that the oil may flow to the engines under gravity.

The fuel oil supply system has to satisfy certain requirements for its satisfactory working:
1. Provisions should be made for cleaning and changing over of lines during emergency.
2. Tight pipe joints should be used in all suction lines.
3. The oil flushing is done through the piping between filter and engine before being placed in service.
4. High grade filters are to be used to hold water, dirt, metallic chips and other foreign matter.

2.7 Cooling System

![Closed cooling water system using soft water coolers](image)
The cooling system in a diesel plant includes coolant pumps, cooling towers or spray ponds, water filtration plant and connecting pipes. The purpose of cooling system is to provide proper circulation of cooling water all around. The engines keep the temperature at a reasonably low level. If the engine is not cooled properly, the high temperature existing in the engines (cylinder and piston are exposed to high temperature of the order of 1000 to 1500°C) would disintegrate the film of lubricating oil, causes warping of valves, piston etc. The overheating of the engine would cause damage to the piston, piston rings, head and cylinder liners. A pump circulates water through cylinder and head jackets to carry away the heat. Some heat is also taken away by the lubricating oil. Same water should be used again and again and hence a method of cooling the cooling water is required. This is achieved by bypassing water through radiators, evaporative coolers, cooling towers, spray ponds etc., nearly 25% to 35% of total heat of the fuel is removed by the cooling system. The heat taken away by oil and radiation heat lost accounts to 3% to 5% of total heat supplied.

3.8 Cooling system for diesel engine

The cooling system in a diesel plant includes coolant pumps, cooling towers or spray ponds, water filtration plant and connecting pipes. The function of cooling system is to provide proper circulation of cooling water all around the engines to keep the temperature at a safe level. Under cooling raises engine temperature, decreases engine performance and its life. Excessive cooling makes the combustion poor and affects the fuel economy. It increases viscosity of oil due to low temperature and hence increases power loss due to friction. Basical there are two methods of cooling.

i. Air cooling

ii. Liquid cooling

Air cooling: In this method, engine cylinder is directly exposed to atmospheric air which carries the heat from the cylinder. The cylinder is finned, particularly heavily near the exhaust. The use of fins over engine cylinder provides additional heat transfer surfaces, thereby increasing rate of heat transfer. Liquid cooling: In this method, the cylinder walls and heads are surrounded with cooling water jackets. The water while circulating through jackets, take the heat from
cylinderwalls by convection and conduction. The heated water itself is cooled by circulating it through air-cooled radiators system. In stationary diesel engine plants the watercooling systems are used and areas follows;

i) Open or single circuit system

Water is pumped from cooling pond to the main-engine jackets. After circulation, water is returned to the cooling pond by spraying through nozzles. The dissolved gasses in the cooling water may corrode the cylinder jackets.

ii) Closed or double circuit cooling system

Double circuit cooling system

In this system, heat exchanger is used in between engine and cooling pond. The water from the pond is pumped through the heat exchanger, where it takes the heat from jacket water and is returned to the cooling pond. The cooled water is again pumped back to the engine side. This method eliminates internal jacket corrosion.

3) Evaporative cooling: In this method, a large surface of the hot water is exposed to an airflow, hereby humidifies the air and cool the remaining water. This can be done by providing cooling towers, evaporative water etc. The cooling action is same in all of them. The atmosphere is a mixture of air and water vapour in proportion and is described by humidity. Proper latent heat of evaporation must be supplied for vapourization of water. The source of heat may be internal energy of the liquid water from which the vapour is being produced. During the process of humidification, some off the warm water goes off into the atmosphere and make up water of 2.5% of water flow must be added to the system.

Atmospheric towers are long and having narrow structures with considerable height. The axis (vertical) of the tower is normal to the prevailing wind and are built to utilize horizontal wind movements. From the top of the towers, water falls through the air currents and evaporatively cooled. These towers are not used in diesel power plants. For effective cooling, tower should be sufficiently high. The cooling water is collected and pumped from the bottom of the tower and supplied to the engine for cooling. A fan is provided in
The use of fan reduces the height of tower. Depending on location, the fan used could be a forced draught type or Induced draught type. The falling water meets the air which is flowing in the opposite direction.

An evaporative cooler is one in which the cooler is constructed from steel including a heat exchanger for cooling the water. This type is not suitable for diesel plants. The evaporative cooling is also known as steam or vapour cooling in which the cooling water temperature reaches to a temperature of 100°C. The cooling of water can be done with minimum of water by using high latent heat of vaporization. The coolant is always in the liquid state, but the steam formed is flashed off in a separate vessel. The fresh water so formed is returned back for cooling. This system is used in many industrial engines. Spray eliminators

Radiator in place of cooling towers, cooling ponds and spray ponds are used. But these are inefficient for bigger power plants.

Lubrication for the diesel engine: As discussed, the role of lubrication system is more important in the diesel power plant than any other plant because of very high pressures and small clearances in these engines.

The lubrication system influences the engine life, efficiency and the extent to which the engine is put in continuous service.

In a diesel engine, the following are the main parts which require lubrication:

1. Piston and cylinders.

2. Crankshaft and connecting rod bearings.

3. Gears and other mechanisms used for power transmission.

4. Integral injection or scavenging air compressors.

Lubrication may be classified into:

1. Full pressure lubrications similar to that used in automobile engines.
2. Mechanical force-feeds lubrication and gravity lubrication from an overhead headtank. In pressure lubrication system, an oil pump is used to deliver the lubricant under pressure to various parts of the engine through a duct system and to the crankshaft and wristpin bearings by drilled passages in the shaft and rods. For lubrication of cylinder walls, oil mist is slung outward from the connecting rod bearings or splash lubrication method is used. Mechanical force-feed lubrication is used to effect the lubrication of cylinders of large and slow-speed engines. The crankcase serves the purpose of oil sump from where the oil may be withdrawn by a pump. The lubricating oil, during its circulation through the lubrication cycle accumulates impurities such as carbon particles, water and metal scrap. It is cleaned by settling, centrifuging, filtering or chemical reclaiming. Mechanical filters such as cloth bags, wool felt pads, paper discs and cartridges of porous material are used for cleaning the oil. In centrifugal cleaning, first screen filters are used to clean the oil and then the oil is passed through high speed centrifuges for ultimate cleaning. The oil should be heated, before it enters to the centrifugal cleaner. The oil consumption is in the range of 2.27 x 10^{-6} to 4.10 x 10^{-6} m^3 per kW hour. In chemical reclaiming method, after filtering, a combination of heat and activated clay are used. In settling method, impurities are made to settle down by allowing the hot oil to enter into a large tank. Clean oil is then used from the top of the tank. The lubricating oil gets heated due to friction between rubbing surfaces and should be cooled before recirculation. The lubricating oil absorbs about 2.5% of the heat of the fuel. The hot lubricating oil may be cooled with the help of cooling water used for engine cooling. The lubricating oil consumption is about 1% of fuel consumption (3 litres per 1000 kWhr generated at full load conditions).

2.8 Lubrication system
The lubrication system includes oil pumps, oil tanks, filters, coolers, purifiers and connecting, the purpose of lubrication system is to reduce the friction and wear of the rubbing.

Lubricating oil is used to

1. Lubricate the moving parts
2. Remove heat from cylinder and bearings
3. Carry away solid matter from rubbing moving parts.
4. Absorb the shock between bearings and other parts and consequently reduce noise.

Pumps are used to deliver the oil to the engine and the oil is recirculated under pressure.

The lubrication system has to effect the lubrication of following engine parts.

1. Main crankshaft bearings
2. Big-end bearing
3. Small end or gudgeon pin bearings
4. Cylinder walls and piston rings
5. Tuning gears.
6. Camshaft and its bearings
7. Valve mechanism
8. Valve guides, valve tappets and rocker arms.

3.9 Lubricating system (continuous centrifuging system)

The lubricating oil in use is subject to changes in operating temperature and results information of sludge and varnish. Therefore, it is necessary to use the oil with engine cleaning properties. In order to improve the oil characteristics, additives such as anti oxidants, detergents, corrosion inhibitors are added with straight mineral oils. Anti oxidants are used to prevent chemical reaction with oxygen and due to heating. The addition of detergents keep the engine clean by controlling lacquer and preventing the deposition of carbon, soot, dirt and combustion.
productsonpistonand rings. A protective filw is formed on engine parts due to the addition of corrosion inhibitors and this film protects the engine parts from corrosion acids, which is due to presence of sulphur in the fuel.

Filters and centrifuges
Filters and centrifuges are used to arrest dirt, metallic chips or other foreign substances in the fuel. Filters may be of dry type and made up of cloth, felt, glass, filter paper, some cellulose material wooletc., or oil bath type. In the later type, the oil is swept over or through an oil bath filter, which retains the oil coated dust particles. The clean fuel oil provides trouble-free operation of the engine. The use of bulk storagetanks removes most of the suspended impurities, water dirt collected from the oil, if it is light and allowed to stand in the storage tank for sometime. This method is too effective, if heavier oils are used or if the temperature of the oil is below 10°C. Hence cleaning done by filtration and centrifuging when the oil is transferred from bulk storage tank to the tanks. Filtering means passing the oil through filters which are mostly of absorbent type and retain the oil contaminants and allow clean oil to pass through. The filters can be cleaned and reused and replacement of the cartridge is not very frequent. In other type of filters, i.e., in oil impingement type, a frame filled with crimped wire or metal shaving is used. A special oil coated, so that when the air passing through the frame, is broken up into a number of small filaments and these filaments make contact with the oil. The property of oil is to seize and hold any dust particles carried by the air. These filters require periodic cleaning by removing water and re-oiling. Sometimes, engine noise may be transmitted back to the outside air through the intake system. In such cases, a silencer is provided between the engine and intake. A typical filter and silencer installation for a diesel engine.

A centrifuge is a device in which the suspended impurities in the oil are removed by giving a rapid whirling motion. This process is known as "centrifuging". This process removes impurities by separating heavier particles from light clean oil. The viscosity of oil is the factor which influences the degree of cleanliness and should be improved by heating the oil. But when the oil is heated to high temperature, the contaminant water may go into the solution with oil and hence avoid separation. So in order to obtain good results, the oil temperature in the range of 15°C to 38°C is considered to be optimum. The centrifuge requires periodic servicing to ensure cleanliness of oil after centrifuging.

2.9 Starting System
The starting system includes storage battery, self starter, and compressed air supply etc., the automobile engines are generally started by cranking. But in power plants, large capacity engines are used and are restarted by: i) Using compressed air ii) By using an auxiliary engine iii) By using electric motors or self starters.

Governing System
The purpose of this system is to regulate the engine speed constant irrespective of load on the plant. Usually, this is done by varying the supply of fuel to the engine according to load.

Engines for power generation

Internal combustion engines are used for power generation, where the supply of coal and water is not available in abundant quantity. An internal combustion engine is one in which combustion of fuel takes place inside a cylinder. A reciprocating piston inside a cylinder develops power. A connecting rod connects piston to the crank shaft and converts reciprocating motion of piston into rotary motion of the crank shaft.

Petrol engines are used in low capacity plants and are primarily intended for emergency service. Diesel engines are suitable for large capacity plants and these engines are mainly used for power generation. The capacity of diesel plants ranges from 2 to 50 MW and are used as standby units in hospitals, cinema halls, telephone exchanges, radio stations, etc. It is one of the most economic means of generating electricity in small scale where cheap fuels are not available and load factors are considerably high.

The diesel plants are more efficient than any other heat engines of comparable size. It is easy to start and can burn a wide variety of fuels. The advantages of diesel engine over petrol engines are

1. At part load and full load, the specific fuel consumption is low.
2. For same cylinder dimensions, high compression ratio yields more power
3. Longer operating life.
4. Reduced fire hazards
5. The vibration and balancing problems are not severe at medium speed operation. In an internal combustion engine, the following steps are followed in the production of power:
   1. Air/airfuel mixture is drawn into the cylinder through valves/ports which is referred to as suction.
   2. Compression of air/airfuel mixture during the upward movement of piston.
   3. Combustion by fuel injection into the highly compressed air or by producing a spark in the compressed airfuel mixture which initiates the combustion.
   4. Expansion of combustion gases which thrusts the piston to perform power stroke.
   5. Exhaust of burnt gases from the engine cylinder.

The diesel engines are more suitable for small and medium output powerplants due to the reasons as follows:

Methods of starting the diesel engine

In power plants, large capacity engines are used and are started by the following devices.
1) By compressed air.
2) By an auxiliary engine (petrol engine)
3) By electric motors.

Compressed air system: Largestationary diesel engines are started with compressed air. In this system compressed air at a pressure of about 17 bar is supplied from an air tank or bottle to the engine intake valve through the distributor or through the inlet manifold. Two or more compressed air storage tanks are provided. A small compressor is installed for supply of compressed air to the storage tanks. During starting of a multi-cylinder engine, compressed air is admitted to one or more cylinders and forces the piston to move downward which in turn rotates the engine shaft. The injection or fuel pumps are inoperative while the speed is gained under air power. This powers the engine much the same as steam works in a steam engine. The air is turned off and oil injection is started and the engine gains momentum and by supplying fuel, the engine will start running.

By an auxiliary engine: In this method, a small petrol engine is mounted close to the main engine and is connected to it through clutch and gear arrangements. Firstly, the clutch is to be disengaged and the petrol engine can be easily started by manual operations. When it has warmed up, the clutch is to be gradually engaged to transmit power to the main engine i.e., the main engine is cranked for starting. The clutch of auxiliary engine automatically disengages after the main engine has started. The capacity of auxiliary engine is sufficient to overcome the friction of the main engine.

By electric motors or self starters: Electric motors or self starters are employed for small gasoline and diesel engines. The engine consists of an electric motor which is used for starting purpose. A storage battery of 12 to 36 volts is used to supply power to an electric motor which drives a pinion which engages a toothed rim on engine fly wheel. A small electric generator, driven by the engine, may also be used to drive the motor. The motor is engaged continuously for about 30 seconds only, after which it is required to cool off for a minute and then re-engaged. This is to be continued till the engine starts up. After the engine has started, the electric motor automatically disengages. This method is more simple and effective than other method.
Method of starting or starting procedure
Before starting the engine, it is necessary to go through all precautions supplied by manufacturers. The process of starting the engine is different for various engines. Some common steps are as listed here:

1. Before starting the engine, it is necessary to check air pressure and any possible air leakage in the air system. In case of electric motor starting, the battery conditions should be checked regularly.

2. It is necessary to check fuel system, lubricating system, and cooling water system.

3. The engine is cranked after ensuring no load on the engine and decompression device is used.

4. By running the engine at slow speed, the working of fuel pump is to be checked. The inspection is to be made for fuel and oil pressures, lubricating oil system etc.,

**HYDRO-ELECTRIC ENERGY**

2.10 Introduction to hydro power
Water is the cheapest source of power. In the earlier days, it was used to run the waterwheels to generate electric power. The power generation by hydro electric plant is nothing but the utilization of the part of hydrological cycle. These plants utilize the energy of water to drive the turbine which in turn run the electric generators. In 1882, the first hydro-electric station was started in America. In India, these plants contribute nearly half of the total power requirement and play a very important role in the development of the country. In India, a hydroelectric power station was initiated with run of river scheme near Darjeling and the first major hydroelectric plant was developed near Mysore in 1902 (Siva Samudram of 4.5 MW capacity). The potential energy of
rain falling on earth's surface, relative to the ocean is converted to mechanical energy by using suitable prime movers i.e., hydraulic turbines. In hydro power generation, the kinetic or potential energy of water may be used. The kinetic energy of water is its energy in motion and is a function of mass and velocity. The potential energy is nothing but the difference of water level between two points i.e., head. In both the cases, water should be available continuously and in ample quantity. The past history of the place of location of the plant must be known to estimate minimum and maximum quantity of water which is available for power generation. The water from natural lakes and reservoirs at high altitudes may be used or storage reservoirs may be constructed to store the water during peak periods and utilise the same during off peak periods. The dams constructed across the flowing stream serve this purpose. A significant amount of rain fall goes in the form of direct evaporation and a major portion of rain fall seeps into the soil to form the underground storage. The remaining small portion of rainfall is utilised for power generation.

Hydro or water power is a conventional renewable source of energy. This energy source is clean, pollution free and environmentally friendly. The hydro projects controls floods in the rivers, stores the water for irrigation and for drinking purpose. The capital cost of the plant is high. As the plants are situated in hilly areas, away from the load centre, the erection and transmission costs are also high. Hence, the cost of power generation is also high in comparison with steam, oil or gas plants. But despite these factors, a number of advantages favours the use of hydro projects.

2.11 Main Elements of hydro electric power plant
The hydroelectric power plant essentially consists of hydraulic structures, power plant etc. In the plant, hydraulic structures mean dams, spillways, head work, diversion works, forebays or surge tanks, penstocks and conduits. The essential elements of waterpower plant are:

i) Catchment area
ii) Reservoir
iii) Dam
iv) Spillways
v) Conduits
vi) Surge tanks
vii) Prime movers
viii) Draft tubes
ix) Power house and equipments.

Catchment area: The catchment area is the whole area behind the dam which is built across a river at a suitable place.
Reservoir: It is the basic requirement of a hydro-electric power plant and the one which is to collect and store whole of the water available from the catchment area behind the dam. The stored water is used in turbines to produce electric power and yields uniform power output throughout the year. A reservoir may be natural type such as a lake or artificial one which is built by erecting a dam across the river. Water held in upstream reservoir is called storage and water behind the dam at the plant is called pondage.

Dam: The dam is the most important element of the water power plant. It is an 'ier built across the river to increase the height of water level behind it (to increase the reservoir capacity) and creates the necessary head to be utilized in the water turbines. Economy and safety are the basic requirements of the dam. The dam should resist water pressure and should be stable under conditions. In hydro-electric plants, several types of dams are used such as concrete or stonemasonry, earth and/or rock fill and timber. Timber and steel are used for dams of height 6 to 12 m only. Earth dams are constructed up to about 100 m. The foundation must provide stability under different forces and has to support the weight. It must be impervious to prevent seepage of water under the dam.

Forebay: It acts as a sort of regulating reservoir temporarily store the water when the load on the plant is reduced and there is with drawl of water from it when load is increased. The river water is diverted away from the main stream. The enlarged portion at the end of canal forms the forebay.

Trashrack: It is provided on the way of water from the dam or from the forebay to prevent the entry of debris which might damage the wicket gates and turbine runners or may choke up the nozzles of the impulse turbine. Manual or mechanical cleaning may be done to remove.

Spill ways: It is a safety device for the dam, discharges the surplus water from the storage reservoir in to the river on the down stream side of the dam. It is arranged in the dam or periphery of the reservoir basin. This should provide structural stability to the dam under all conditions of floods. There are several designs of spill ways such as simple spillway, side channel spillway, saddlespillways, siphon spillway, solid gravity spillway, chute or trough spillway, emergency spillway etc.

Conduits: Inlet water way or head race is the passage of water from dam to the turbines and tail race (outer water way) is the passage of water from the wheels. The inlet waterway consists of tunnels, canals, flumes, fore bays, penstocks and surge tanks. The tunnels are made by cutting them mountains where topography prevents the use of
canal or pipeline. Headwork includes, gates valves and trash rack etc. The conduit may be open (canals and flumes) or closed one (tunnels, pipe lines and penstocks).

Pen stock: A penstock is a closed pressure pipe (supplying water under pressure) made of reinforced concrete or steel, used to supply water to the turbines. It is a pipe of shorter length used to connect turbine and main water way. The penstocks are used where the slope is too great for a canal, especially where the land pitches steeply to the power house. As the working pressure or head of water increases, the thickness required in the penstock also increases.

A penstock of larger diameter, gives lesser frictional loss. The flow of water through the penstock decides the diameter, and the product of discharge and head gives the horse power which the penstock can carry. It indicates strength of the penstock. In the location of a penstock, economical shortest route is always desired. It is desirable to locate the penstock always sloping towards the power house, but the extent of slope may be varied to suit the topography. In order to provide adequate water seal under all conditions, especially at low water, at the dam or forebay. The intake of penstock should be at a lower level. Generally penstocks are not covered, because exposed pipes are cheaper and maintenance and repair becomes very easy. Covered penstocks are used in the places where there is a chance of sliding of snow, rock and earth etc. In the penstock, velocity of water ranges from 2 to 6 ml/sec. If the water velocity increases, size of the penstock required decreases and consequently its cost also reduces, but frictional losses increase. The life of the penstock may be increased by using a protective corrosion resistant coating on the steel penstock. Penstocks may be buried or supported on the piers and craddles.

2.12 Classification of Hydro Plant

The hydro electric power plants are classified according to Head of water available

a) Low head Plants:

These power plants are also known as canal power plants. In these plants, the water head available is less than 30 metres. The necessary water head is created by constructing a dam across the river and the water is diverted into a canal which allows the water to
flowing to a forebay, from where the water is made to flow through turbines. Then the water is discharged into the river through a tail race. The powerhouse is located near the dam itself and does not require a surge tank. This plant uses vertical shaft Francis turbine or Kaplan turbine.

(b): Medium Head Plants:
In these plants, the operating head of water ranges from 30m to 100 metres. The forebay is provided at the beginning of penstock, serves as water reservoir and conveys water to the turbines through penstocks. Open canals are used to carry the water from main reservoir to the forebay which itself acts as a surge tank. Forebay also stores the rejected water when the load on the turbine decreases. Francis turbines are used in these type of plants. factor is less than one. Therefore, for satisfactory working of the plant, it is to be designed for average load and this type is known as base load plant. A small plant known as peak load plant peak load plant is used to satisfy the load which is coming above the mean load.

c) High head plants
When the available water head for power generation exceeds 100 metre, the plant is known as high head plant. During rainy season, usually the water is stored in lakes or high mountains. From the reservoirs, water is passed through tunnels which distribute the water to the penstocks through which the water is conveyed to the turbines. A surge tank is attached to the penstock to reduce the water hammer effect on the penstock. Waterflow is regulated by head gates at the tunnel intake, butterfly valves at the entry to the penstocks and gate valves at the turbines. These plants are usually provided with pelton turbines for power generation.

d) Peak load plants
These plants are mainly intended to supply power during peak loads. Some peak plants, deliver power during average and also peak load as and when it is there. Runof plants with pondage and pumped storage plants are used as peak load plants. In the first, it uses a large pond which provides extensive seasonal storage. These work on relatively higher heads and load factor is considerably low.

According to quantity of water available for power generation
(a) Run on River plant without pondage
This type of plant has no control over the river flow. The plant does not store water and uses the water as it comes. During low load and high flood conditions, water will be wasted by over the dam spill ways. During dry seasons, the low flow of water reduces the plant capacity. These plants are usually used to supply peak load. The non-uniformity of supply makes its utility very less in comparison with other types of plants.

(b) Run of river plant with pondage
In the plant, addition of a pond increases the useful ness of the run off river plant. The water is stored behind a dam and this increases the stream capacity for a short period. The conditions at the tail race should be such that the water level in the tail race should not be increased during floods as it decreases the effective head of the plant. This plant can be used as base load or peak load plant. This plant is more reliable and its generating capacity is not fully dependent on the water flow rates available.

(c) Storage type plants
This type of plant stores the water during rainy season in the reservoir and it is released during dry season. The reservoir incorporated is of a sufficiently large size to allow carryover storage from the wet season to dry season. The power generation in dry seasons will not be affected.

According to nature of load
The load on the power plant varies depending on seasons and every hour in a day. Consider a load curve as shown in figure 4.9 for an industrial town. The peak load is the plant capacity to satisfy the demand. If the plant is designed for peak load capacity, then the working of the plant is economical as most of the time the plant is working under low load conditions and the load affects plant can be used as a base load plant as well as a peak load plant as water is available with controls required. Most of the hydro-electric plants in India as well as in the world are used to supply the peak load for the base load power plants and to supply the sudden peak load for ash duration i.e., a few hours or few days in a year. These are used in the places where the water is not available in sufficient quantity for power generation.
In this plant, a penstock connects the headwater pond and tail water pond. The generating Pumping plant is located on the lower side as shown. The baseload plant generates some surplus electric energy during off peak hours. This energy is being used to pump the water from tail water pond to the head water pond and this energy will be stored there. During peak load time, this energy will be released by allowing water to flow from head water pond through the turbine of the pumped storage plant.

Pumped storage plant is a special type of hydroelectric plant works in combination with plantsto improve the overall efficiency of the combined system. The plant uses very little rate for its operation and hence decreases the operating cost of the thermal plant.

### 2.13 Storage and pondage

Storage means, collection of water in the upstream reservoirs to increase the capacity stream over an extended period of several months. The water is stored in a reservoir for continuous generation of power throughout the year and the power generation is not affected by the variation in the rainfall during the year. The excess water is stored in the reservoir during rainy season and it is released during run off (dry) periods. Storage plants may work satisfactorily as baseload and peak load plants. Maximum storage should be provided with economic expenditure. There are two types of storage.

i) The storage of water is provided for one year only (considering losses also), so that there is no carry over water for the next season.

ii) The water is stored, so as to be useful even during the worst dry periods.

Pondage means, collection of water behind a dam at the plant and increases the stream capacity for a short period, i.e., for a week. The generating capacity of the plant is less dependent on the flow rates of water available and the plant with pondage is more reliable than that without pondage. Arunof river plant without pondage uses water just as it comes, without storing. There is no control on flow of water so that water is wasted during high floods or low loads. The plant capacity is reduced during low run off period. The capacity of pondage should be such that, it should take care of hour to hour fluctuations in load on the plant through out the period.
2.14 Hydrology
Hydrology is the science that deals with the depletion and replenishment of water resources on and beneath the surface of earth. It is the natural science in which rain fall and run off can be analysed and studied and occurrence and availability of water can be studied. It also deals with all forms of water i.e., solid, liquid and vapour. The study of hydrology provides information about transportation of water from one place to another, and from one form to another. The science of hydrology is very important in the design of irrigation structures, planning and construction of bridges and flood control works etc.

Hydrologic cycle
We know that, the clouds are formed due to evaporation of water from plants, rivers and oceans and the evaporated water is carried with air in the form of vapour. In the atmosphere, the vapour falls in the form of water or snow depending on atmospheric temperature, when these are cooled below the dew point temperature. This evaporation (water lost in atmosphere as vapour) and precipitation (vapour condensed back in the form of rain, snow, hail, dew, sleet or frost) continues for ever and there by maintains a balance between these two. This is known as "Hydrologic cycle".

The Hydrological cycle involves various processes such as transfer of moisture from thesea to the land and back to the sea again. The hydro logic equation is expressed as evaporation

\[ P = R + E \]

\[ P = \text{Precipitation} \]
\[ R = \text{Runoff} \]
\[ E = \text{Evaporation} \]

Precipitation (Rain fall); It includes all the water that falls from atmosphere to the earth surface i.e., vapour condensed in the form of rain, snow, hail, dew, sleet, or frost. It consists of i) Liquid precipitation (rain fall) and ii) Solid precipitation (snow, hail etc).

Runoff and surface run off: The portion of rain fall or precipitation, flows through the catchment area on the surface of the earth is known as runoff or discharge or stream flow. It includes all the water flowing in the stream channel at any given section. The remaining portion of the rainfall is directly evaporated by the sun, taken by the vegetation and growing crops and some percolates into the ground. Run off occurs when the rate of precipitation exceeds the rate at which
water infiltrates into the soil. The factors which influence the rate and volume of runoff are duration, intensity and distribution of rainfall.

The surface runoff means the water that reaches the stream channel without first percolating down to the water table (WT).

**Evaporation:** The change of phase of water from liquid to vapor state is called evaporation.

**Transpiration:** It is the process by which the plant releases water to the atmosphere.

Runoff can be measured daily, monthly seasonally or annually by using the following methods:

i) From rainfall records

ii) By using empirical equations

iii) By using runoff curves and tables and

iv) Discharge observation method.

### 2.15 Hydrograph

A hydrograph is a graphical representation showing discharge (runoff) of flowing water with respect to time for a specified time. It indicates variation of flow or discharge with time. A hydrograph may be plotted for hours, days, weeks or several months. It is plotted with flow as the ordinate (in m³/sec) and time intervals as abscissas (in hours, days etc.). Besides the variation of flow, indicated by a hydrograph, it also indicates the power available from the stream at different times of the day, week or year. A hydrograph also indicates extreme conditions of flow and helps in
analyzing the effect of storage on flow. The characteristics of the catchment and precipitation over it, will affect the nature of hydrograph of stream of river. Flood flow of the rivers can also be assessed and hence for a given storm, anticipated hydrograph of the given river could be drawn.

A hydrograph is used to determine
1. Flow rate at any instant during the duration period.
2. As an area under hydrograph gives volume of water in a particular duration, the total volume of flow during that period can be determined.
3. The mean annual runoff for each month of the year.
4. The maximum and minimum runoff for the year and for each month.
5. Flood duration and frequency and maximum rate of runoff during the floods.

The peak flow shows only a momentary value. Therefore it is required to analyse the full hydrograph of flow and the concept of unit hydrograph has been introduced. i.e., The two identical storms produces same hydrographs for the run off. Usually identical storms rarely occurs and generally rainfall varies in duration. Hence for the basin, a typical hydrograph is to be constructed which could be used as a unit of measurement of run off. A unit hydrograph is one which represents unit runoff resulted from an intenserainfall of Unit duration and specific areal distribution.

### 2.16 Flow duration curve
Curves show the relation between flows, plotted as the ordinate and length as they are available and plotted on abscissa. This curve represent the run off time in the another form and is obtained from a hydrograph. The flow duration between flow available during a period and the fraction of time. If the potential flow is plotted on the ordinate, then the curve is known as "Power duration useful to analyse development of water power. The flow duration curve gives at the site, and may be used to find maximum and minimum flow conditions. Drawn by using hydrograph from the available run off data and it is required to time during which certain flows are available. This information is obtained either from hydrograph and is tabulated. Then the flow duration curve can be 00% time on the x axis and run off on Y axis. Duration curve is the graphical representation of flow arranged in the descending mean monthly discharge at a site is as shown. Draw the hydrograph curve by taking time in months on abcissa ordinate. From this draw flow duration curve by finding length of time.
Uses of flow duration curve
i) Used for comparison between streams
ii) Used for preliminary studies
iii) It evaluates low level flows.
iv) It helps in planning and design of water resource projects.
v) It helps in designing drainage systems and in flood control studies.

Disadvantages of flow duration curve
i) It does not present the flows in natural sequence of occurrence
ii) The curve will not give any idea whether the lowest flows occurred in consecutive periods or were scattered throughout the considered period.

2.17 Mass curve
In a hydrostation, the capacity of the reservoir is computed by using a plot known as "mass curve". This plot gives the storage requirement that is needed to produce a certain dependable flow from fluctuating discharge of a river by a reservoir. A mass curve is defined as a graph of cumulative volumes of water that can be stored from streamflow against time in days, weeks, or months. The integral curve of the hydrograph leads to mass curve and this expresses the area under hydrograph from one time to another. In the mass curve at any point, the curve slope represents the change of volume per change of time or the flow rate at that moment. Hence, when the flow of the river is large, the curve is steep and when the flow is small, it gives a flat curve. By storage for the same mass flow, the plant generating capacity can be increased by modifying the waterflow as per plant requirements.

Advantages
1. The peak load capacity of the plant is increased at comparatively low capital cost.
2. The operating efficiency is high
3. The plant is partly independent of streamflow conditions.
4. The plant load factor is improved.
5. Load on the hydroelectric plant remains uniform.
6. There is an overall gain in the pumped storage plant as the energy available during peak load duration is higher than that of during off-peak load duration.

2.18 Surge tanks
A surge tank is an additional storage reservoir fitted to the penstock, as near as possible to the turbine. Usually surge tanks are provided in high head or medium head plants where there is a considerable distance between the water source and turbine, necessitating a long penstock. It reduces the distance between free water surface and turbine and hence reduces the effect of waterhammer on penstock of turbine. Therefore the surge tank furnishes the following functions.
1) It stores the water during load rejection by the turbine and provides additional water during additional load on the turbine.
2) During sudden changes in the conditions of water flow, it relieves the waterhammer pressures within the penstock. Thus it regulates the water flow to relieve water hammer pressures and to improve the performance of the machines by providing better speed regulation.
3) It reduces the distance between free water surface of the reservoir and turbine and hence reduces the effect of waterhammer.

During governor of the turbine, when load on turbine decreases, the governor closure gates of the turbine partly to adjust water flow rate in order to maintain constant speed of the runner. Under this condition, water moving to the turbine has to move backward and is stored in the surge tank. In absence of surge tank, this backward movement of water may result in sudden pressure rise in the penstock resulting in water hammer phenomenon. The strength of the penstock may burst.

**Waterhammer:** It is defined as the change in pressure rapidly above or below normal pressure caused by sudden changes in the rate of water flow through the pipe according to demand of turbine. It occurs at all the points in the penstock between forebay or surge tank and turbines. During turbine governor, the gates (valves) supplying water to the turbines are suddenly closed when the load on turbine decreases. This sudden retardation of the flow in the penstock results in sudden pressure rise. Its fluctuations in the penstock during reduction of load on turbine is known as water hammer. When the load on the turbine...
increases, it needs more water and hence turbine gates suddenly open causing a rush of water through pipe. This creates a vacuum in the pipe carrying water.

**Types of surge tanks:** At the top, the surge tanks may be opened or closed. In case of open type, it should be lower than the level of water in the reservoir. The various types of surge tanks are

(a) **Simple surge tank:** A simple surge tank is a plain cylindrical tank connected by a vertical branch of pipe to the penstock. In this type, if overflow is allowed, it eliminates the loss of pressure in the pipe, but overflow surge tanks are uneconomical. Surge tanks are built in large size, so that even during full load conditions on the turbine, water cannot overflow. Usually, surge tanks are located on ground surface, above the penstock line. This type of tank is more expensive and uneconomical due to its large size and hence rarely used when compared to other types. The effective water surface inclined at an angle 8' to the horizontal. This reduces size of the tank required. In case of inclined surge tanks, height of surge tank can be reduced for the same diameter or diameter of the tank can be reduced for the same height. But this type is more costlier than other types due to difficulty in construction and is also rarely used unless the topographical conditions are in favour.

(c) **Expansion chamber and gallery type surge tank**

Expansion timber lower gallery - Expansion chamber surge tank

This type of tank consists of an expansion tank at the top and expansion at the bottom to limit the extreme surges. The expansion chamber absorbs rising surges, and lower gallery reserve the water for starting the turbine or to meet increasing load on the turbine. The upper one must be above the maximum reservoir level and lower one must be below the lowest steady running level in the surge tank.

(d) **Restricted orifice or throttled surge tanks**

The simple surge tanks are not suitable for medium and large head plants. Therefore, some modifications are incorporated in the restricted orifice surge tank.

In this type, a restricted orifice is provided between the conduit and the tank. A considerable amount of friction loss is created when the water flows in and out of the tank through the orifice.

During low load conditions of the turbine, the surplus water passes through the restricted orifice and immediately a retarding head, equal to the loss due to restricted orifice, is built up in
the conduit. The size of the restricted head can be designed for any desired retarding and accelerating heads. If the area of restricted orifice is equal to or greater than conduit area, the tank is said to be a simple tank and retarding head is negligible. If an infinitely small restricted orifice is used, then the retarding head becomes equal to the water hammer in the conduit without. The size of the restricted orifice selected in such a way that the initial retarding head is equal to the rise of water surface in the tank during rejection of full load by the turbine. This type is more efficient and economical than simple tank, but the main disadvantage is that the considerable portion of water hammer pressure is directly transmitted to the low pressure conduit and also induces sudden fluctuations of head on the turbine.

(e) Differential surge tank

This type of surge tank is the compromise between simple and restricted orifice surge tank. In this type, an internal riser whose area equal to that of conduit is provided in the cylindrical chamber. An outer chamber connects the riser at its base through ports. When the load changes, the water level in the riser also changes rapidly and produces sudden deceleration or acceleration of the conduit flow. In the outer chamber, water level moves more slowly and thus lags behind that in the riser. In differential surge tank, even though the action is very rapid, it gives reasonably low pressure rises and surges of low amplitude.

2.19 Gates

i) Vertical lift gate: cross section of vertical lift gate. On the crest of the dam, vertical guides on piers provides path for sliding motion of steel gates. These steel gates are used for small power plants. The gate lifting mechanism must be able to overcome high frictional losses developed in the guides due to high hydrostatic force on the gate. A gate of 5m² area weighs 150 tonnes and has to withstand 2000 tonnes of water load.

ii) Radial gate: cross section of a radial or tainter gate. A steel framework supports the gate which is in the form of a segment of a cylinder as shown in figure. The frame is pivoted on trunnions. The gate is also attached with hoisting cables and other end of cables are attached to the winches on the platform above the gate. A motor drives the winches for the sliding gate and for the same size of sliding gates, the hoist load is also much less.
iii) **Rolling gate**: cross section of rolling gate. It consists of cylindrical drum made of steel. The lower portion of gate is a cylindrical segment and touches ~ spill way crest. The rolling cylinder rolls on the rack provided, with the help of hoist cable. These are preferred for long spans and moderate height.

iv) **Drum gate**: The figure 4.17(d) shows cross section of drum gate. It is also suitable for long spans. The gate is a segment of a cylinder which can fit in the recess provided in the top of the spillway. When water enters under force to the recess, the hollow drum gate raises up to the closed position. The lower edge of the flap is edged to the upstream part of the dam and the upper edge position by chains or screwed rodssupported by an overhead bridge. The flood water is passed over crest of the size openings.

### 2.20 Advantages and disadvantages of hydro electric plants

**Advantages**

1. The operating cost including auxiliaries is considerably low (Rs 120 per KW at 1001 load factor).
2. Maintenance and running cost of the plant is low.
3. No nuisance of smoke, exhaust gases, soot etc., and hence the atmosphere is not polluted.
4. No ash disposal problem.
5. In addition to electric power generation, plants are also used for irrigation and flood control.
6. These plants are more economical than other type of plants as it involves no fuel charges.
7. The plant life is more and plant efficiency does not change with age of plant.
8. No fuel transportation problem.
9. There are no stand by losses.
10. The plants are located away from developed areas, and hence the cost of land is not a major problem.
11. The plant requires less skilled operators.
12. These plants can meet sudden changes of load without loss of efficiency.
Disadvantages
1. The initial cost of the plant is high, as it includes construction of a dam.
2. The power generation depends only on the quantity of water available which in turn depends upon rainfall.
3. These plants are usually located away from the load centres and use long transmission lines. Therefore, the cost of transmission lines and losses in them are more.
4. Plant erection time is more.

2.21 Question bank
1. What are the applications of Diesel power plant?
2. What are the advantages and disadvantages of air cooling system?
3. For a diesel power station briefly describe the Lubrication system.
4. Draw the general schematic of Diesel power plant.
5. Why cooling of diesel engine is necessary?
6. Sketch and briefly explain the working of Exhaust System.
7. Give any four important applications of Lubrication System.
8. List six advantages and Disadvantages of Diesel power plant.
9. Draw the general layout of Diesel power plant and explain the working of different systems.
10. With the help of a neat diagram explain (i) thermostat cooling and (ii) thermosyphon cooling.
11. State the important factors considered while selecting a site for hydro-electric power plant.
12. Draw a neat flow sheet diagram of a hydro electric power plant indicating the essential elements.
13. At a particular site the mean discharge of a river (in millions of m$^3$) in 12 months from January to December are 30, 25, 20, 0, 10, 50, 80, 100, 110, 65, 45 and 30 respectively. Draw the flow duration curve on a graph sheet. Also estimate the power developed in MW if the available head is 90m and the overall efficiency of generation is 87.4%. Assume each month of 30 days.
14. Define hydrograph and unit hydrograph and explain its importance in the design of storage in the hydro electric power plant.
15. Explain the working of hydro electric power plant with the help of a neat sketch.
16. With the help of a neat sketch explain pumped storage plant.
2.22 Outcomes:

Student should be able to understand the

1. Main Components and working of diesel engine power plant.
2. Basic concepts, working and applications of hydro electric power plant

2.23 Further reading: