EEC560 Electric Power Plants
Lec. 3

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Diesel Power Station

- *A generating station in which diesel engine is used as the prime mover for the generation of electrical energy is known as* **diesel power station.**

- The diesel burns inside the engine and the products of this combustion act as the "working fluid" to produce mechanical energy.

- The diesel engine drives the alternator which converts mechanical energy into electrical energy. As the generation cost is considerable due to high price of diesel, therefore, such power stations are only used to produce small power.

- Although steam power stations and hydro-electric plants are invariably used to generate bulk power at cheaper cost, yet diesel power stations are finding favor at places where demand of power is less, sufficient quantity of coal and water is not available and the transportation facilities are inadequate.

- These plants are also used as standby sets for continuity of supply to important points such as hospitals, radio stations, cinema houses and telephone exchanges.

Advantages

(i) The design and layout of the plant are quite simple.
(ii) It occupies less space as the number and size of the auxiliaries is small.
(iii) It can be located at any place.
(iv) It can be started quickly and can pick up load in a short time.
(v) There are no standby losses.
(vi) It requires less quantity of water for cooling.
(vii) The thermal efficiency of the plant is higher than that of a steam power station.
(viii) It requires less operating staff.

Disadvantages

(i) The plant has high running charges as the fuel (*i.e.*, diesel) used is costly.
(ii) The plant does not work satisfactorily under overload conditions for a longer period.
(iii) The plant can only generate small power.
(iv) The cost of lubrication is generally high.
(v) The maintenance charges are generally high.

Schematic Arrangement of Diesel Power Station

Apart from the diesel generator set, the plant has the following auxiliaries :

(*i*) *Fuel supply system.* It consists of storage tank, strainers, fuel transfer pump and all day fuel tank.

(*ii*) *Air intake system.* This system supplies necessary air to the engine for fuel combustion.

(*iii*) *Exhaust system.* This system leads the engine exhaust gas outside the building and discharges it into atmosphere. A silencer is usually incorporated in the system to reduce the noise level.

(*iv*) *Cooling system.* The heat released by the burning of fuel in the engine cylinder is partially converted into work. The remainder part of the heat passes through the cylinder walls, piston, rings etc. and may cause damage to the system. In order to keep the temperature of the engine parts within the safe operating limits, cooling is provided. The cooling system consists of a water source, pump and cooling towers.

(*v*) *Lubricating system.* This system minimizes the wear of rubbing surfaces of the engine. It comprises of lubricating oil tank, pump, filter and oil cooler. The clean lubricating oil is delivered to the points which require lubrication. The oil coolers incorporated in the system keep the temperature of the oil low.

(*vi*) *Engine starting system.* This is an arrangement to rotate the engine initially, while starting, until firing starts and the unit runs with its own power. Small sets are started manually by handles but for larger units, compressed air is used for starting.

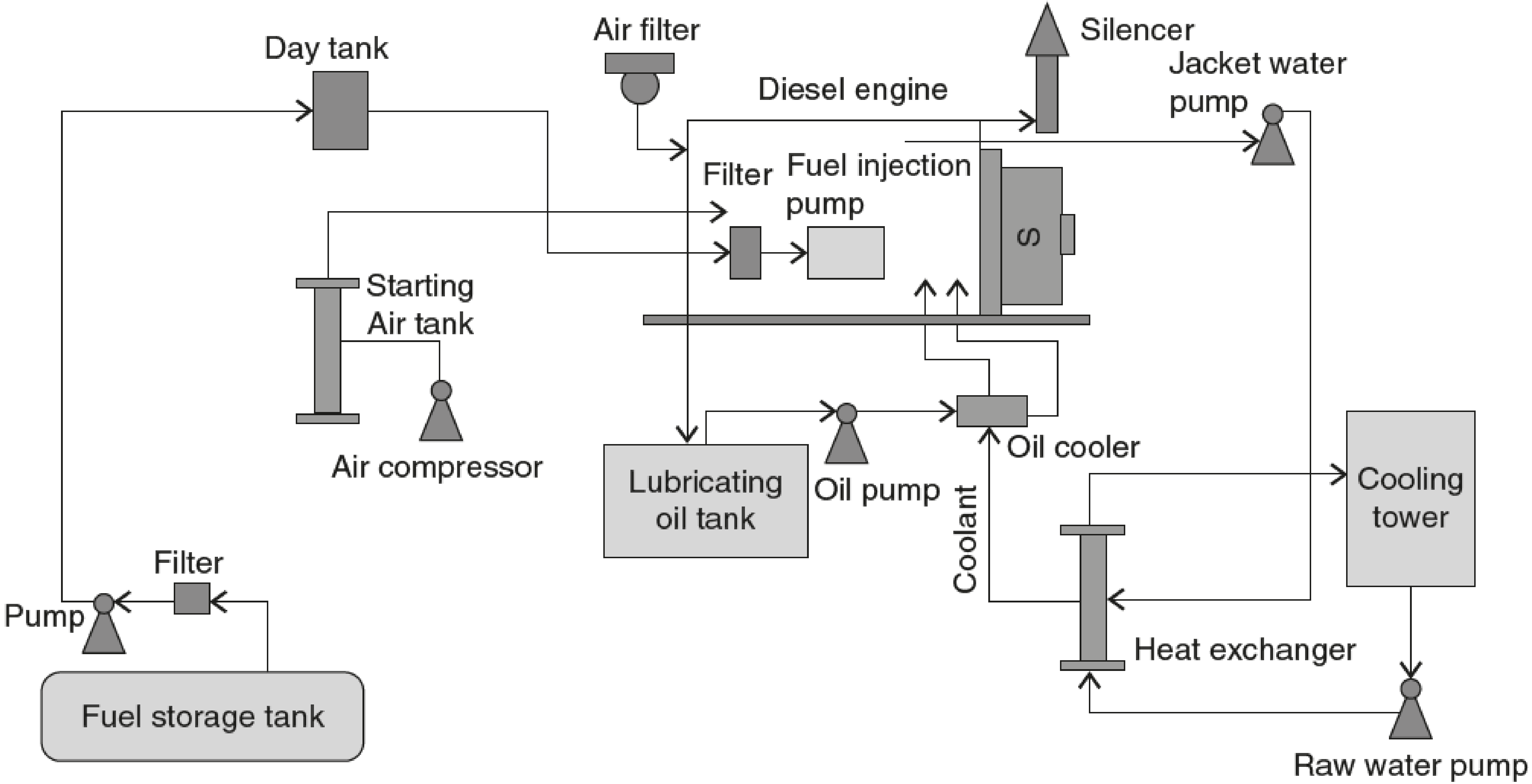


Fig. 13.6 *General Layout of DG Plant*

Example 2.14. *A diesel power station has fuel consumption of 0·28 kg per kWh, the calorific value of fuel being 10,000 kcal/kg. Determine (i) the overall efficiency, and (ii) efficiency of the engine if alternator efficiency is 95%.*

Solution.

$$\text{Heat produced by } 0{\cdot}28 \text{ kg of oil} = 10{,}000 \times 0{\cdot}28 = 2800 \text{ kcal}$$

$$\text{Heat equivalent of 1 kWh} = 860 \text{ kcal}$$

(*i*) $$\text{Overall efficiency} = \frac{\text{Electrical output in heat units}}{\text{Heat of combustion}} = 860/2800 = 0{\cdot}307 = \mathbf{30{\cdot}7\%}$$

(*ii*) $$\text{Engine efficiency} = \frac{\text{Overall efficiency}}{\text{Alternator efficiency}} = \frac{30 \cdot 7}{0 \cdot 95} = \mathbf{32{\cdot}3\%}$$

Example 2.15. *A diesel power station has the following data :*

Fuel consumption/day	= *1000 kg*
Units generated/day	= *4000 kWh*
Calorific value of fuel	= *10,000 kcal/kg*
Alternator efficiency	= *96%*
Engine mech. efficiency	= *95%*

Estimate (i) specific fuel consumption, (ii) overall efficiency, and (iii) thermal efficiency of engine.

Solution.

(*i*) Specific fuel consumption = 1000/4000 = **0·25 kg/kWh**

(*ii*) Heat produced by fuel per day

= Coal consumption/day × calorific value

= $1000 \times 10{,}000 = 10^7$ kcal

Electrical output in heat units per day

= $4000 \times 860 = 344 \times 10^4$ kcal

$$\text{Overall efficiency} = \frac{344 \times 10^4}{10^7} \times 100 = \mathbf{34{\cdot}4\%}$$

(*iii*) $$\text{Engine efficiency, } \eta_{engine} = \frac{\eta_{overall}}{\eta_{alt.}} = \frac{34 \cdot 4}{0 \cdot 96} = 35{\cdot}83\%$$

$$\text{Thermal efficiency, } \eta_{ther} = \frac{\eta_{engine}}{\text{Mech. } \eta \text{ of engine}} = \frac{35 \cdot 83}{0 \cdot 95} = \mathbf{37{\cdot}71\%}$$

Example 2.16. *A diesel engine power plant has one 700 kW and two 500 kW generating units. The fuel consumption is 0·28 kg per kWh and the calorific value of fuel oil is 10200 kcal/kg. Estimate (i) the fuel oil required for a month of 30 days and (ii) overall efficiency. Plant capacity factor = 40%.*

Solution.

(*i*) Maximum energy that can be produced in a month

$$= \text{Plant capacity} \times \text{Hours in a month}$$

$$= (700 + 2 \times 500) \times (30 \times 24) = 1700 \times 720 \text{ kWh}$$

$$\text{Plant capacity factor} = \frac{\text{Actual energy produced}}{\text{Max. energy that could have been produced}}$$

or

$$0{\cdot}4 = \frac{\text{Actual energy produced}}{1700 \times 720}$$

$\therefore$ Actual energy produced in a month

$$= 0{\cdot}4 \times 1700 \times 720 = 489600 \text{ kWh}$$

Fuel oil consumption in a month

$$= 489600 \times 0{\cdot}28 = \mathbf{137088 \text{ kg}}$$

(*ii*)

$$\text{Output} = 489600 \text{ kWh} = 489600 \times 860 \text{ kcal}$$

$$\text{Input} = 137088 \times 10200 \text{ kcal}$$

$$\therefore \quad \text{Overall efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{489600 \times 860}{137088 \times 10200} = \mathbf{0{\cdot}3 \text{ or } 30\%}$$

Nuclear Power Station

A generating station in which nuclear energy is converted into electrical energy is known as a **nuclear power station.**

- In nuclear power station, heavy elements such as Uranium (U235) or Thorium (Th232) are subjected to nuclear fission in a special apparatus known as a *reactor.*
- The heat energy thus released is utilized in raising steam at high temperature and pressure. The steam runs the steam turbine which converts steam energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy.
- The most important feature of a nuclear power station is that huge amount of electrical energy can be produced from a relatively small amount of nuclear fuel as compared to other conventional types of power stations.
- It has been found that complete fission of 1 kg of Uranium (U235) can produce as much energy as can be produced by the burning of 4,500 tons of high grade coal.
- Although the recovery of principal nuclear fuels (*i.e.*, Uranium and Thorium) is difficult and expensive, yet the total energy content of the estimated world reserves of these fuels are considerably higher than those of conventional fuels, *viz.*, coal, oil and gas.

Advantages

(*i*) The amount of fuel required is quite small. Therefore, there is a considerable saving in the cost of fuel transportation.

(*ii*) A nuclear power plant requires less space as compared to any other type of the same size.

(*iii*) It has low running charges as a small amount of fuel is used for producing bulk electrical energy.

(*iv*) This type of plant is very economical for producing bulk electric power.

(*v*) It can be located near the load centers because it does not require large quantities of water and need not be near coal mines. Therefore, the cost of primary distribution is reduced.

(*vi*) There are large deposits of nuclear fuels available all over the world. Therefore, such plants can ensure continued supply of electrical energy for thousands of years.

(*vii*) It ensures reliability of operation.

Disadvantages

(*i*) The fuel used is expensive and is difficult to recover.
(*ii*) The capital cost on a nuclear plant is very high as compared to other types of plants.
(*iii*) The construction and commissioning of the plant requires greater technical know-how.
(*iv*) The fission by-products are generally radioactive and may cause a dangerous amount of radioactive pollution.
(*v*) Maintenance charges are high due to lack of standardization. Moreover, high salaries of specially trained personnel employed to handle the plant further raise the cost.
(*vi*) Nuclear power plants are not well suited for varying loads as the reactor does not respond to the load fluctuations efficiently.
(*vii*) The disposal of the by-products, which are radioactive, is a big problem. They have either to be disposed off in a deep trench or in a sea away from sea-shore.

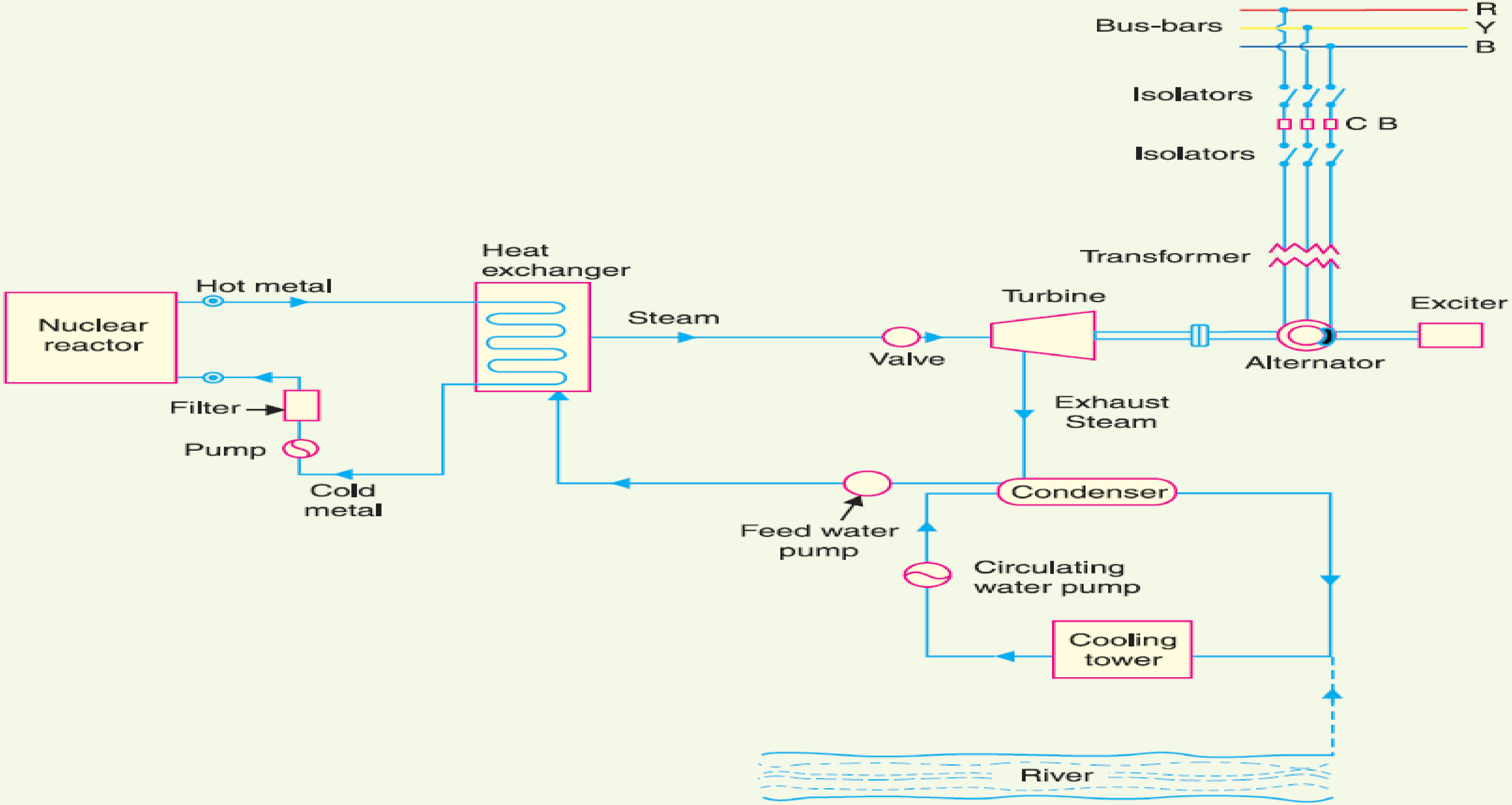
Schematic Arrangement of Nuclear Power Station

The schematic arrangement of a nuclear power station is shown in Fig. 2.7. The whole arrangement can be divided into the following main stages :
(*i*) Nuclear reactor (*ii*) Heat exchanger (*iii*) Steam turbine (*iv*) Alternator.

(*i*) Nuclear reactor. It is an apparatus in which nuclear fuel (U235) is subjected to nuclear fission. It controls the *chain reaction* that starts once the fission is done. If the chain reaction is not controlled, the result will be an explosion due to the fast increase in the energy released.

(*ii*) Heat exchanger. The coolant gives up heat to the heat exchanger which is utilized in raising the steam. After giving up heat, the coolant is again fed to the reactor.

(*iii*) Steam turbine. The steam produced in the heat exchanger is led to the steam turbine through a valve. After doing a useful work in the turbine, the steam is exhausted to condenser. The condenser condenses the steam which is fed to the heat exchanger through feed water pump.
(*iv*) Alternator. The steam turbine drives the alternator which converts mechanical energy into electrical energy. The output from the alternator is delivered to the bus-bars through transformer, circuit breakers and isolators.



Schematic arrangement of Nuclear Power Station

Fig. 2.7

Selection of Site for Nuclear Power Station

The following points should be kept in view while selecting the site for a nuclear power station :

(*i*) *Availability of water.* As sufficient water is required for cooling purposes, therefore, the plant site should be located where ample quantity of water is available, *e.g.*, across a river or by sea-side.

(*ii*) *Disposal of waste.* The waste produced by fission in a nuclear power station is generally radioactive which must be disposed off properly to avoid health hazards. The waste should either be buried in a deep trench or disposed off in sea quite away from the sea shore.

(*iii*) *Distance from populated areas.* The site selected for a nuclear power station should be quite away from the populated areas as there is a danger of presence of radioactivity in the atmosphere near the plant. However, as a precautionary measure, *a dome* is used in the plant which does not allow the radioactivity to spread by wind or underground waterways.

(*iv*) *Transportation facilities.* The site selected for a nuclear power station should have adequate facilities in order to transport the heavy equipment during erection and to facilitate the movement of the workers employed in the plant.

Nuclear Power Station

Example 2.17. *An atomic power reactor can deliver 300 MW. If due to fission of each atom of* $_{92}U^{235}$ *, the energy released is 200 MeV, calculate the mass of uranium fissioned per hour.*

Solution.

Energy received from the reactor

$$= 300 \text{ MW} = 3 \times 10^8 \text{ W (or Js}^{-1})$$

$$\text{Energy received/hour} = (3 \times 10^8) \times 3600 = 108 \times 10^{10} \text{ J}$$

$$\text{Energy released/fission} = 200 \text{ MeV} = 200 \times 10^6 \times 1{\cdot}6 \times 10^{-19} \text{ J} = 3{\cdot}2 \times 10^{-11}\text{J}$$

Number of atoms fissioned per hour

$$= \frac{108 \times 10^{10}}{3 \cdot 2 \times 10^{-11}} = 33{\cdot}75 \times 10^{21}$$

Now 1 gram-atom (*i.e.*, 235g) has $6{\cdot}023 \times 10^{23}$ atoms.

∴ Mass of Uranium fissioned per hour

$$= \frac{235}{6 \cdot 023 \times 10^{23}} \times 33{\cdot}75 \times 10^{21} = \mathbf{13{\cdot}17g}$$

Gas Turbine Power Plant

- *A generating station which employs gas turbine as the prime mover for the generation of electrical energy is known as a* **gas turbine power plant**

- In a gas turbine power plant, air is used as the working fluid. The air is compressed by the compressor and is led to the combustion chamber where heat is added to air, thus raising its temperature.

- Heat is added to the compressed air either by burning fuel in the chamber or by the use of air heaters. The hot and high pressure air from the combustion chamber is then passed to the gas turbine where it expands and does the mechanical work. The gas turbine drives the alternator which converts mechanical energy into electrical energy.

- It may be mentioned here that compressor, gas turbine and the alternator are mounted on the same shaft so that a part of mechanical power of the turbine can be utilized for the operation of the compressor. Gas turbine power plants are being used as standby plants for hydro-electric stations, as a starting plant for driving auxiliaries in power plants etc.

Advantages

(*i*) It is simple in design as compared to steam power station since no boilers and their auxiliaries are required.

(*ii*) It is much smaller in size as compared to steam power station of the same capacity. This is expected since gas turbine power plant does not require boiler, feed water arrangement etc.

(*iii*) The initial and operating costs are much lower than that of equivalent steam power station.

(*iv*) It requires comparatively less water as no condenser is used.

(*v*) The maintenance charges are quite small.

(*vi*) Gas turbines are much simpler in construction and operation than steam turbines.

(*vii*) It can be started quickly form cold conditions.

(*viii*) There are no standby losses. However, in a steam power station, these losses occur because boiler is kept in operation even when the steam turbine is supplying no load.

Disadvantages

(*i*) There is a problem for starting the unit. It is because before starting the turbine, the compressor has to be operated for which power is required from some external source. However, once the unit starts, the external power is not needed as the turbine itself supplies the necessary power to the compressor.

(*ii*) Since a greater part of power developed by the turbine is used in driving the compressor, the net output is low.

(*iii*) The overall efficiency of such plants is low (about 20%) because the exhaust gases from the turbine contain sufficient heat.

(*iv*) The temperature of combustion chamber is quite high (3000^{o}F) so that its life is comparatively reduced.

Schematic Arrangement of Gas Turbine Power Plant

The schematic arrangement of a gas turbine power plant is shown in Fig. 2.9.

The main components of the plant are : (*i*) Compressor (*ii*) Regenerator (*iii*) Combustion chamber (*iv*) Gas turbine (*v*) Alternator (*vi*) Starting motor

(*i*) Compressor. The compressor used in the plant is generally of rotatory type. The air at atmospheric pressure is drawn by the compressor *via* the filter which removes the dust from air. The rotatory blades of the compressor push the air between stationary blades to raise its pressure. Thus air at high pressure is available at the output of the compressor.

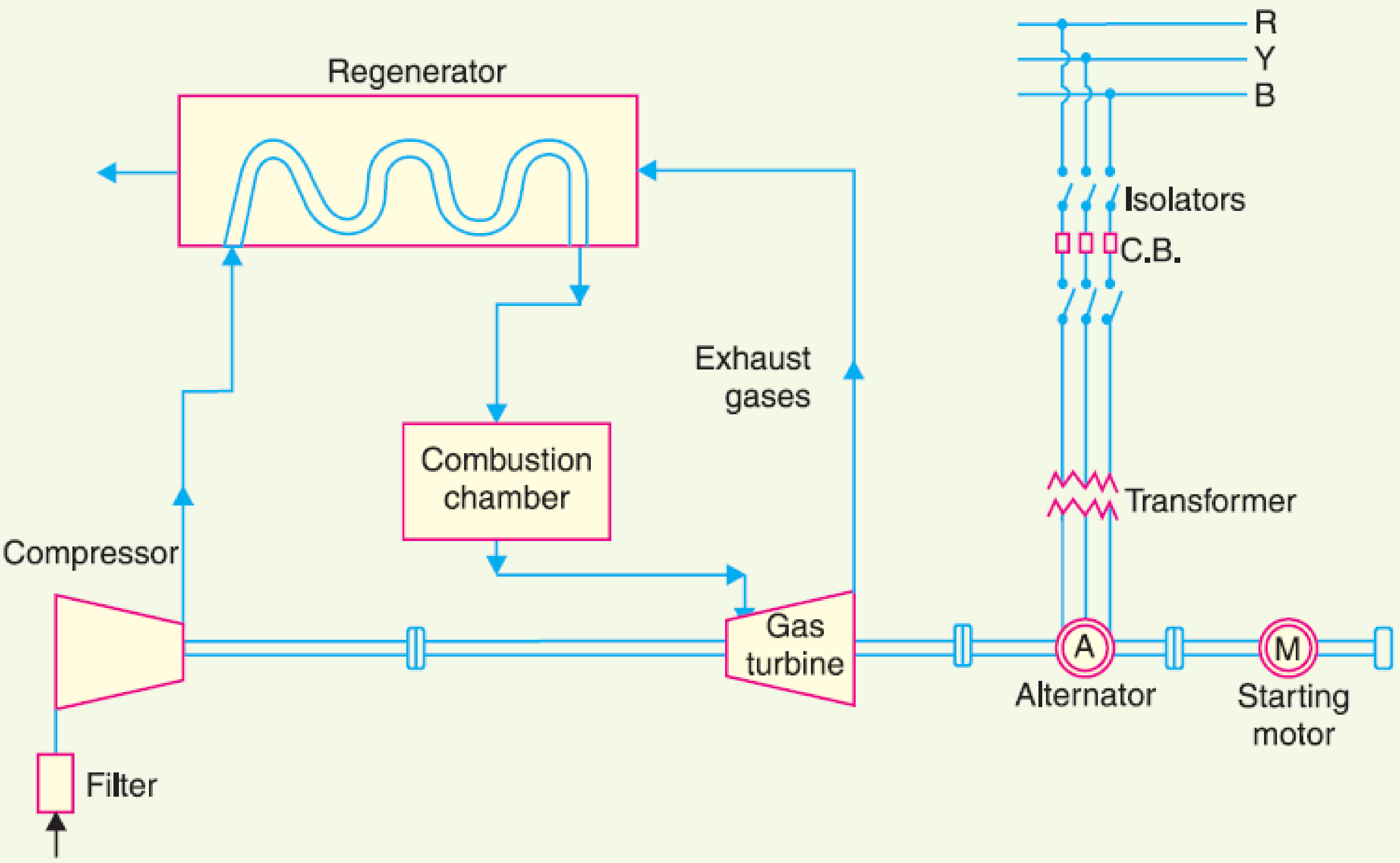
(*ii*) Regenerator. A regenerator is a device which recovers heat from the exhaust gases of the turbine. The exhaust is passed through the regenerator before wasting to atmosphere. The compressed air from the compressor passes through the tubes on its way to the combustion chamber. In this way, compressed air is heated by the hot exhaust gases.

(*iii*) Combustion chamber. The air at high pressure from the compressor is led to the combustion chamber *via* the regenerator. In the combustion chamber, heat is added to the air by burning oil. The oil is injected through the burner into the chamber at high pressure to ensure atomization of oil and its thorough mixing with air. The result is that the chamber attains a very high temperature (about 3000°F). The combustion gases are suitably cooled to 1300°F to 1500°F and then delivered to the gas turbine.

(*iv*) Gas turbine. The products of combustion consisting of a mixture of gases at high temperature and pressure are passed to the gas turbine. These gases in passing over the turbine blades expand and thus do the mechanical work. The temperature of the exhaust gases from the turbine is about 900°F.

(*v*) Alternator. The gas turbine is coupled to the alternator. The alternator converts mechanical energy of the turbine into electrical energy. The output from the alternator is given to the bus-bars through transformer, circuit breakers and isolators.

(*vi*) Starting motor. Before starting the turbine, compressor has to be started. For this purpose, an electric motor is mounted on the same shaft as that of the turbine. The motor is energized by the batteries. Once the unit starts, a part of mechanical power of the turbine drives the compressor and there is no need of motor now.



Schematic arrangement of gas turbine power plant.

2.18 Comparison of the Various Power Plants

The comparison of steam power plant, hydro-electric plant, diesel power plant and nuclear power plant is given below in the tabular form :

S.No.	Item	Steam Power Station	Hydro-electric Power Plant	Diesel Power Plant	Nuclear power Plant
1.	*Site*	Such plants are located at a place where ample supply of water and coal is available, transportation facilities are adequate	Such plants are located where large reservoirs can be obtained by constructing a dam *e.g.* in hilly areas.	Such plants can be located at any place because they require less space and small quantity of water.	These plants are located away from thickly populated areas to avoid radioactive pollution.
2.	*Initial cost*	Initial cost is lower than those of hydroelectric and nuclear power plants.	Initial cost is very high because of dam construction and excavation work.	Initial cost is less as compared to other plants.	Initial cost is highest because of huge investement on building a nuclear reactor.
3.	*Running cost*	Higher than hydroelectric and nuclear plant because of the requirement of huge amount of coal.	Practically nil because no fuel is required.	Highest among all plants because of high price of diesel.	Except the hydroelectric plant, it has the minimum running cost because small amount of fuel can produce relatively large amount of power.
4.	*Limit of source of power*	Coal is the source of power which has limited reserves all over the world.	Water is the source of power which is not dependable becuase of wide variations in the rainfall every year.	Diesel is the source of power which is not available in huge quantities due to limited reserves.	The source of power is the nuclear fuel which is available in sufficient quantity. It is because small amount of fuel can produce huge power.
5.	*Cost of fuel transportation*	Maximum because huge amount of coal is transported to the plant site.	Practically nil.	Higher than hydro and nuclear power plants	Minimum because small quantity of fuel is required.
6.	*Cleanliness and simplicity*	Least clean as atmosphere is polluted due to smoke.	Most simple and clean.	More clean than steam power and nuclear power plants.	Less cleaner than hydroelectric and diesel power plants.

S.No.	Item	Steam Power Station	Hydro-electric Power Plant	Diesel Power Plant	Nuclear power Plant
7.	*Overall efficiency*	Least efficient. Overall efficiency is about 25%.	Most efficient. Overall efficiency is about 85%.	More efficient than steam power station. Efficiency is about 35%.	More efficient than steam power station.
8.	*Starting*	Requires a lot of time for starting.	Can be started instantly.	Can be started quickly.	Can be started easily.
9.	*Space required*	These plants need sufficient space because of boilers and other auxiliaries.	Require very large area because of the reservoir.	Require less space.	These require minimum space as compared to any other plant of equivalent capacity.
10.	*Maintenance cost*	Quite high as skilled operating staff is required.	Quite low.	Less	Very high as highly trained personnel are required to handle the plant.
11.	*Transmission and distribution cost*	Quite low as these are generally located near the load centres.	Quite high as these are located quite away from the load centres.	Least as they are generally located at the centre of gravity of the load.	Quite low as these are located near load centres.
12.	*Standby losses*	Maximum as the boiler remains in operation even when the turbine is not working.	No standby losses.	Less standby losses.	Less.