EEC560 Electric Power Plants
Lec. 2

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Hydro-electric Power Station

- *A generating station which utilizes the potential energy of water at a high level for the generation of electrical energy is known as a* **hydro-electric power station.**

- Hydro-electric power stations are generally located in hilly areas where dams can be built conveniently and large water reservoirs can be obtained.

- In a hydro-electric power station, water head is created by constructing a dam across a river or lake. From the dam, water is led to a water turbine.

- The water turbine captures the energy in the falling water and changes the hydraulic energy (*i.e.*, product of head and flow of water) into mechanical energy at the turbine shaft. The turbine drives the alternator which converts mechanical energy into electrical energy.

- Hydro-electric power stations are becoming very popular because the reserves of fuels (*i.e.*, coal and oil) are depleting day by day. They have the added importance for flood control, storage of water for irrigation and water for drinking purposes.

Advantages

(*i*) It requires no fuel as water is used for the generation of electrical energy.

(*ii*) It is quite neat and clean as no smoke or ash is produced.

(*iii*) It requires very small running charges.

(*iv*) It is comparatively simple in construction and requires less maintenance.

(*v*) It does not require a long starting time like a steam power station.

(*vi*) It is robust and has a longer life.

(*vii*) Such plants serve many purposes. In addition to the generation of electrical energy, they also help in irrigation and controlling floods.

(*viii*) Although such plants require the attention of highly skilled persons at the time of construction, yet for operation, a few experienced persons may do the job well.

Disadvantages

(*i*) It involves high capital cost due to construction of dam.

(*ii*) There is uncertainty about the availability of huge amount of water due to dependence on weather conditions.

(*iii*) Skilled and experienced hands are required to build the plant.

(*iv*) It requires high cost of transmission lines as the plant is located in hilly areas which are quite away from the consumers.

Schematic Arrangement of Hydro-electric Power Station

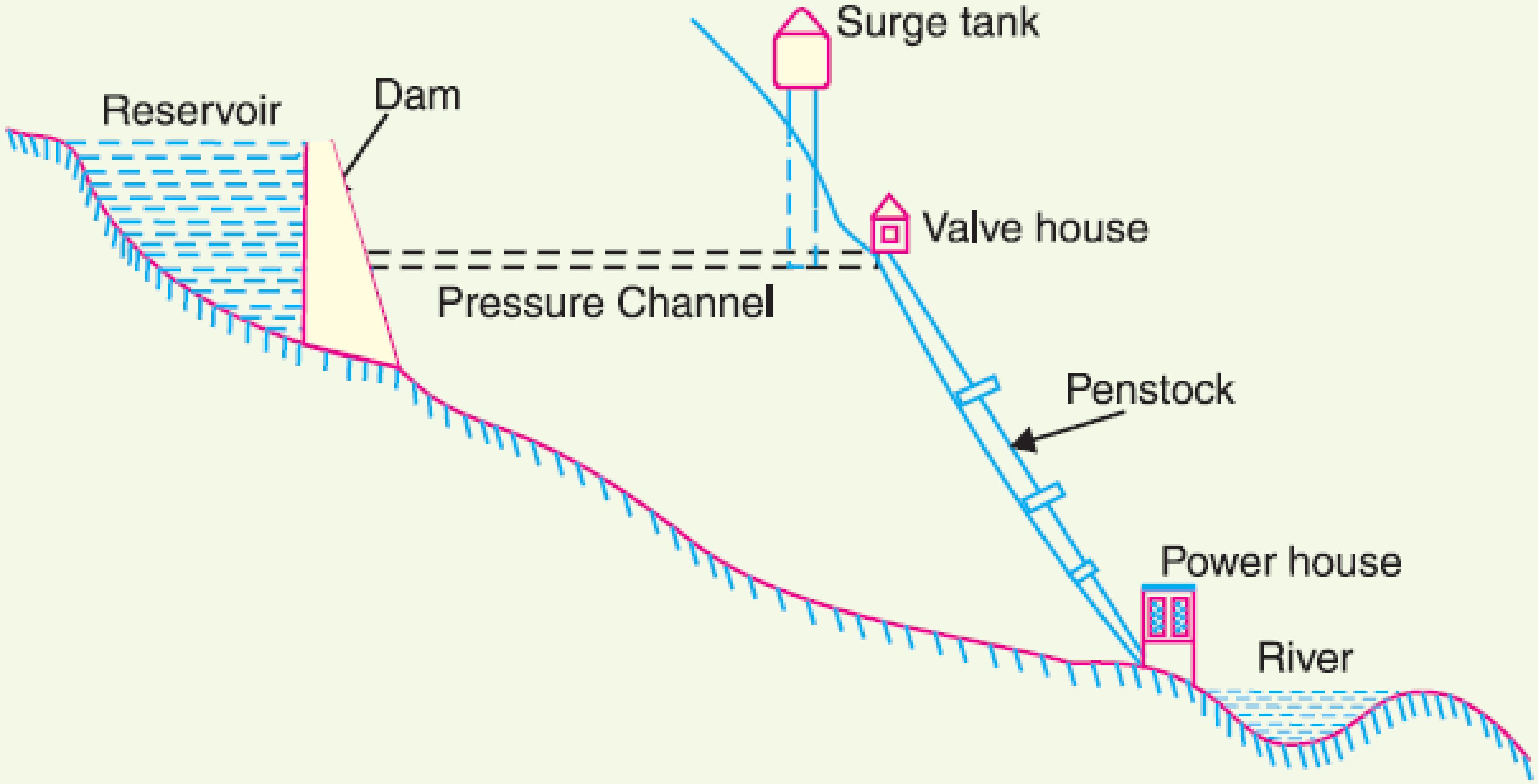
- The schematic arrangement of a modern hydro-electric plant is shown in Fig. 2.2.

- The dam is constructed across a river or lake and water from the catchment area collects at the back of the dam to form a reservoir.

- A pressure tunnel is taken off from the reservoir and water brought to the valve house at the start of the penstock.

- From the valve house, water is taken to water turbine through a huge steel pipe known as *penstock*. The water turbine converts hydraulic energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy.

- A surge tank (open from top) is built just before the valve house and protects the penstock from bursting in case the turbine gates suddenly close due to electrical load being thrown off.
- When the gates close, there is a sudden stopping of water at the lower end of the penstock and consequently the penstock can burst. The surge tank absorbs this pressure swing by increase in its level of water.



Schematic arrangement of a Hydro-electric plant

Fig. 2.2

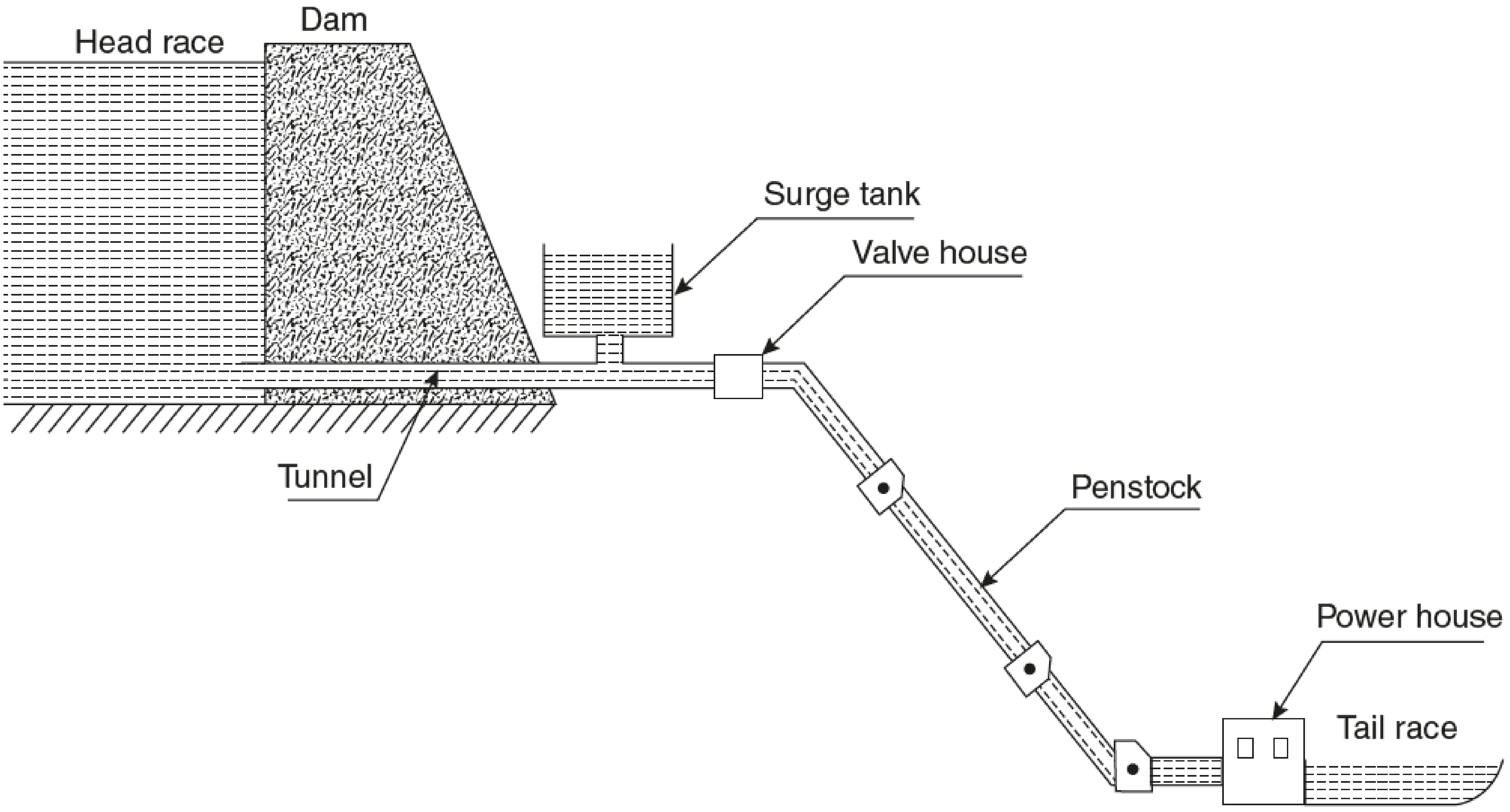


Fig. 1.2 *A Hydraulic Power Plant*

Choice of Site for Hydro-electric Power Stations

The following points should be taken into account while selecting the site for a hydro-electric power station :

(*i*) *Availability of water.* Since the primary requirement of a hydro-electric power station is the availability of huge quantity of water, such plants should be built at a place (*e.g.*, river, canal) where adequate water is available at a good head.

(*ii*) *Storage of water.* There are wide variations in water supply from a river or canal during the year. This makes it necessary to store water by constructing a dam in order to ensure the generation of power throughout the year. The storage helps in equalizing the flow of water so that any excess quantity of water at a certain period of the year can be made available during times of very low flow in the river.

(*iii*) *Cost and type of land.* The land for the construction of the plant should be available at a reasonable price. Further, the bearing capacity of the ground should be adequate to withstand the weight of heavy equipment to be installed.

(*iv*) *Transportation facilities.* The site selected for a hydro-electric plant should be accessible by rail and road so that necessary equipment and machinery could be easily transported.

It is clear from the above mentioned factors that ideal choice of site for such a plant is near a river in hilly areas where dam can be conveniently built and large reservoirs can be obtained.

Constituents of Hydro-electric Plant

The constituents of a hydro-electric plant are :

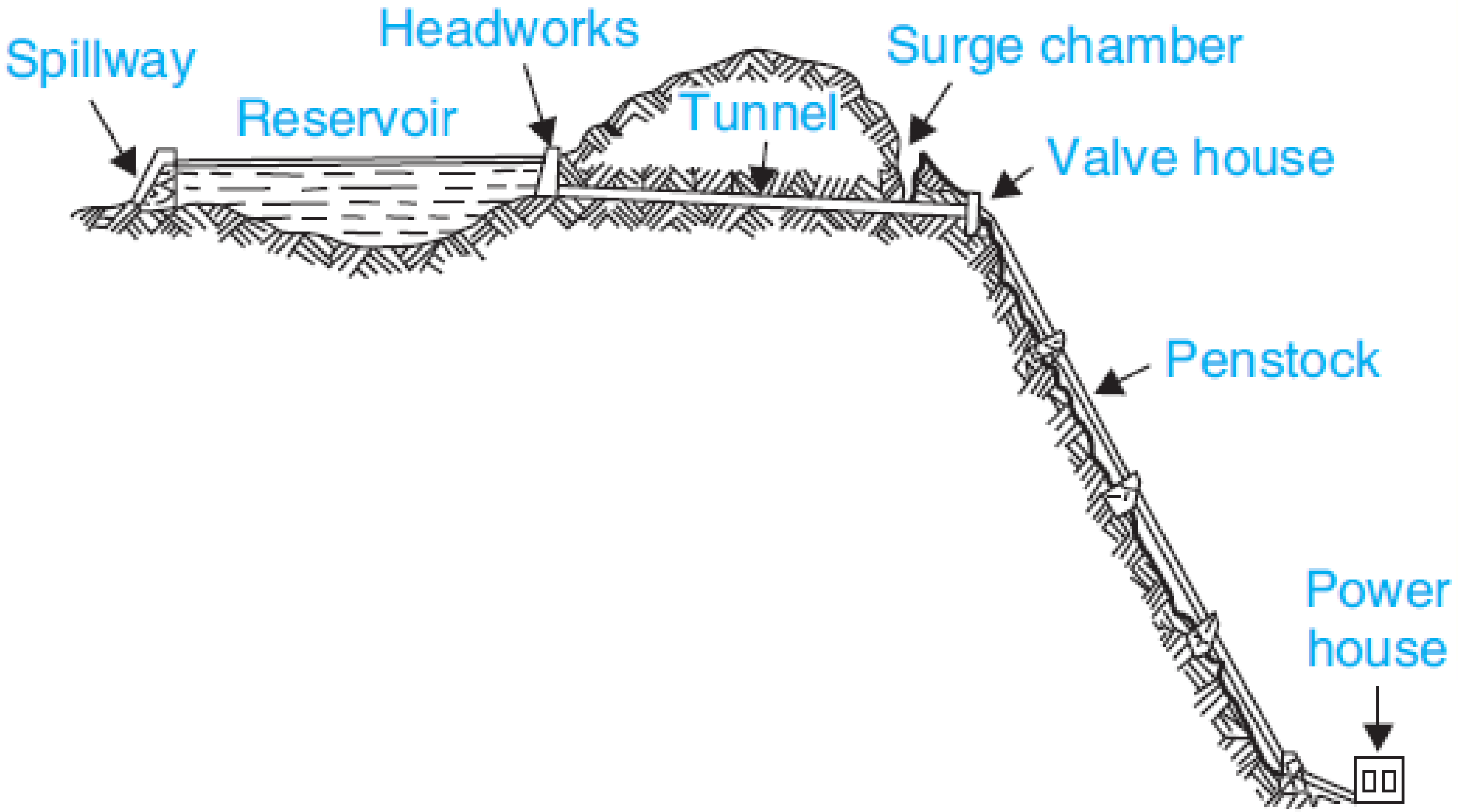
(1) hydraulic structures **(2)** water turbines and **(3)** electrical equipment.

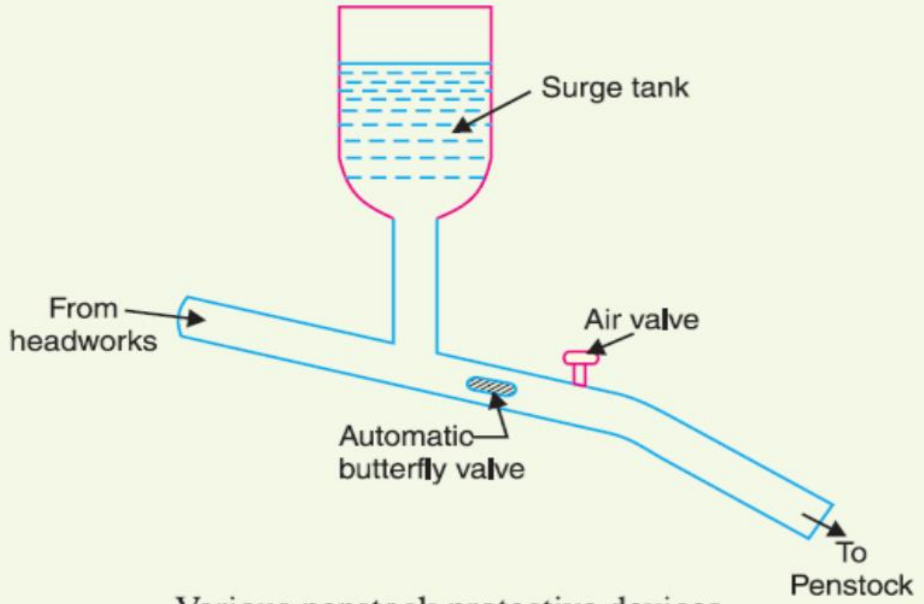
1. Hydraulic structures. Hydraulic structures in a hydro-electric power station include dam, spillways, headworks, surge tank, penstock and accessory works.

(i) Dam. A dam is a barrier which stores water and creates water head.

(ii) Spillways. There are times when the river flow exceeds the storage capacity of the reservoir. Such a situation arises during heavy rainfall in the catchment area. In order to discharge the surplus water from the storage reservoir into the river on the down-stream side of the dam, spillways are used.

(iii) Headworks. The headworks consists of the diversion structures at the head of an intake. The flow of water into and through headworks should be as smooth as possible to avoid head loss and cavitation. For this purpose, it is necessary to avoid sharp corners and abrupt contractions or enlargements.





Various penstock protective devices

Fig. 2.3

(*iv*) ***Surge tank.*** Open conduits leading water to the turbine require no protection. However, when closed conduits are used, protection becomes necessary to limit the abnormal pressure in the conduit. For this reason, closed conduits are always provided with a surge tank.

- A surge tank is a small reservoir or tank (open at the top) in which water level rises or falls to reduce the pressure swings in the conduit.
- A surge tank is located near the beginning of the conduit.
- When the turbine is running at a steady load, there are no surges in the flow of water through the conduit *i.e.*, the quantity of water flowing in the conduit is just sufficient to meet the turbine requirements.
- However, when the load on the turbine decreases, the governor closes the gates of turbine, reducing water supply to the turbine. The excess water at the lower end of the conduit rushes back to the surge tank and increases its water level. Thus the conduit is prevented from bursting.
- On the other hand, when load on the turbine increases, additional water is drawn from the surge tank to meet the increased load requirement. Hence, a surge tank overcomes the abnormal pressure in the conduit when load on the turbine falls and acts as a reservoir during increase of load on the turbine.

(*v*) *Penstocks.* Penstocks are open or closed conduits which carry water to the turbines.

- They are generally made of reinforced concrete or steel. Concrete penstocks are suitable for low heads (< 30 m) as greater pressure causes rapid deterioration of concrete. The steel penstocks can be designed for any head; the thickness of the penstock increases with the head or working pressure.

- Various devices such as automatic butterfly valve, air valve and surge tank (See Fig. 2.3) are provided for the protection of penstocks. Automatic butterfly valve shuts off water flow through the penstock promptly if it ruptures.

- Air valve maintains the air pressure inside the penstock equal to outside atmospheric pressure. When water runs out of a penstock faster than it enters, a vacuum is created which may cause the penstock to collapse. Under such situations, air valve opens and admits air in the penstock to maintain inside air pressure equal to the outside air pressure.

2. Water turbines. Water turbines are used to convert the energy of falling water into mechanical energy. The principal types of water turbines are : (*i*) Impulse turbines (*ii*) Reaction turbines

(*i*) *Impulse turbines.* Such turbines are used for high heads. In an impulse turbine, the entire pressure of water is converted into kinetic energy in a nozzle and the velocity of the jet drives the wheel. The example of this type of turbine is the Pelton wheel (See Fig. 2.4). It consists of a wheel fitted with elliptical buckets along its periphery. The force of water jet striking the buckets on the wheel drives the turbine. The quantity of water jet falling on the turbine is controlled by means of a *needle* or *spear* (not shown in the figure) placed in the tip of the nozzle. The movement of the needle is controlled by the governor. If the load on the turbine decreases, the governor pushes the needle into the nozzle, thereby reducing the quantity of water striking the buckets. Reverse action takes place if the load on the turbine increases.

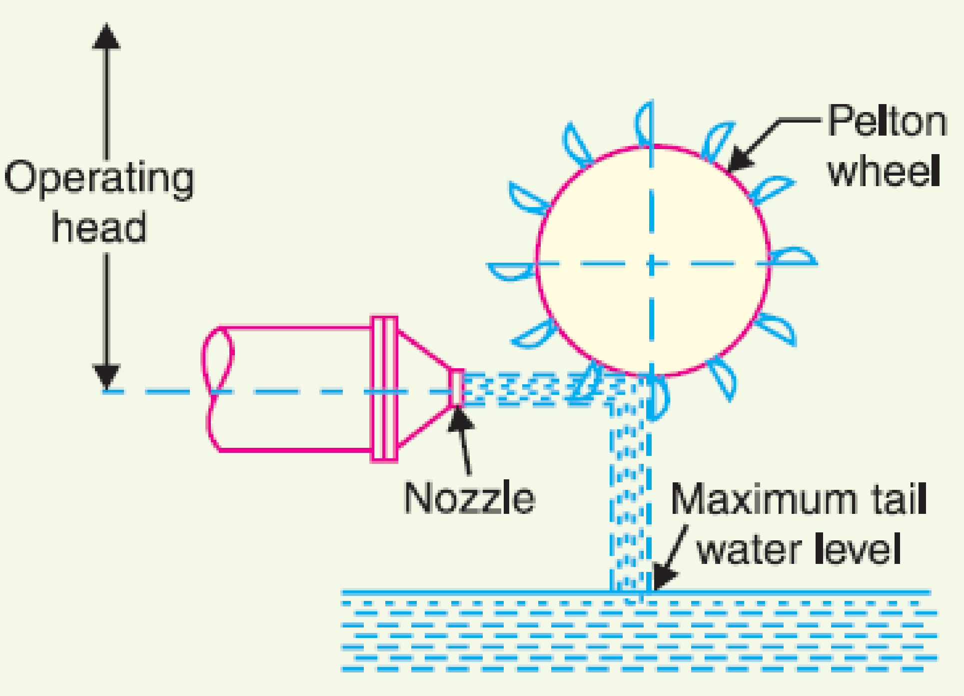


Fig. 2.4 Pelton Wheel

(*ii*) *Reaction turbines.* Reaction turbines are used for low and medium heads. In a reaction turbine, water enters the runner partly with pressure energy and partly with velocity head.

Bhakra Dam

3. Electrical equipment. The electrical equipment of a hydro-electric power station includes alternators, transformers, circuit breakers and other switching and protective devices.

HYDRO-ELECTRIC (STORAGE TYPE) PLANT IN COMBINATION WITH STEAM PLANT

- *Hydro-plants can take up the load quickly and follow the peak variation much better than thermal plants.*

- There is a great reliability in hydro-plants and it is still more in a combined system.

- In a combined system of hydro and thermal, water storage increases the application of more hydro-power in normal or heavy run-off years, while steam plant can help during the time of drought.

- *When the runoff is sufficient ,* the *hydro-plant is used as base load and thermal plant works as peak load plant.*

- *Thermal plant is used as base load plant during the drought period and hydro-plant works as peak load plant.* Fig. 8.2 (*a*), (*b*) shows their uses as base load or as peak load plant.

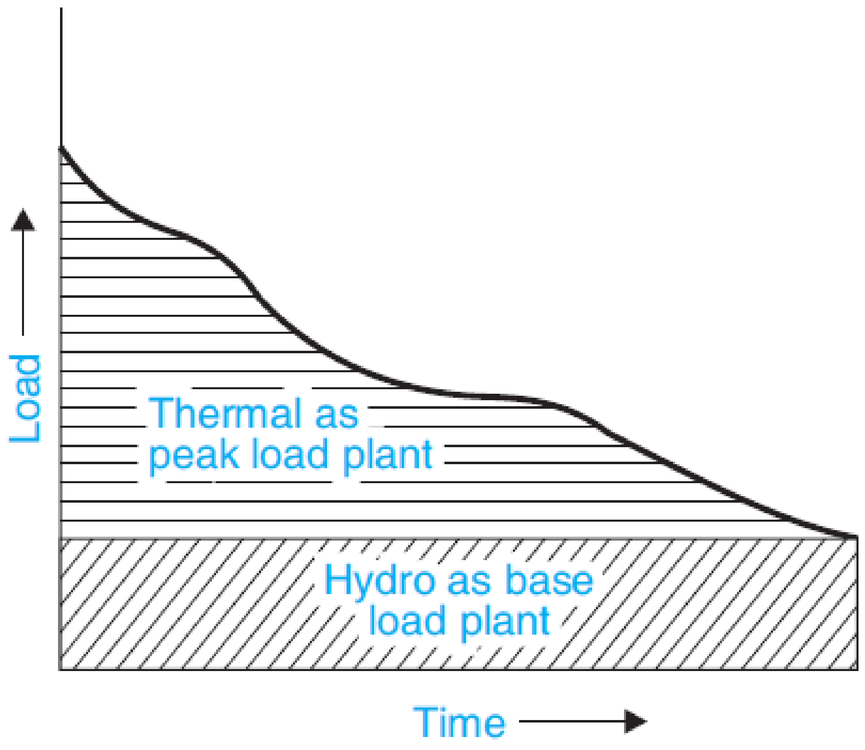


Fig. 8.2 (*a*). Hydro-plant used as base load plant during normal run-off in an interconnected system.

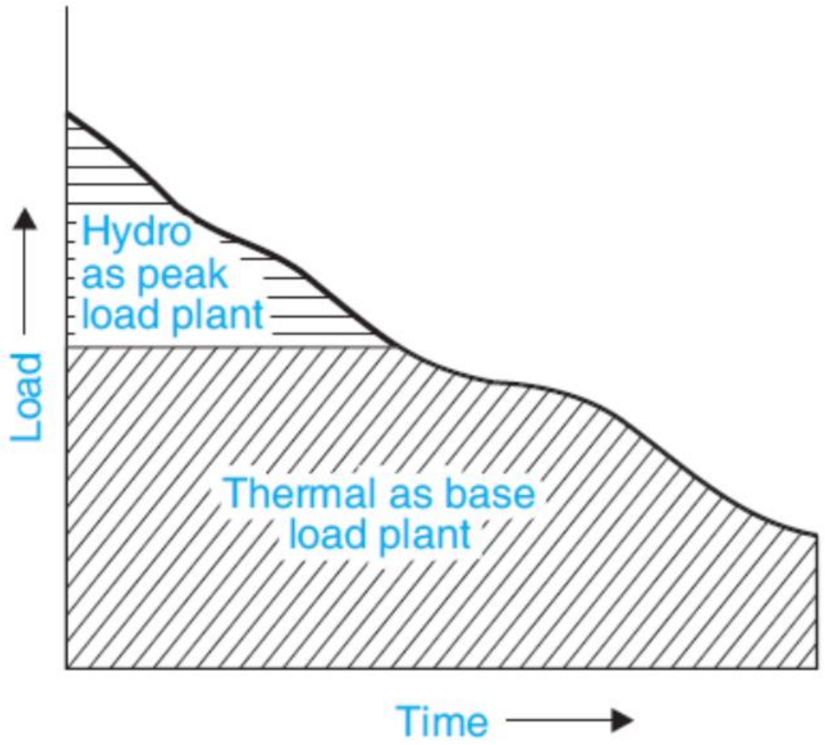


Fig. 8.2 (*b*). Hydro-plant used as peak load during drought period in an interconnected system.

Example 2.6. *A hydro-electric generating station is supplied from a reservoir of capacity 5×10^6 cubic metres at a head of 200 metres. Find the total energy available in kWh if the overall efficiency is 75%.*

Solution.

Weight of water available is

$$W = \text{Volume of water} \times \text{density}$$
$$= (5 \times 10^6) \times (1000) \qquad (\because \text{ mass of } 1\text{m}^3 \text{ of water is } 1000 \text{ kg})$$
$$= 5 \times 10^9 \text{ kg} = 5 \times 10^9 \times 9{\cdot}81 \text{ N}$$

$$\text{Electrical energy available} = W \times H \times \eta_{overall} = (5 \times 10^9 \times 9{\cdot}81) \times (200) \times (0{\cdot}75) \text{ watt sec}$$
$$= \frac{(5 \times 10^9 \times 9 \cdot 81) \times (200) \times (0 \cdot 75)}{3600 \times 1000} \text{ kWh} = \mathbf{2.044 \times 106 \text{ kWh}}$$

Example 2.7. *It has been estimated that a minimum run off of approximately 94 m^3/sec will be available at a hydraulic project with a head of 39 m. Determine (i) firm capacity (ii) yearly gross output. Assume the efficiency of the plant to be 80%.*

Solution.

Weight of water available, $W = 94 \times 1000 = 94000$ kg/sec

Water head, $H = 39$ m

$$\text{Work done/sec} = W \times H = 94000 \times 9{\cdot}81 \times 39 \text{ watts}$$
$$= 35,963 \times 10^3 \text{ W} = 35,963 \text{ kW}$$

This is gross plant capacity.

(i) Firm capacity = Plant efficiency × Gross plant capacity

$$= 0{\cdot}80 \times 35{,}963 = \mathbf{28{,}770 \text{ kW}}$$

(ii) Yearly gross output = Firm capacity × Hours in a year

$$= 28{,}770 \times 8760 = \mathbf{252 \times 10^6 \text{ kWh}}$$

Example 2.9. *Calculate the average power in kW that can be generated in a hydro-electric project from the following data*

Catchment area $= 5 \times 10^9\ m^2$ *; Mean head,* $H = 30\ m$

Annual rainfall, $F = 1{\cdot}25\ m$ *; Yield factor,* $K = 80\ \%$

Overall efficiency, $\eta_{oveall} = 70\ \%$

If the load factor is 40% , what is the rating of generators installed ?

Solution.

Volume of water which can be utilised per annum

$$= \text{Catchment area} \times \text{Annual rainfall} \times {}^{*}\text{yield factor}$$

$$= (5 \times 10^9) \times (1{\cdot}25) \times (0{\cdot}8) = 5 \times 10^9\ \text{m}^3$$

Weight of water available per annum is

$$W = 5 \times 10^9 \times 9{\cdot}81 \times 1000 = 49{\cdot}05 \times 10^{12}\ \text{N}$$

Electrical energy available per annum

$$= W \times H \times \eta_{overall} = (49{\cdot}05 \times 10^{12}) \times (30) \times (0{\cdot}7)\ \text{watt-sec}$$

$$= \frac{(49 \cdot 05 \times 10^{12}) \times (30) \times (0 \cdot 7)}{1000 \times 3600}\ \text{kWh} = 2 \cdot 86 \times 10^8\ \text{kWh}$$

$\therefore$ Average power $= 2{\cdot}86 \times 10^8/8760 =$ **32648 kW**

$$\text{Max. demand} = \frac{\text{Average demand}}{\text{Load factor}} = \frac{32648}{0 \cdot 4} = \mathbf{81620\ kW}$$

Therefore, the maximum capacity of the generators should be 81620 kW.

Example 2.10. *A hydro-electric power station has a reservoir of area 2·4 square kilometres and capacity 5×10^6 m^3. The effective head of water is 100 metres. The penstock, turbine and generation efficiencies are respectively 95%,90% and 85%.*

(i) Calculate the total electrical energy that can be generated from the power station.

(ii) If a load of 15,000 kW has been supplied for 3 hours, find the fall in reservoir level.

Solution.

(i) Wt. of water available, W = Volume of reservoir × wt. of 1m^3 of water

$$= (5 \times 10^6) \times (1000) \text{ kg} = 5 \times 10^9 \times 9{\cdot}81 \text{ N}$$

Overall efficiency, $\eta_{overall} = 0{\cdot}95 \times 0{\cdot}9 \times 0{\cdot}85 = 0{\cdot}726$

Electrical energy that can be generated

$$= W \times H \times \eta_{overall} = (5 \times 10^9 \times 9{\cdot}81) \times (100) \times (0{\cdot}726) \text{ watt-sec.}$$

$$= \frac{(5 \times 10^9 \times 9 \cdot 81) \times (100) \times (0 \cdot 726)}{1000 \times 3600} \text{ kWh} = \mathbf{9{,}89{,}175 \text{ kWh}}$$

(ii) Let x metres be the fall in reservoir level in 3 hours.

$$\text{Average discharge/sec} = \frac{\text{Area of reservoir} \times x}{3 \times 3600} = \frac{2 \cdot 4 \times 10^6 \times x}{3 \times 3600} = 222 \cdot 2x \text{ m}^3$$

Wt. of water available/sec, $W = 222{\cdot}2x \times 1000 \times 9{\cdot}81 = 21{\cdot}8x \times 10^5$ N

Average power produced $= W \times H \times \eta_{overall}$

$$= (21{\cdot}8x \times 10^5) \times (100) \times (0{\cdot}726) \text{ watts}$$

$$= 15{\cdot}84x \times 10^7 \text{ watts} = 15{\cdot}84x \times 10^4 \text{ kW}$$

But kW produced = 15,000 (*given*)

$\therefore \quad 15{\cdot}84x \times 10^4 = 15{,}000$

or
$$x = \frac{15{,}000}{15 \cdot 84 \times 10^4} = 0 \cdot 0947 \text{ m} = \mathbf{9.47 \text{ cm}}$$

Therefore, the level of reservoir will fall by 9·47 cm.

Alternative method

$$\text{Level of reservoir} = \frac{\text{Vol. of reservoir}}{\text{Area of reservoir}} = \frac{5 \times 10^6}{2 \cdot 4 \times 10^6} = 2 \cdot 083 \text{ m}$$

$$\text{kWh generated in 3 hrs} = 15000 \times 3 = 45{,}000 \text{ kWh}$$

If kWh generated are 9,89,175 kWh, fall in reservoir level = 2·083 m

If kWh generated are 45,000 kWh, fall in reservoir level

$$= \frac{2 \cdot 083}{9{,}89{,}175} \times 45{,}000 = 0 \cdot 0947 \text{ m} = \mathbf{9.47 \text{ cm}}$$

Example 2.12. *A run-of-river hydro-electric plant with pondage has the following data :*

Installed capacity = 10 MW ; *Water head, H = 20 m*

Overall efficiency, $\eta_{overall}$ *= 80%* ; *Load factor = 40%*

(i) Determine the river discharge in m^3*/sec required for the plant.*

(ii) If on a particular day, the river flow is 20 m^3*/sec, what load factor can the plant supply ?*

Solution.

(i) Consider the duration to be of one week.

Units generated/week = Max. demand × L.F. × Hours in a week

$= (10 \times 10^3) \times (0{\cdot}4) \times (24 \times 7)$ kWh

$= 67{\cdot}2 \times 10^4$ kWh ... *(i)*

Let Q m^3/sec be the river discharge required.

Wt. of water available/sec, $w = Q \times 9{\cdot}81 \times 1000 = 9810\, Q$ newton

Average power produced $= w \times H \times \eta_{overall} = (9810\, Q) \times (20) \times (0{\cdot}8)$ W

$= 156960\, Q$ watt $= 156{\cdot}96\, Q$ kW

Units generated/week $= (156{\cdot}96\, Q) \times 168$ kWh $= 26{,}369$ Q kWh ... *(ii)*

Equating exps. *(i)* and *(ii)*, we get,

$$26{,}369\, Q = 67{\cdot}2 \times 10^4$$

$$\therefore \quad Q = \frac{67 \cdot 2 \times 10^4}{26{,}369} = \mathbf{25.48\, m^3/sec}$$

(ii) If the river discharge on a certain day is 20 m^3/sec, then,

Power developed $= 156{\cdot}96 \times 20 = 3139{\cdot}2$ kW

Units generated on that day $= 3139{\cdot}2 \times 24 = 75{,}341$ kWh

$$\text{Load factor} = \frac{75{,}341}{10^4 \times 24} \times 100 = \mathbf{31.4\%}$$

Example 2.13. *The weekly discharge of a typical hydroelectric plant is as under :*

Day	*Sun*	*Mon*	*Tues*	*Wed*	*Thurs*	*Fri*	*Sat*
Discharge(m^3/*sec*)	500	520	850	800	875	900	546

The plant has an effective head of 15 m and an overall efficiency of 85%. If the plant operates on 40% load factor, estimate (i) the average daily discharge (ii) pondage required and (iii) installed capacity of proposed plant.

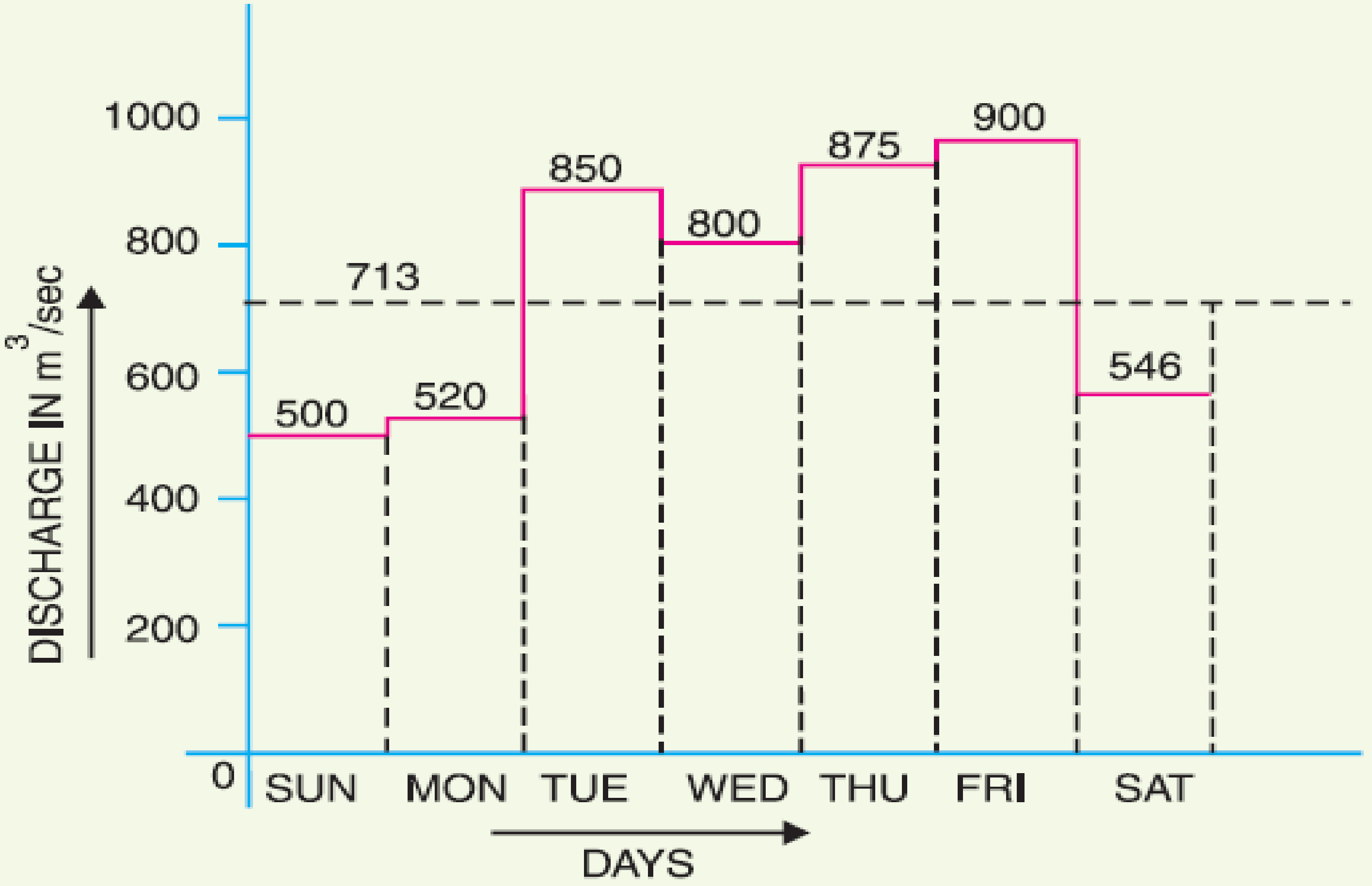


Fig. 2.5

Solution.

Fig. 2.5 shows the plot of weekly discharge. In this graph, discharge is taken along *Y*-axis and days along *X*-axis.

(*i*) Average daily discharge $= \dfrac{500 + 520 + 850 + 800 + 875 + 900 + 546}{7}$

$= \dfrac{4991}{7} =$ **713 m³/sec**

(*ii*) It is clear from graph that on three dyas (*viz*., Sun, Mon. and Sat.), the discharge is less than the average discharge.

Volume of water actually available on these three days

$= (500 + 520 + 546) \times 24 \times 3600 \text{ m}^3 = 1566 \times 24 \times 3600 \text{ m}^3$

Volume of water required on these three days

$= 3 \times 713 \times 24 \times 3600 \text{ m}^3 = 2139 \times 24 \times 3600 \text{ m}^3$

Pondage required $= (2139 - 1566) \times 24 \times 3600 \text{ m}^3 =$ $\mathbf{495 \times 10^5\ m^3}$

(*iii*) Wt. of water available/sec, $w = 713 \times 1000 \times 9{\cdot}81$ N

Average power produced $= w \times H \times \eta_{overall} = (713 \times 1000 \times 9{\cdot}81) \times (15) \times (0{\cdot}85)$ watts

$= 89180 \times 10^3$ watts $= 89180$ kW

Installed capacity of the plant

$= \dfrac{\text{Output power}}{\text{Load factor}} = \dfrac{89180}{0{\cdot}4} = 223 \times 10^3 \text{ kW} =$ **223 MW**