The flow duration curve is then plotted as shown in Fig. 6.58.

Note. When selecting a suitable site for a hydropower plant the flow data for a number of years is collected and hydrographs and flow duration curves and the various periods are determined.

Example 6.36. *The runoff data of a river at a particular site is tabulated below :*

Month	*Mean discharge per month (millions of cu m)*	*Month*	*Mean discharge per month (millions of cu m)*
January	40	*July*	75
February	25	*August*	100
March	20	*September*	110
April	10	*October*	60
May	0	*November*	50
June	50	*December*	40

(*i*) *Draw a hydrograph and find the mean flow,*

(*ii*) *Also draw the flow duration curve,*

(*iii*) *Find the power in MW available at mean flow if the head available is 80 m and overall efficiency of generation is 85%.*

Take each month of 30 days.

Solution. (*i*) **Hydrograph :**

The *hydrograph* for the given data is drawn as shown in Fig. 6.59.

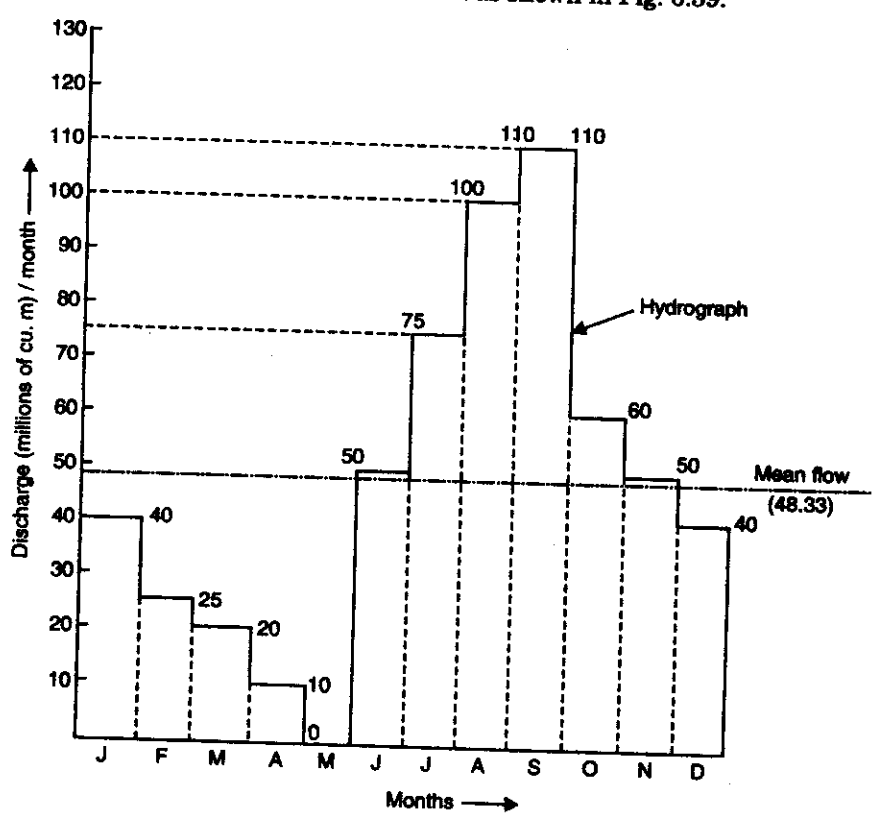

Fig. 6.59. Hydrograph.

The mean discharge for the given data

$$= \frac{40 + 25 + 20 + 10 + 0 + 50 + 75 + 100 + 110 + 60 + 50 + 40}{12}$$

$$= \frac{580}{12} = 48.33 \text{ millions of m}^3\text{/month.}$$

(*ii*) **Flow duration curve :**

To obtain the *flow duration curve* it is necessary to find the *lengths of time* during which certain flows are available. This information is tabulated, using the hydrograph, in the table below :

Discharge per month (millions of m^3)	Total number of months during which flow is available	Percentage time
0	12	100
10	11	91.7
20	10	83.3
25	9	75
40	8	66.7
50	6	50
60	4	33.3
75	3	25.0
100	2	16.7
110	1	8.3

The flow duration curve can be drawn using the data tabulated as shown in Fig. 6.60.

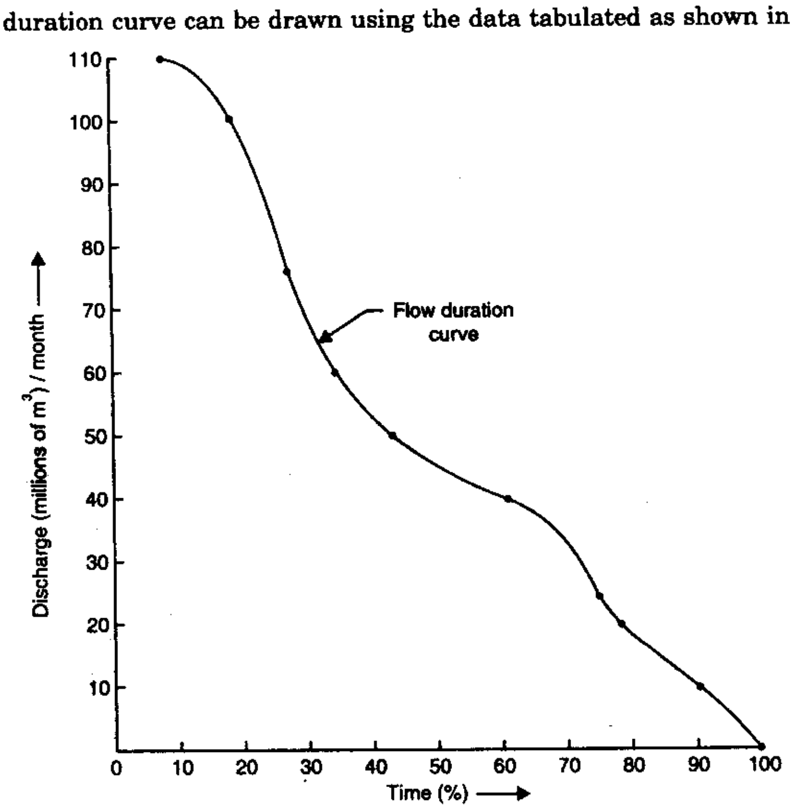

Fig. 6.60. Flow duration curve.

(*iii*) **Average MW energy available :**

$$= \eta_0 \, wQH \times \frac{1}{1000} \text{ MW} \qquad \text{(where } w = 9.81 \text{ kN/m}^3\text{)}$$

$$\left[\text{where } Q \text{ (discharge in m}^3\text{/s)} = \frac{48.33 \times 10^6}{30 \times 24 \times 3600}\right]$$

$$= 0.85 \times \frac{9.81 \times 48.33 \times 10^6 \times 80}{(30 \times 24 \times 3600)} \times \frac{1}{1000} \text{ MW}$$

= **12.4 MW. (Ans.)**

Example 6.37. *The nature of load required for 24 hours and thermal efficiencies of the plant at the respective loads are given in the table below :*

Time period	*Load (MW)*	*Thermal efficiency (% age)*
10 A.M. to 6 P.M.	*120*	*32%*
6 P.M. to 8 P.M.	*60*	*24%*
8 P.M. to 12 A.M.	*30*	*15%*
12 A.M. to 6 A.M.	*15*	*10%*
6 A.M. to 10 A.M.	*75*	*25%*

(i) Find the total input to the thermal plant if the load is supplied by the single thermal plant only.

(ii) If the above load is taken by combined thermal and pump storage plant, then find the percentage saving in the input to the plant. Thermal efficiency at full load = 32%.

(iii) The overall efficiencies in both cases.

In pump storage plant, the pump and turbine are separate. The efficiency of pump is 82% and water turbine is 92%.

Solution. The load curve, drawn as per the data given, is shown in Fig. 6.61.

Total output per day $= 75 \times 4 + 120 \times 8 + 60 \times 2 + 30 \times 4 + 15 \times 6$

$= 300 + 960 + 120 + 120 + 90 = 1590$ MWh

(*i*) **Total input to the thermal plant :**

The input to the thermal plant

$$= \frac{75 \times 4}{0.25} + \frac{120 \times 8}{0.32} + \frac{60 \times 2}{0.24} + \frac{30 \times 4}{0.15} + \frac{15 \times 6}{0.1}$$

$= 1200 + 3000 + 500 + 800 + 900 =$ **6400 MWh. (Ans.)**

(*ii*) **Percentage saving in the input to plant :**

The overall efficiency of the pump storage plant

$= 0.82 \times 0.92 = 0.7544$ or 75.44%.

Assume that the capacity of the thermal plant is x MW when it is working in combination with pump-storage plant.

The energy used from the thermal plant to pump the water of pump storage plant during off-peak period *must be equal to* the energy supplied by the pump-storage plant during peak period.

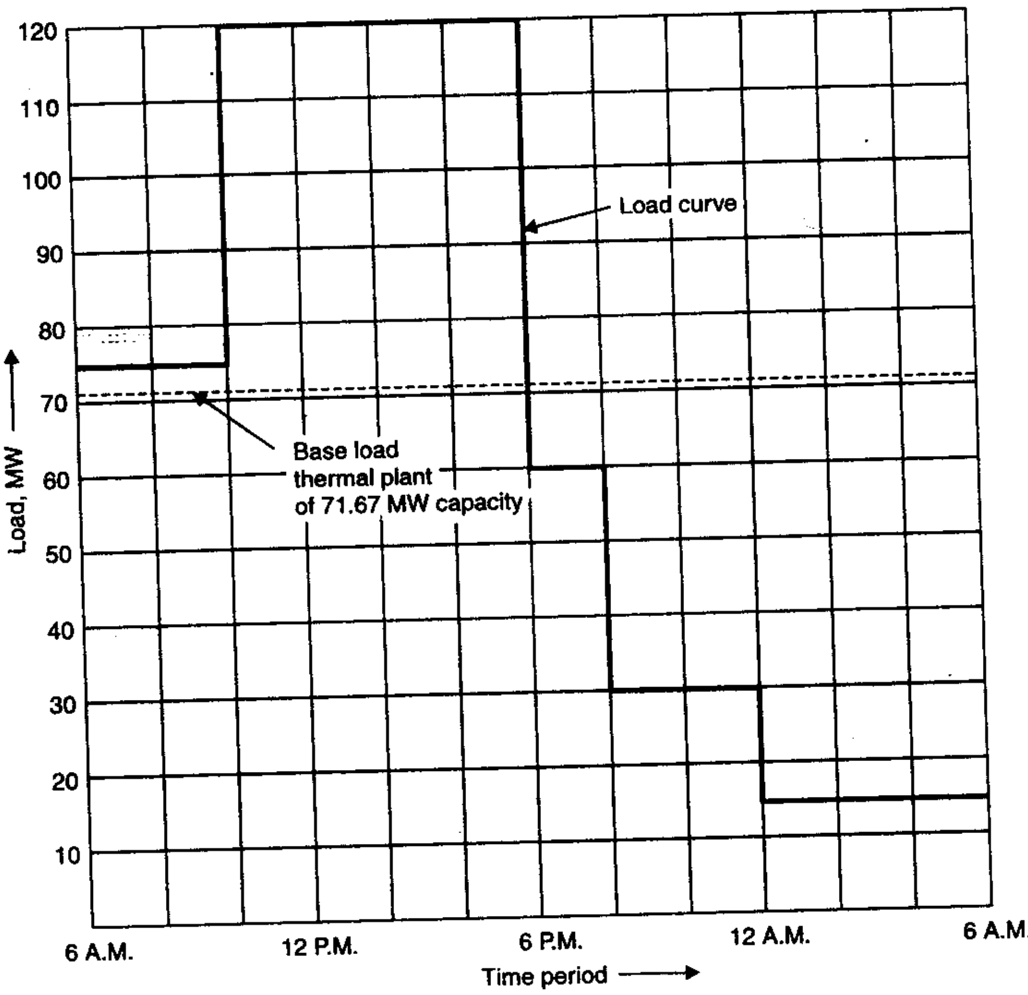

Fig. 6.61

From the Fig. 6.61, we have

$$[(x-60)\times 2+(x-30)\times 4+(x-15)\times 6]\times 0.7544=(75-x)\times 4+(120-x)\times 8$$

or $$[(2x-120)+(4x-120)+(6x-90)]\times 0.7544=(300-4x)+(960-8x)$$

or $$(12x-330)\times 0.7544=1260-12x$$

or $$9.053x-248.95=1260-12x$$

$\therefore$ $$x=\frac{1260+248.95}{(9.053+12)}=71.67\text{ MW}$$

The energy supplied in the second case

$$=\frac{71.67\times 24}{0.32}=5375\text{ MWh}$$

The percentage saving in input if the load is taken by combined thernmal and pump storage plant.

$$=\frac{6400-5375}{6400}=0.16\text{ or } \mathbf{16\%.}\ \textbf{(Ans.)}$$

(*iii*) The overall efficiency in the *first case*

$$= \frac{1590}{6400} = 0.2484 = \mathbf{24.84\%}. \quad \textbf{(Ans.)}$$

The overall efficiency in the *second case*

$$= \frac{1590}{5375} = 0.2958 \text{ or } \mathbf{29.58\%}. \quad \textbf{(Ans.)}$$

Example 6.38. *At a particular site of a river, the mean monthly discharge for 12 months is tabulated below :*

Month	*Discharge (millions of m^3 per month)*	*Month*	*Discharge (millions of m^3 per month)*
April	*250*	*Oct.*	*1000*
May	*100*	*Nov.*	*750*
June	*750*	*Dec.*	*750*
July	*1250*	*Jan.*	*500*
Aug.	*1500*	*Feb.*	*400*
Sep.	*1200*	*Mar.*	*300*

(i) Draw hydrograph for the given discharges and find the average monthly flow.

(ii) Also draw the flow duration curve.

(iii) The power available at mean flow of water if available head is 90 metres at the site and overall efficiency of the generation is 82 percent.

Take 30 days in a month.

Solution. (*i*) **Hydrograph :**

The hydrograph, drawn as per data given, is shown in Fig. 6.62.

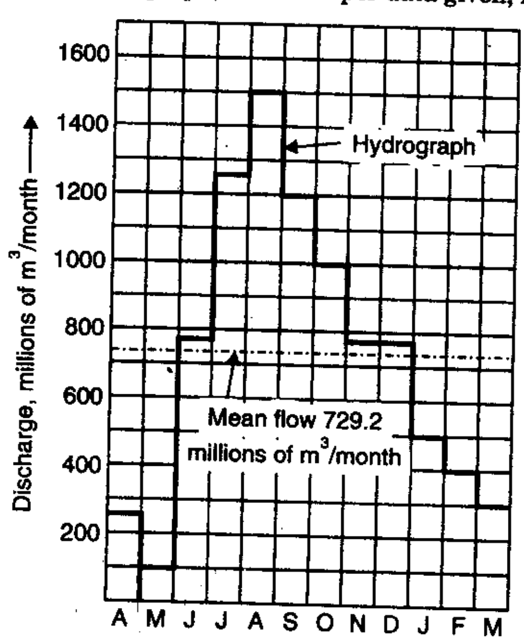

Fig. 6.62. **Hydrograph.**

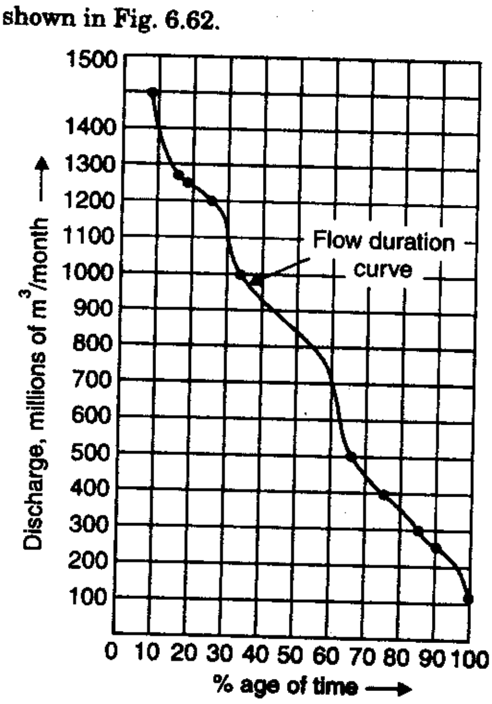

Fig. 6.63. **Flow duration curve.**

The average monthly flow (Refer Fig. 6.62)

$$= \frac{250 + 100 + 750 + 1250 + 1500 + 1200 + 1000 + 750 + 750 + 500 + 400 + 300}{12}$$

= 729.2 millions of m³/month.

(*ii*) **Flow duration curve :**

In order to obtain the *flow duration curve* it is necessary to find the lengths of time during which certain flows are available. This information is tabulated, using the hydrograph, in the following table :

Discharge per month millions of m³	*Total number of months during which flow is available*	*Percentage time during which flow is available*
100	12	100
250	11	91.8
300	10	83.40
400	9	76.00
500	8	66.60
750	7	58.40
1000	4	33.30
1200	3	25.00
1250	2	16.65
1500	1	8.325

By using the above tabulated data, the *flow duration curve* can be drawn as shown in Fig. 6.63.

(*iii*) **Power available at mean flow of water :**

The mean/average flow available per second

$$= \frac{729.2 \times 10^6}{30 \times 24 \times 3600} = 281.3 \text{ m}^3/\text{s}$$

Average kW available at the site

$$= \frac{wQH}{1000} \times \eta_g \text{ MW} \qquad (\because \; w = \rho_g = 1000 \times 9.81 = 9.81 \text{ kN/m}^3)$$

$$= \frac{9.81 \times 281.3 \times 90}{1000} \times 0.82 = \mathbf{203.6 \ MW}. \quad \textbf{(Ans.)}$$

Example 6.39. *The data for a weekly flow at a particular site is given below for 12 weeks :*

Week	*Weekly flow, m³/s*	*Week*	*Weekly flow, m³/s*
1	*3000*	*7*	*600*
2	*2000*	*8*	*2250*
3	*2700*	*9*	*4000*
4	*1000*	*10*	*2000*
5	*750*	*11*	*1500*
6	*500*	*12*	*1000*

With the help of mass curve, find the size of the reservoir and the possible rate of available flow after the reservoir has been built.

Solution. In order to draw *mass curve*, we need to find the cumulative volume of water that can be stored week after week. This is done as tabulated in the table on the next page.

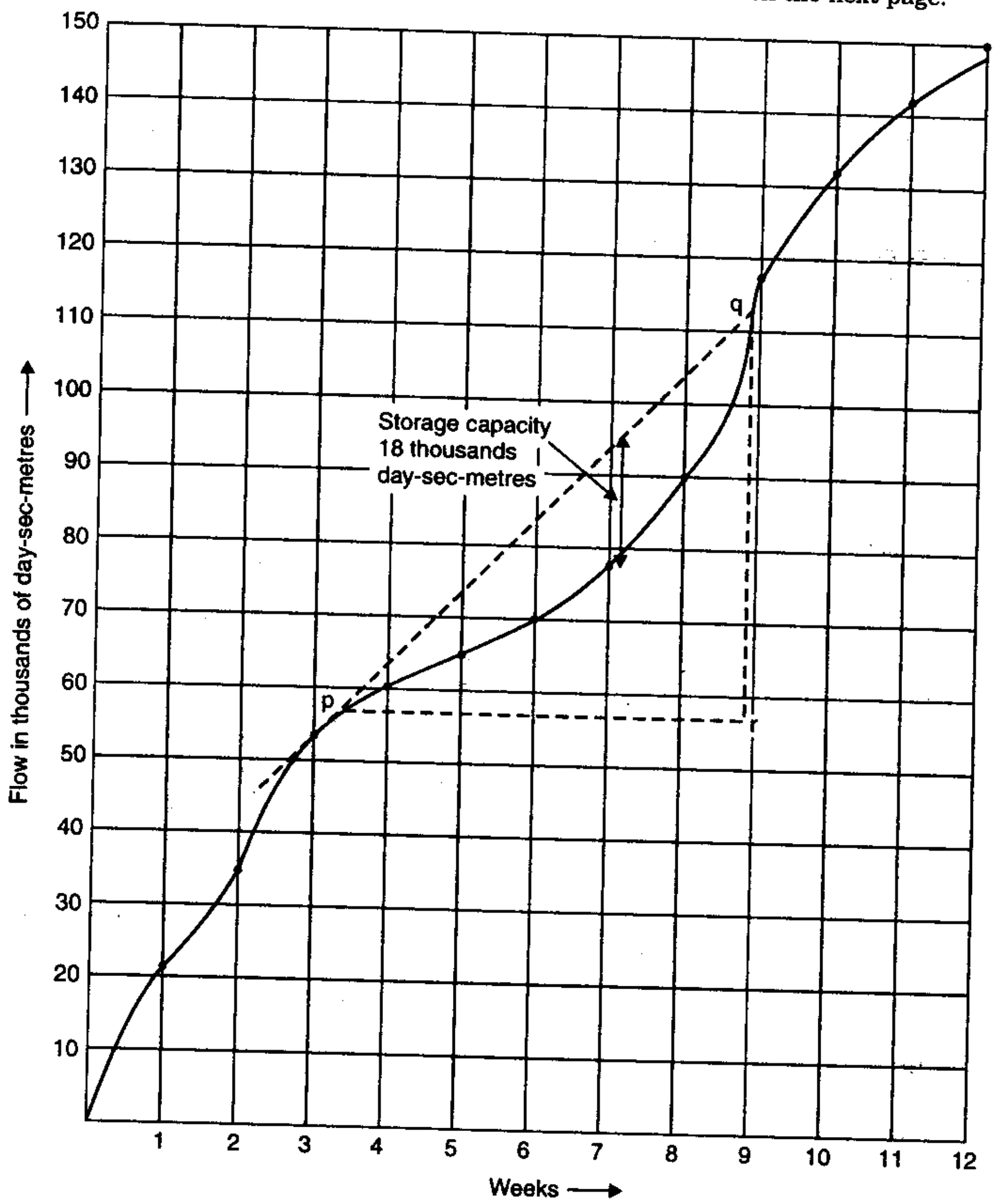

Fig. 6.64

Week (a)	*Weekly flow in* m^3/s (b)	*Weekly flow in day-sec-metre* (c) = (b) × 7	*Cumulative volume in day-sec-metres* (d)
1	3000	21000	21000
2	2000	14000	35000
3	2700	18900	53900
4	1000	7000	60900
5	750	5250	66150
6	500	3500	69650
7	600	4200	73850
8	2250	15750	89600
9	4000	28000	117600
10	2000	14000	131600
11	1500	10500	142100
12	1000	7000	149100

If the *mean flow* is available in the week at the given rate, then the total flow in the week = 7 × day × m^3/sec = 7 × day-sec-metres.

By using the above tabulated data, the mass curve can be drawn as shown in Fig. 6.64.

- Draw the tangent at the highest point on the mass curve from 'p' and *measure the highest distance between the tangent drawn and mass curve which gives the capacity of the reservoir.*

  In this **capacity of the reservior = 18 × 10³ day-sec-metres. (Ans.)**
- The *slope of the line 'pq' gives the flow rate available for the given capacity reservoir.*

$$\therefore \quad \textbf{Flow rate available} = \frac{qr}{pr} = \frac{54 \times 10^3 \text{ (day - sec - metres)}}{5.5 \times 7 \text{(days)}} = \textbf{1402.6 m}^3\textbf{/s.} \quad \textbf{(Ans.)}$$

Example 6.40. *The following run-off data is collected for twelve months at a particular site :*

Month	*Flow per month, millions of* m^3	*Month*	*Flow per month, millions of* m^3
1	50	7	95
2	25	8	20
3	10	9	15
4	40	10	100
5	5	11	85
6	5	12	40

Determine the following :

(i) The required capacity for the uniform flow of 25 millions m^3 *per month throughout the year.*

(ii) Spill-way capacity.

(iii) Average flow capacity if whole water is used and required capacity of the resevoir for this condition.

Solution. In order to draw the ***mass curve,*** we need to find the cumulative volume of water that can be stored month after month. This is done as shown in the following table :

Month	Flow per month (millions of m^3)	Cumulative volume, (millions of m^3)
1	50	50
2	25	75
3	10	85
4	40	125
5	5	130
6	5	135
7	95	230
8	20	250
9	15	265
10	100	365
11	85	450
12	40	490

By using the above tabulated data, the mass curve can be drawn as shown in Fig. 6.65.

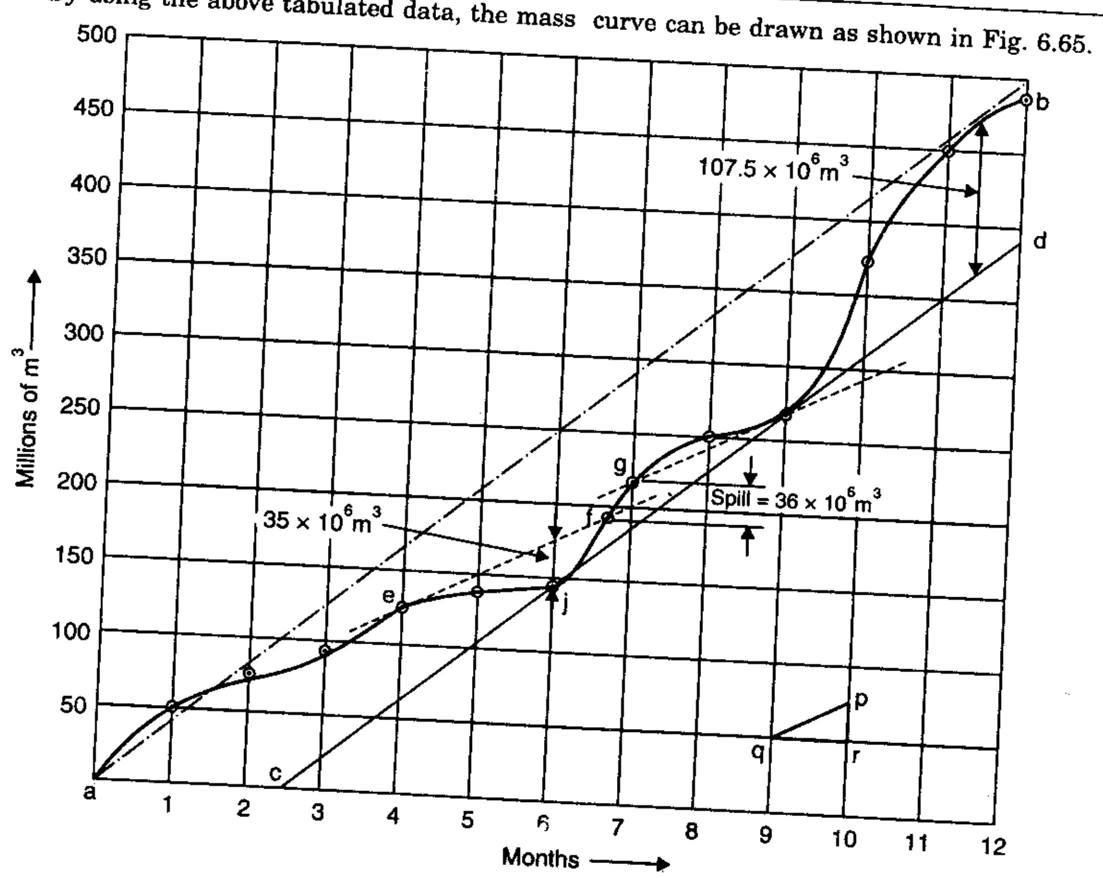

Fig. 6.65

(*i*) **Required capacity for the uniform flow of 25 millions – m^3 per month :**

- For finding the capacity of the reservoir for uniform flow of 25 millions – m^3 per month, construct the Δpqr as shown in Fig. 6.65. *qr* repersents one month and *pr* represents 25 millions – m^3.
- Now draw the parallel lines to the line *pq* through the points *e* and *g* which are apex of mass curve. The greatest departure of the mass curve from these lines represents the storage capacity.

∴ *Storage capacity* $= \mathbf{35 \times 10^6\ m^3}$. **(Ans.)**

(*ii*) **Spillway capacity :**

Spillway capacity required (Fig. 6.65)

$= \mathbf{36 \times 10^3\ m^3}$. **(Ans.)**

(*iii*) **Average flow capacity**

- Join points *a* and *b*, then the slope of the line *ab* represents the uniform discharge throughout the year,

$$= \frac{490}{12} \times 10^6 = \mathbf{40.83 \times 10^6\ m^3/month.}\quad \textbf{(Ans.)}$$

- Draw the line *cd* parallel to *ab* which touches the mass curve to its lowest point '*j*'. The *maximum departure of the line cd from the mass curve represents the required* ***storage capacity*** *for the uniform supply of 40.83 × 10⁶ m³/month.* In this case, storage capacity required

$= \mathbf{107.5 \times 10^6\ m^3}$. **(Ans.)**

HIGHLIGHTS

1. A *dam* is a barrier to confine or raise water for storage or diversion to create a hydraulic head.
2. A *canal* is an open waterway excavated in natural ground. A *flume* is an open channel excavated on the surface or supported above ground on a trestle. A *tunnel* is a closed channel excavated through a natural obstruction such as a ridge of higher land between the dam and the powerhouse.
3. A *surge tank* is a small reservoir or tank in which the water level rises or falls to reduce the pressure swings so that they are not transmitted in full to a closed circuit.
4. A *draft tube* serves the following two purposes :
   (*i*) It allows the turbine to be set above tail-water level, without loss of head, to facilitate inspection and maintenance.
   (*ii*) It regains, by diffuser action, the major portion of the kinetic energy delivered to it from the runner.
5. The plants which cater for the base load of the system are called *'base load plants'* whereas the plants which can supply the power during peak loads are known as *peak load plants*.
6. Microhydel plants (microstations) make use of standardized *bulb sets* with unit output ranging from 100 to 1000 kW working under heads between 1.5 to 10 metres.
7. The *specific speed* of a turbine is defined as the speed of a geometrically similar turbine that would develop one brake horse power under a head of one metre.
8. The *Pelton* turbine is a tangential flow impulse turbine. The pressure over the Pelton wheel is constant and equal to atmosphere, so that energy transfer occurs due to purely impulse action.
9. The modern *Francis* water turbine is an inward mixed flow reaction turbine. It operates under medium heads and also requires medium quantity of water.
10. In the *propeller turbine* the runner blades are fixed and non-adjustable. In *Kaplan turbine*, which is a modification of propeller turbine the runner blades are adjustable and can be rotated about the pivots fixed to the boss of the runner.
11. *'Cavitation'* may be defined as the phenomenon which manifests itself in the pitting of the metallic surfaces of turbine parts because of formation of cavities.

12. *'Hydrology'* may be defined as the science which deals with the depletion and replenishment of water resources.
13. Run-off includes all the water flowing in the stream channel at any given section. It can be measured by the following methods :
    (*i*) From rainfall records (*ii*) Empirical formulae
    (*iii*) Run-off curves and tables (*iv*) Discharge observation method.
14. *Hydrograph* is defined as a graph showing discharge (run-off) of flowing water with respect to time for a specified time. It indicates the power available from the stream at different times of day, week or year.
15. *Flow duration curve* represents the run-off data for the given time. It is plotted between flow available during a period *versus* the fraction of time.
16. *Mass curve* is the graph of the cumulative values of water quantity (run-off) against time. It is an integral curve of the hydrograph which expresses the area under the hydrograph from one time to another.

THEORETICAL QUESTIONS

1. Give the application of hydro-electric plants.
2. Enumerate advantages and disadvantages of hydro-plants.
3. Enumerate and explain briefly the factors which should be considered while selecting the site for hydro-electric plant.
4. Enumerate essential elements of hydro-electric power plant.
5. What is a catchment area ?
6. What is a reservoir ?
7. What is a dam ? What are its various types ?
8. Explain briefly any two of the following dams :
    (*i*) Rockfill dams (*ii*) Buttress dams
    (*iii*) Timber dams.
9. What is a spillway ? Explain any two types of spillways.
10. What is the difference between canal, flume and tunnel ?
11. What is a surge tank ?
12. Explain with a neat diagram any one of the following surge tanks :
    (*i*) Inclined surge tank (*ii*) Restricted orifice surge tank
    (*iii*) Differential surge tank.
13. What are the functions of a draft tube ?
14. How are hydro-electric power plants classified ?
15. Explain a high head power plant giving its layout clearly.
16. Explain with a neat sketch a pumped storage plant.
17. What is the function of a hydraulic turbine ? How are the turbines classified ?
18. Explain the working of a 'Pelton turbine' with the help of a neat diagram.
19. With the help of a schematic diagram explain the working of the modern Francis turbine.
20. What is a Kaplan turbine ? How does it differ from a propeller turbine ?
21. What are tubular or bulb turbines ?
22. What do you mean by 'specific speed' of a turbine ?
23. What is cavitation ? How can it be avoided/checked ?
24. Describe briefly the methods of governing an impulse turbine ?
25. What points should be considered while selecting a right type of turbine ?
26. Enumerate the various controls which are provided in an hydro-electric power plant.
27. Explain the advantages of combined operation of hydro-electric station and thermal station.
28. Compare hydro and thermal power plants.
29. List the advantages and disadvantages of underground power house/station.
30. What safety measures need to be taken for the safe operation of an hydro-electric plant ?

31. What do you mean by 'preventive maintenance' of hydro-plant ?
32. Define hydrology.
33. Draw and explain the hydrologic cycle.
34. Define run-off. How is it measured ?
35. List the factors which affect run-off.
36. What is a hydrograph ?
37. What is a unit hydrograph ? What are the limitations to the use of unit hydrographs ?
38. What is a flow duration curve ?
39. What is a mass curve ?
40. Write a short note on hydropower development in India.

UNSOLVED EXAMPLES

1. A penstock is working under a water head of 200 metres. Its diameter is 2.5 metres. Find its thickness if the efficiency of the joint is 80% and allowable stress in the material is 1100 kgf/cm^2. [**Ans.** 2.8 cm]
2. A Pelton wheel has a mean bucket speed of 10 metres per second with a jet of water flowing at the rate of 700 litres/sec. under a head of 30 metres. The buckets deflect the jet through an angle of 160°. Calculate :
   (*i*) The horse power (*ii*) Efficiency of the turbine
   Assume coefficient of velocity as 0.98. [**Ans.** (*i*) 254.12 H.P. (*ii*) η_h = 94.54%]
3. A Pelton wheel is to be designed for the following specifications :
   Power = 16000 B.H.P. ; Head = 380 metres ; Speed = 750 r.p.m. ; Overall efficiency = 86% ; Jet diameter is not to exceed one-sixth of the wheel diameter.
   Determine : (*i*) The wheel diameter, (*ii*) The number of jets required, and (*iii*) Diameter of the jet.
   Take C_v (coefficient of velocity) = 0.985 and speed rated = 0.45. [**Ans.** (*i*) 0.989 m (*ii*) 2 (*iii*) 0.165 m]
4. A Francis turbine with an overall efficiency of 75% is required to produce 203 H.P. It is working under a head of 7.62 m. The peripheral velocity = 0.26 $\sqrt{2gH}$ and the radial velocity of flow at inlet is 0.96 $\sqrt{2gH}$. The wheel runs at 150 r.p.m. and the hydraulic losses in the turbine are 22% of the available energy. Assuming radial discharge, determine :
   (*i*) The guide blade angle, (*ii*) The wheel vane angle at inlet,
   (*iii*) Diameter of the wheel at the inlet, and (*iv*) Width of the wheel at inlet.
   [**Ans.** (*i*) 37° 37′ (*ii*) 37° 44.4′ (*iii*) 0.4047 m (*iv*) 0.177 m]
5. The following data is given for a Francis turbine. Net head H = 60 m ; Speed N = 700 r.p.m. ; Shaft horse power = 400 H.P. ; η_0 = 84% ; η_h = 93% ; Flow ratio = 0.20 ; breadth ratio n = 0.1 ; Outer diameter of the runner = 2 × inner diameter of runner. The thickness of vanes occupy 5% of circumferential area of the runner, velocity of flow is constant at inlet and outlet and discharge is radial at outlet. Determine :
   (*i*) Guide blade angles, (*ii*) Runner vane angles at inlet and outlet,
   (*iii*) Diameters of runner of inlet and outlet, and (*iv*) Width of wheel at inlet.
   [**Ans.** (*i*) 13° 55.7′ (*ii*) 41° 5.4′ (*iii*) 34° 44.4′ (*iv*) 5.4 cm]
6. A Kaplan turbine develops 33500 H.P. at an average head of 39 metres. Assuming a speed ratio of 2, flow ratio of 0.6, diameter of the boss equal to 0.35 times the diameter of the runner and an overall efficiency of 90%, calculate the diameter, speed and specific speed of the turbine.
   [**Ans.** 0.875 m, 422.61 r.p.m., 7963.65 r.p.m.]
7. A turbine develops 10000 H.P. under a head of 25 metres at 135 r.p.m. Calculate the specific speed of the turbine and state the type of the turbine. [**Ans.** 241.49, Francis]
8. A turbine is to operate under a head of 25 m at 200 r.p.m. The discharge is 9 m^3/sec. If the efficiency is 90%, determine :
   (*i*) Specific speed of the machine (*ii*) Power generated, and
   (*iii*) Type of turbine. [**Ans.** (*i*) 185.89 r.p.m. (*ii*) 2700 H.P. (*iii*) Francis]
9. Calculate the specific speed of a turbine and suggest the type of turbine required for a river having a discharge of 250 litres/sec. with a available head of 50 metres. Assume efficiency of turbine as 80% and speed 450 r.p.m. [**Ans.** 39.9, Pelton turbine]

10. The quantity of water available for hydro-electric station is 260 m^3/sec. under a head of 1.7 m. Assuming the speed of the turbine 50 r.p.m. and its efficiency of 82.5%, determine the number of turbine units required. Assume the specific speed of 890. **[Ans.** 4]

11. A run-off rate of 400 m^3/sec and head of 45 m is available at a site proposed for hydro-electric power plant. Assuming the turbine efficiency of 90% and speed of 250 r.p.m., find the least number of machines all of equal size required if (*i*) Francis turbine not greater than 200 specific speed or (*ii*) Kaplan turbine not greater than 600 specific speed is used. **[Ans.** (*i*) 16, (*ii*) 3]

12. At a proposed site of hydro-electric power plant the available discharge and head is 340 m^3/sec. and 30 m respectively. The turbine efficiency is 88%. The generator is directly coupled to the turbine. The frequency of generation is 50 Hz and number of poles used are 24. Find least number of machines required if (*i*) A Francis turbine with a specific speed of 300 is used (*ii*) A Kaplan turbine with a specific speed of 800 is used. **[Ans.** (*i*) 17 (*ii*) 2]

13. The following data relates to a hydro-electric power station :
Head = 380 m ; Discharge = 4 m^3/sec ; Turbine efficiency = 80% ; Generator frequency = 50 Hz.
Determine : (*i*) Output (*ii*) Type of turbine (*iii*) Speed of turbine.
[Ans. (*i*) 16200 H.P. (*ii*) Pelton (*iii*) 333 r.p.m. (corrected)]

14. At a particular hydro-electric power plant site, the discharge of water is 400 m^3/sec and the head is 25 m. The turbine efficiency is 88%. The generator is directly coupled to the turbine having frequency of generation of 50 Hz, and number of poles as 24. Calculate the least number of turbines required if,
(*i*) A Francis turbine is used with a specific speed of 300,
(*ii*) A Kaplan turbine is used with a specific speed of 750. **[Ans.** (*i*) 26 (*ii*) 5]

15. A flow of 80 m^3/sec. under a head of 120 m is available at a site for a hydro-power plant. If the turbine efficiency is 90% and generator efficiency is 94% determine the following :
(*i*) Power developed (*ii*) Number of units required and their capacities.
[Ans. (*i*) 115200 H.P. ; (*ii*) Two, 39.85 mW (each generator)]

16. A proposed hydro-electric station has an available head of 100 metres, a catchment area of 225 sq. km, the rainfall of which is 140 cm per annum. If 60% of the total rainfall can be collected, calculate the power that could be generated. Suggest suitable ratings of generators. **[Ans.** 5880 kW, 3000 kW capacity]

17. The following data is available for a hydro-power plant :
Available head = 130 m ; catchment area = 2200 sq. km. ; annual average rainfall = 150 cm ; turbine efficiency = 86% ; generator efficiency = 91% , percolation and evaporation losses = 18%.
Determine power developed in MW taking load factor as unity. **[Ans.** 8.546 MW]

18. From the investigation of a hydrosite the following data is available :
Available head = 50 m ; catchment area = 50 sq. km. ; rainfall = 150 cm per year ; 70% of rainfall can be utilized ; turbine efficiency = 80% ; generator efficiency = 91% ; penstock efficiency = 75% ; load factor = 60%.
Determine the suitable capacity of a turbo-generator.
[Ans. 750 kW (maximum rating), Francis or Kaplan turbine]

19. Calculate the power that can be developed from a hydro-electric power station having the following data :
Catchment area = 100 sq. km. ; average value of annual rainfall = 120 cm ; Run-off = 80% ; available head = 300 m ; overall efficiency of the power station = 75%. **[Ans.** 7.48 MW]

20. In a hydro-electric power plant the reservoir is 200 m above the turbine house. The annual replenishment of reservoir is 40×10^{10} kg. Calculate the energy available at the generating station bus bars if the loss of head in the hydraulic system is 20 m and the overall efficiency of the station is 80%. In the maximum demand of 40 MW is to the supplied determine the diameter of two steel penstocks.
[Ans. 13.48×10^7 kWh ; 0.49 m]

21. It is observed that a run-of-river power plant operates as peak load point with a weekly load factor of 24% all this capacity being firm capacity. Determine the minimum flow in river so that power plant may act as base load point.

The following data is supplied : Rated installed capacity of generating plant = 12 MW ; operating head = 18 m ; plant efficiency = 85%.

If the stream flow is 17 m^3/sec, calculate the daily load factor of the plant. **[Ans.** 19.36 m^3/sec. ; 21.2%]

22. Find the firm capacity of a run-of-river hydropower plant to be used as 9 hours peaking plant assuming daily flow in a river to be constant at 16 m^3/sec. Also calculate pondage factor and pondage if the head of the plant is 12 m and overall efficiency is 80%. **[Ans.** 2048 H.P. ; 2.67 ; 5468 H.P. ; 8.64×10^5 m^3]
23. The gross head of a pump storage power plant is 300 m. The diameter and length of the headrace tunnel are 3.8 m and 650 m respectively. The flow velocity is 7 m/sec. and friction factor is 0.017. If the overall efficiency of pumping and generation are 84% and 89% respectively, determine the plant efficiency. The power plant discharges directly in the lower reservoir. **[Ans.** 71.2%]
24. At a particular site the mean discharge (in millions of m^3) of a river in 12 months from January to December is respectively 80, 50, 40, 20, 0, 100, 150, 200, 220, 120, 100, 80.
    (*i*) Draw a hydrograph and find the mean flow
    (*ii*) Also draw the flow duration curve
    (*iii*) Find the power in MW available at mean flow if the head available is 100 m and overall efficiency of generation is 80%.
    Take the each month of 30 days. **[Ans.** (*i*) 96.67 millions of m^3/month (*iii*) 29.2 MW]

COMPETITIVE EXAMINATIONS QUESTIONS

1. (*a*) Name the types of dam used for hydro-electric power plants.
   (*b*) With the help of diagram explain the functions of the following parts of a hydro-electric power station :
   (*i*) Spillway; (*ii*) Forebay; (*iii*) Penstock.
   (*c*) The mean weekly discharge for 12 weeks of a river is given below :

Week	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
Discharge m^3/sec	100	200	300	1200	600	900	800	600	1000	600	400	200

   Calculate the average power in kW that can be generated by a hydro-electric station with the above mentioned discharge characteristic and a head of 100 m. The overall efficiency of the plant may be assumed to be 60%.
2. (*a*) Why is it necessary to have combined operation of different types of power stations ?
   (*b*) Explain how the operations of hydro-electric and thermal power plants in a power system can be combined economically.
   (*c*) Two units, each of 200 MW, in a steam power station are operating in parallel and have their fuel incremental cost characteristics as,

$$\frac{dF_2}{dF_1} = \text{Rs. } (0.08\, P_1 + 15)/\text{MWh} \text{ ; and}$$

$$\frac{dF_1}{dF_2} = \text{Rs. } (0.1\, P_2 + 13)/\text{MWh}.$$

   If the total load is 300 MW, what will be the economic sharing of load between the units ? If the load is shared equally for 1000 hours, what will be the loss in comparison to the case when the load is shared economically ?
3. (*a*) What is the function of surge tank in a hydro-electric plant ? Explain with the help of neat diagram.
   (*b*) Explain the governing system of a modern Pelton turbine with the help of a neat sketch.
   (*c*) What is the significance of specific speed in the selection of hydro-electric turbines ? Derive the equation for the specific speed of the turbine.

4. (*a*) Explain a method of drawing flow duration curves and explain their use in selecting the site for hydro-electric plant.

(*b*) What are the different types of spillways used in practice ? Discuss the advantages of one over the other.

5. (*a*) Explain the construction of flow duration curve and discuss its importance in comparing the power potentiality of different storages used for power generation.

(*b*) It is proposed to develop 2000 H.P. at a site where 150 m of head is available. What type of turbine would be employed if it had to run at 300 r.p.m. ? If the same turbine is now used under a head of 30 m, find the power developed and its r.p.m.

6. (*a*) What do you understand by hydrology ? How does the study of hydrology help in selecting the site for a hydro-electric plant ?

(*b*) Describe briefly the working of a pumped storage plant. Where can such type of plants be installed ?

7. (*a*) Explain the working of combined hydro and steam plants. Under what circumstances will you classify them as peak load and base load plants ?

(*b*) A run-off rate of 400 m^3/sec and head of 45 m is available at a site proposed for hydro-electric power plant. Assuming the turbine efficiency of 90% and speed of 50 r.p.m., find out the least number of machines, all of equal size required, if Francis turbine not greater than 200 specific speed is used.

8. Write in brief on the following :

(*a*) Type of hydro-electric plants and their field of use

(*b*) Solar power and its uses

(*c*) Function of surge tanks in hydro-electric plants.

9. (*a*) Explain the combined working of hydro and steam plants.

(*b*) Write a note on geo-thermal energy for power generation.

10. (*a*) Discuss the differences between Kaplan, Francis and Pelton turbines and state the types of power plants they are suitable for.

(*b*) At a particular hydro-electric power plant site the discharge of water is 400 m^3/sec and the head is 25 m. The turbine efficiency is 88%. The generator is directly coupled to the turbine having frequency of generation 50 cycles/sec and number of poles as 24. Calculate the least number of turbines required if (*i*) a Francis turbine is used with a specific speed of 300, and (*ii*) a Kaplan turbine with a specific speed of 750 is used.

11. (*a*) Draw a layout of a medium head hydro-electric plant using Francis turbines.

(*b*) A hydroplant operates under a mean head of 40 m. The reservoir has a catchment area of 480 square km. Find the capacity of the plant in kW if the average annual rainfall in the area is 1100 mm and 20% of the rainfall is lost due to evaporation etc. The loss of head in the penstock is estimated to be 10%. The turbine efficiency is 85% and the generator efficiency is 92%.

12. (*a*) Define hydrograph. How is the run-off measured in practice ?

(*b*) From the following table of the mean monthly discharge for 12 months of a river at a site, draw (*i*) the hydrograph and find the average monthly flow ; (*ii*) the power available at mean flow of water for head 90 m and overall efficiency of generation 90%. Take 30 days in a month.

Month	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Q-$m^3 \times 10^6$	500	200	1500	2500	3000	2400	2000	1500	1500	1000	800	600

13. (*a*) Why is governing of hydraulic turbines necessary ? Explain the governing mechanism of a Kaplan turbine.

(*b*) Derive an expression for the specific speed of a hydraulic turbine and calculate it for a turbine operating under a head of 24 m and running at 400 r.p.m. The rate of discharge is 9 m^3/sec and turbine η is 90%.

14. (*a*) Sketch a layout of a hydraulic power plant suitable for high heads. Label the various parts and explain their functions.

(*b*) At a potential hydraulic plant site the average elevations of head water and tail water levels are 605 m and 520 m respectively. The average annual water flow was determined to be equal to that volume flowing through a rectangular channel 10 m wide and a depth of 0.12 m and an average velocity of 5 m/s. Find the annual electric energy in kWh that the site can produce with turbine efficiency of 85% and generator efficiency of 95%. Take the loss of head works equal to 3% of the available head.

15. (*a*) What is a flow duration curve ? Explain its utility.

(*b*) Define the specific speed of a hydraulic turbine. A hydro-electric power plant site is capable of developing 101250 h.p. If the turbine has to work under a head of 29.5 m and at a speed of 166.7 r.p.m., find out the number of turbine units required.

(*c*) Explain the governing method adopted for a large Pelton wheel giving functions of each component of the governor.

16. (*a*) How is the cost of electrical energy generated determined ? Explain the effect of load factor of an electric power station on the cost per kWh generated.

(*b*) Discuss the advantages of operating storage type hydro-electric plant in combination with steam plant.

17. (*a*) Sketch hydrograph, flow duration curve and mass duration curves. Discuss the utility of each.

(*b*) Draw a pumped storage scheme and discuss how this scheme results in overall economy in the case of inter-connected station.

(*c*) A hydro-electric scheme has a catchment area of 120 sq. km. The available run-off is 50% with annual rainfall of 100 cm. A head of 250 m is available on the average. Efficiency of the power plant is 70%. Find (*i*) average power produced, and (*ii*) capacity of the power plant.

18. (*a*) Show schematically the layout of a hydro-plant. What are the safety devices used in these plants ? Discuss briefly the function of each.

(*b*) The available quantity of water and head at a proposed site of hydro-electric power plant is 400 m^3/sec and 30 m respectively. Assuming the turbine efficiency of 90% and speed of 250 r.p.m., find the least number of turbines required if (*i*) Francis turbine with a specific speed of 300 is used, and (*ii*) Kaplan turbine with a specific speed of 800 is used.

19. (*a*) Explain the construction of flow duration curve and discuss its significance.

(*b*) What do you understand by 'pump storage power plant' ? What are the advantages and limitation of this plant ? Where should such plants be best applied ?

(*c*) Define specific speed as applied to water turbines. What information does specific speed give and how is it used in practice ?

20. (*a*) What different methods are used to measure the rainfall ? Explain any one of them.

(*b*) Define hydrograph and explain its importance in the design of storage type hydro electric power plants.

(*c*) A run-off rate of 400 m/s and head of 45 m is available at a site proposed for hydro-electric power plant. Assuming the turbine efficiency of 90% and speed of 250 r.p.m. find the least number of machines all of equal size required if (*i*) Francis turbine not greater than 200 specific speed or (*ii*) Kaplan turbine not greater than 600 specific speed is used.

21. (*a*) What different methods are used to find the average rainfall ? Discuss the relative merits. Explain the methods.

(*b*) A test is conducted on a model of $\frac{1}{4}$ size of prototype under the head of 36 m to find the performance of prototype. The head available for the prototype is 100 m and it has to run at 428 r.p.m. Find the power developed by the prototype. The H.P. developed by the model is 135 H.P. when the water supplied is 0.324 m^3/s. Assume the efficiency of the prototype 3% greater than the efficiency of the model. State the type of runner used.

22. Write short notes on the following (5 × 4) :

(*i*) Governing of water turbines ; (*ii*) Circuit breakers ;

(*iii*) Magneto hydrodynamics (MHD) ; (*iv*) Moderators in nuclear power plants.

23. (*a*) Explain the various methods used for calculating the average of rainfall depending upon the area of basin.

(*b*) What are the different factors to be considered while selecting the site for hydro-electric power plant ?

(*c*) A turbine is to run at 200 r.p.m. under the available head of 25 m. The flow rate available is 9 m^3/sec. If the turbine efficiency is 90%, calculate (*i*) the specific speed, (*ii*) power developed, and (*iii*) speed and power, if the head is reduced to 15 m.

24. (*a*) Describe the function of surge tank and penstock used in the storage type hydro-electric plant.
(*b*) Explain briefly with line sketch a typical high pressure intake head works for a hydro-electric power station.
(*c*) A model is to be designed to find the performance of a prototype Francis runner. The prototype turbine has to develop 50,000 hp under a head of 225 m. The available head and flow in the laboratory for model testing are 36 m and 0.17 m^3/sec. The prototype runner runs at 600 r.p.m. and assuming overall efficiency of 90%, calculate (*i*) suitable scale ratio for the model, (*ii*) power developed by the model and (*iii*) the speed of the model runner.

25. (*a*) What are the factors to be taken into consideration for the selection of a hydroelectric plant ?
(*b*) Draw line sketch of a small medium head hydroplant showing dam, headworks, penstock and powerhouse.
(*c*) A hydroelectric station is to be designed for a catchment area of 102.5 sq. km, run-off 70 percent and the average rain as 127 cm. The head available is 381 metres. What power in MW can be developed if the overall efficiency of the plant is 80 percent ?

26. (*a*) What are the principal factors that make up the unit cost of power generation in a power plant ? Explain in brief how each affects the output cost.
(*b*) Compare steam and hydro plants as regards fixed and operating costs.
(*c*) The yearly duration curve of a certain plant can be considered as a straight line from 20000 to 3000 kW. To meet this load three turbo-generator units, two rated at 10000 kW each and one at 5000 kW, are installed. Determine installed capacity, capacity factor load factor and utilization factor.

27. (*a*) What are the advantages and disadvantages of a hydroelectric power plant over a thermal one ?
(*b*) What do you mean by 'specific speed' of a water turbine ? State its significance.
(*c*) Describe a method of governing a Pelton wheel with a neat sketch.

28. (*a*) Name the different types of hydraulic turbines used in hydel power stations. Also discuss briefly the suitability of each type for a particular range of net heads.
(*b*) Classify hydro plants and explain the use of each plant.
(*c*) Describe briefly the working of a pumped storage plant. Where can each type of plant be installed ?

29. (*a*) Explain the importance of hydrograph and flow duration curve on the selection of reservoir storage capacity. What do you understand by a 'pump storage plant' ?
(*b*) The table below provides data on the load requirement during 24-hour period at a certain location :

Time period	12 mid-night to 6 am	6 am to 10 am	10 am to 6 pm	6 pm to 8 pm	8 pm to 12 mid-night
Load in mW	20	100	160	80	40

If the load is shared by a combination of thermal and 'pump storage hydroplant' with the thermal plant carrying the base load lying somewhere between 80 MW, 100 MW, estimate the energy supplied to the thermal plant in MWh during 24 hours and the overall efficiency of the combined plant.

Assume $\eta_{thermal}$ at full load = 35%

η_{pump} = 80%

$\eta_{hydraulic\ turbine}$ = 90%.

30. (*a*) Enumerate the factors that you would consider while installing a hydropower plant.
(*b*) A turbine developing 7353 kW at a head of 27.4 with an overall efficiency of 80%, is to be supplied from a reservoir. The estimated run-off in m^3/month for 12 consecutive months of 30 days is given below :

$10^7 \times$ (9.64, 10.2, 8.64, 7.51, 6.8, 8.08, 11.34, 9.07, 8.64, 11.35, 9.92, 8.93)

Assuming that the reservoir is full at the beginning determine (*i*) the minimum capacity of the reservoir to assure the required demand and (*ii*) the quantity that is wasted during the year.

31. Write notes on any two of the following :
(*i*) Surge tanks ;
(*ii*) Storage and pondage ;
(*iii*) Electrostatic precipitators.

7

Nuclear Power Plant

7.1. GENERAL ASPECTS OF NUCLEAR ENGINEERING

7.1.1. Atomic Structure

— **Atomic model.** An element is defined as a substance *which cannot be decomposed into other substances*. The *smallest particle* of an element which takes part in chemical reaction is known as an *'atom'*. The word atom is derived from Greek word 'Atom' which means indivisible and for a long time the atom was considered as such. *Dalton's atomic theory* states that (*i*) all the atoms of one element are precisely alike, have the same mass but differs from the atoms of other elements (*ii*) the chemical combination consists of the union of a small fixed number of atoms of one element with a small fixed number of other elements.

Various atomic models proposed by scientists over the last few decades are : 1. Thompson's plum puddling model, 2. Rutherford's nuclear model, 3. Bohr's model, 4. Sommerfeld's model, 5. Vector model, 6. Wave-mechanical model.

— The complex structure of atom can be classified into *electrons* and *nucleus*. The nucleus consists of *protons* and *neutrons* both being referred as *nucleons*. *Protons* are *positively* charged and *neutrons* are *neutral*, thus making complete nucleus as positively charged.

— The *electrons* carry *negative* charge and circulate about the nucleus. As the positive charge on proton particle is equal to the negative charge on electron particle, and the *number of electrons is equal to the number of protons*, atom is a neutral element. Any addition of the number of electrons to the neutral atom will make it negatively charged. Similarly any subtraction of the electrons will make it positively charged. Such an atom is known as *ion* and the process of charging the atom is termed an *ionisation*.

— The nuclear power engineering is specially connected with *variation of nucleons in nucleus*. Protons and neutrons are the particles having the mass of about 1837 times and 1839 times the mass of an electron.