CHAPTER – 3

HYDRAULIC TURBINE CLASSIFICATION AND SELECTION

3.1 Introduction (Reaction Turbines)

The hydraulic turbine is a mechanical device that converts the potential energy contained in an elevated body of water (a river or reservoir) into rotational mechanical energy.

Selecting the type, kind, (within type) configuration, (horizontal or vertical) size, and number of turbine units that best suit a project is a detailed process. Size and number of units are discussed in chapter-2. This involves technical, environmental, financial, and other considerations. The most inexpensive turbine may not be the best solution to the available head and flow. For small hydro up to 5 MW units size standard turbines are recommended. For units above 5 MW size information exchange with turbine manufacturers is recommended for turbine selection at project stage. The selection procedure is prepared for selection of turbine based on the techno economic consideration to permit rapid selection of proper turbine unit, estimation of its major dimensions and prediction of its performance.-

3.2 Site Data

It is presumed that the data with regard to design head (Para 3.2.2) design discharge, number and types of units and capacity are known. Departure from these guidelines for selection etc. as discussed may be necessary to meet the special requirements and conditions of individual sites.

3.2.1 Net Head

The effective head available to the turbine unit for power production is called the net head. Selection of rated and design head requires special attention in reaction turbines. Definition of these heads are given in Para 3.2.2. The turbine rating is given at rated head.

Determination of rated head, design head and maximum and minimum net head is important. Permissible departure from design head for reaction turbines for optimum efficiency and cavitation characteristics based on experience data is shown in table 3.1.

3.2.2 Definition of Head

EFFECTIVE HEAD (Net Head) - The effective head is the net head available to the turbine unit for power production. This head is the static gross head, the difference between the level of water in the Forebay/impoundment and the tailrace water level at the outlet, less the hydraulic losses of the water passage as shown in Figure 3. 1. The effective head must be used for all power calculations. The hydraulic losses can vary from essentially zero for flume-type turbine installations to amounts so significant for undersized outlet conduit that the energy potential of the site is seriously restricted. The hydraulic losses in closed conduit can be calculated using the principles set out in general hydraulic textbooks. In addition to conduit losses, an allowance for a loss through the intake structure should also be included. In general a hydraulic loss of one velocity head (velocity squared divided by 2 x acceleration due to gravity) or greater would not be uncommon. The hydraulic losses through the turbine and draft tube are accounted for in the turbine efficiency.

Gross Head (H_g) – is the difference in elevation between the water levels of the forebay and the tailrace.

Maximum Head ($H_{max.}$) – is the gross head difference in elevation between the maximum forebay (head water) level without surcharge and the tailrace level without spillway discharge, and with one unit operating at speed no-load (turbine discharge of approximately 5% of rated flow). Under this condition, hydraulic losses are negligible and may be disregarded.

Minimum Head ($H_{min.}$) – is the net head resulting from the difference in elevation between the minimum forebay (head water) level and the tailrace level minus losses with all turbines operating at full specified gate opening.

Table 3. 1

Type of turbine	Maximum head (percent h_d)	Minimum head (percent h_d)
Francis	125	65
Propeller – fixed blade turbine	110	90
Kaplan – Adjustable blade propeller turbine	125	65

Weighted Average Head - is the net head determined from reservoir operation calculations which will produce the same amount of energy in kilowatt-hours between that head and maximum head as is developed between that same head and minimum head.

Design Head (h_d) – is the net head at which peak efficiency is desired. This head should preferably approximate the weighted average head, but must be so selected that the maximum and minimum heads are not beyond the permissible operating range of the turbine. This is the head which determines the basic dimensions of the turbine and therefore of the power plant.

IEC Definitions - IEC defines head as specific hydraulic energy (J/kg) available between the high and low pressure sections of the machine.

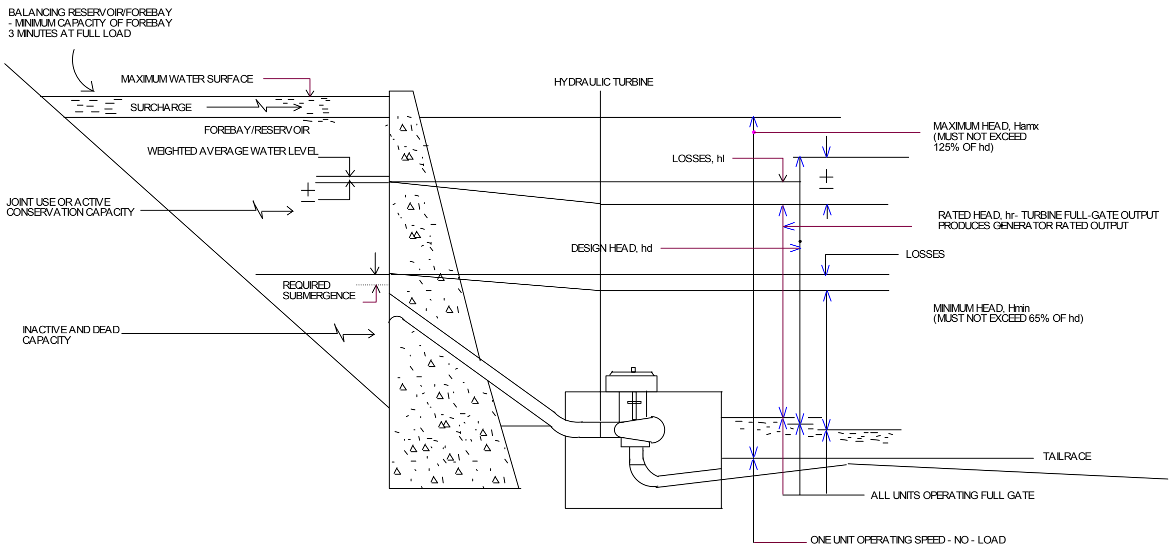


Figure 3. 1

Rated head (h_r) – is the net head at which the full-gate output of the turbine produce the generator rated output in kilowatts. The turbine nameplate rating usually is given at this head. Selection of this head requires foresight and deliberation.

Permissible range of head for reaction turbines for optimum efficiency and cavitation characteristics based on experience data is given in table 3.1.

3.3 CLASSIFICATION AND TYPES OF TURBINES

Turbines can be either reaction or impulse types. The turbines type indicates the manner in which the water causes the turbine runner to rotate. Reaction turbine operates with their runners fully flooded and develops torque because of the reaction of water pressure against runner blades. Impulse turbines operate with their runner in air and convert the water's pressure energy into kinetic energy of a jet that impinges onto the runner buckets to develop torque.

Reaction turbines are classified as Francis (mixed flow) or axial flow. Axial flow turbines are available with both fixed blades (Propeller) and variable pitch blades (Kaplan). Both axial flow (Propeller & Kaplan) and Francis turbines may be mounted either horizontally or vertically. Additionally, Propeller turbines may be slant mounted.

3.3.1 Francis Turbines

A Francis turbine is one having a runner with fixed buckets (vanes), usually nine or more, to which the water enters the turbine in a radial direction, with respect to the shaft, and is discharged in an axial direction. Principal components consist of the runner, a water supply case to convey the water to the runner, wicket gates to control the quantity of water and distribute it equally to the runner and a draft tube to convey the water away from the turbines.

It exists in large numbers throughout the world. It is applied at head ranges generally from about 15 to 750 meters and in power ranges from about 0.25 to 800 MW per unit. There are also numerous small units at very low heads.

A Francis turbine may be operated over a range of flows approximately 40 to 105% of rated discharge. Below 40% rated discharge, there can be an area of operation where vibration and/or power surges occur. The upper limit generally corresponds to the generator rating. The approximate head range for operation is from 65% to 125% of design head. In general, peak efficiencies of Francis turbines, within the capacity range of 25 MW, with modern design tool like CFD (computational fluid dynamics) have enabled to achieve peak efficiency in the range of 93 to 94%.

The conventional Francis turbine is provided with a wicket gate assembly to permit placing the unit on line at synchronous speed, to regulate load and speed, and to shutdown the unit. The mechanisms of large units are actuated by hydraulic servomotors. Small units may be actuated by electric motor gate operations. It permits operation of the turbine over the full range of flows. In special cases, where the flow rate is constant, Francis turbines without wicket gate mechanisms may be used. These units operate in case of generating units in Micro Hydro range (up to 100 kW) with Electronic Load Controller or Shunt Load Governors. Start up and shut down of turbines without a wicket gate is normally accomplished using the shut off valve at the turbine inlet. Synchronizing is done by manual load control to adjust speed.

Table 3.2: Indian Project Data of Francis Turbine
Source: - Bharat Heavy Electrical Ltd. India Publication Entitled "Hydro-Electric Installation"

S. No	Power Station	Agency	No. of units x size (MW)	Head (M)	Speed (RPM)	Year of Commissioning (expected)	Specific speed	Type of turbine	Specific speed Ns marked in Figure 3.12
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1.	Nathpa Jakhri (BHEL Unit)	NJPC	1 x 250	428	300	2003	93.32	Vertical Francis	52
2.	Dehar	BCB	6 x 165	282	300	1977	203.21	Vertical Francis	53
3.	Pong	BCB	6 x 60	65.5	166.7	1978	265.38	Vertical Francis	54
4.	Chibro	UPSEB	4 x 60	110	250	1975	208.18	Vertical Francis	55
5.	Khodri	UPSEB	4 x 30	57.9	200	1984	262.69	Vertical Francis	56
6.	Khara	UPSEB	3 x 24	42.6	187	1992	322.37	Vertical Francis	57
7.	Khandong	NEEPCO	2×25	99.0	333.3	1984	204.37	Vertical Francis	12
8.	Kakkad	KSEB	2×25	123.5	428.6	1999	199.34	Vertical Francis	13
9.	Mahi Stage-I	RSEB	2×25	40.0	150.0	1986	285.53	Vertical Francis	14
10.	Doyang	NEEPCO	3×25	67.0	250.0	2000	249.74	Vertical Francis	15
11.	Khara	UPSEB	3×24	42.6	187.0	1992	322.37	Vertical Francis	16

S. No	Power Station	Agency	No. of units x size (MW)	Head (M)	Speed (RPM)	Year of Commissioning (expected)	Specific speed	Type of turbine	Specific speed Ns marked in Figure 3.12
12.	Pattani	EGA Thailand	3×24	58.0	214.3	1981	251.19	Vertical Francis	17
13.	Tenom Pangi	SEB Malaysia	3×22	66.6	300.0	1983	283.24	Vertical Francis	18
14.	Kundah-V	TNEB	1×21.6	259.1	750.0	1988	128.42	Vertical Francis	19
15.	Madhikheda	MPEB	3×20	52.75	250.0	2005	301.19	Vertical Francis	20
16.	Rangit	NHPC	3×20	129.67	428.6	2000	167.76	Vertical Francis	21
17.	Birsinghpur	MPEB	1×20	40.0	200.0	1991	340.51	Vertical Francis	22
18.	Poringal Kuthu	KSEB	1×16	165.3	600.0	1999	155.07	Vertical Francis	23
19.	Bhatsa	GOM	1×15	70.0	375.0	1991	274.71	Vertical Francis	24
20.	Sumbal Sindh	Govt. of J&K	2×11.3	149.0	500.0	1973	123.65	Vertical Francis	25
21.	Gumma	HPSEB	2×1.5	176.75	1500.0	2000	109.17	Vertical Francis	26
22.	Karnah	Govt. of J&K	2×1.0	36.0	750.0	1991	325.72	Vertical Francis	27

Francis turbines may be mounted with vertical or horizontal shafts. Vertical mounting allows a smaller plan area and permits a deeper setting of the turbine with respect to tailrace water elevation locating the generator below tailrace water. Turbine costs for vertical units are higher than for horizontal units because of the need for a larger thrust bearing. However, the savings on construction costs for medium and large units generally offset this equipment cost increase. Horizontal units are more economical for smaller sets with higher speed applications where standard horizontal generators are available. A typical horizontal axis Francis turbine is shown in figure 3.2.

The water supply case is generally fabricated from steel plate. However open flume and concrete cases may be used for heads below 15 meters.

Francis turbines are generally provided with a 90-degree elbow draft tube, which has a venturi design to minimize head loss. Conical draft tubes are also available, however the head loss will be higher and excavation may be more costly.

A list of typical large and small hydro projects with Francis turbines in the country manufactured/supplied by M/s Bharat heavy Electricals Ltd. (BHEL) – the largest manufactures of hydro electric equipment in the country is given in table 3.2.

A typical vertical Francis turbine transverse section of Bhakra Left Bank power plant (5 x 90MW) is shown in figure 3.3 (a) & figure 3.3 (b). This is the first large power house designed indigenously with the help of American consultants with imported machines and commissioned 1st unit in 1960. The power units were subsequently updated, renovated and modernized.

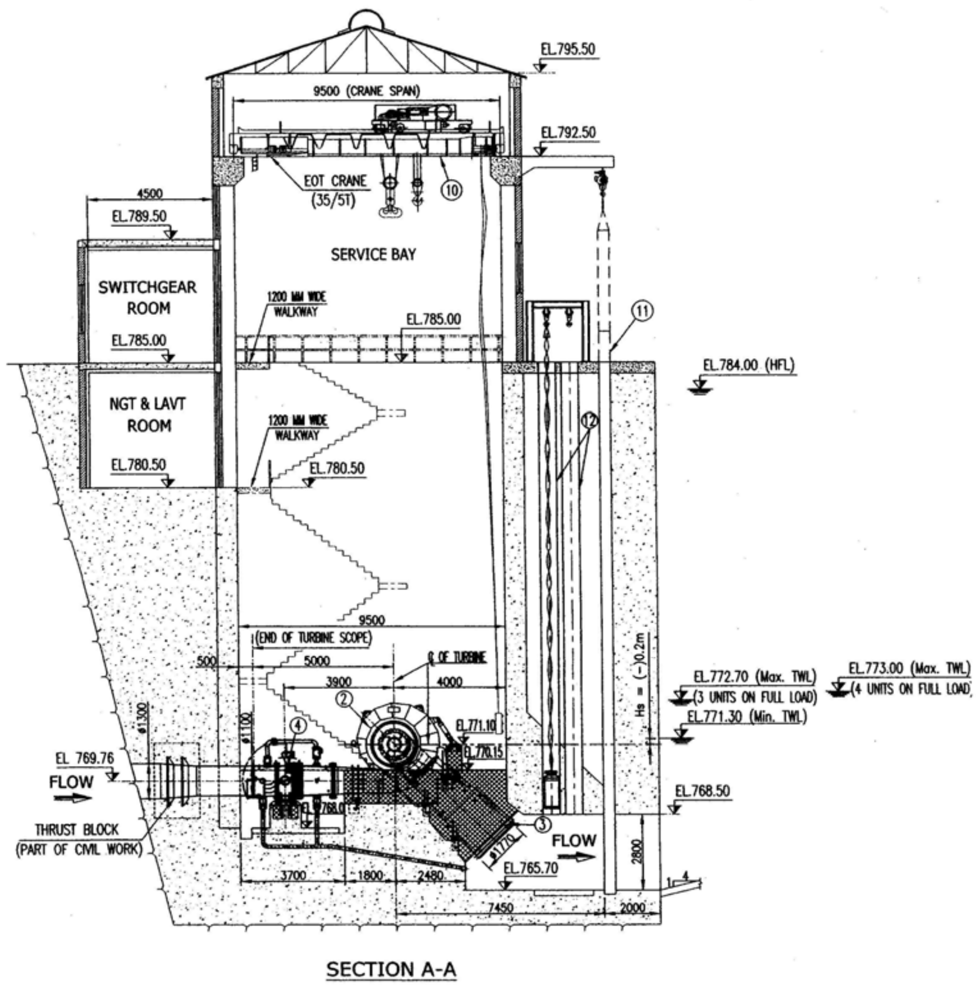
Provision for removing runner from below through an access gallery after removal of bottom cover for quick repair of excessive pitting, metal erosion, corrosion in case of presence of injurious elements in water is sometimes made.

3.3.2 Axial Flow Turbines

Axial flow turbines are those in which water flow through the runner is aligned with the axis of rotation. Axial flow hydraulic turbines have been used for net heads up to 75 meters with power output up to 200

MW. However, they are generally used in head applications below 35 meters. Tubular turbines (S-type) are used below 30 meters head and 8 MW capacity. Bulb units can be used to about 25 meters head and up to about 100 MW capacity. In SHP Bulb units can be used for low heads if runner diameter is more than 1 meter. Specific mechanical designs, civil construction, and economic factors must be given full consideration when selecting among these three axial flow turbine arrangements.

A Kaplan/propeller turbine is one having a runner with three, four, five or six blades in which the water passes through the runner in an axial direction with respect to the shaft. The pitch of the blades may be fixed or movable. Principal components consist of a water supply case, wicket gates, a runner and a draft tube. Axial flow turbine with movable blades is called Kaplan turbines. Axial flow turbines with fixed blades is called propeller turbine. An axial flow turbine with movable blades but fixed guide vanes (no wicket gates) is called semi Kaplan turbine.



Rated head	:	103.345 m
Runner diameter	:	856 mm
Type of turbine	:	Horizontal Francis
Rated turbine/generator speed	:	750 RPM
Butterfly valve	:	Ø 1100

Figure 3.2: Horizontal Francis Turbine (4 x 4000 kW) Halaipani Project (Arunachal Pradesh) (Source: AHEC Projects Data)

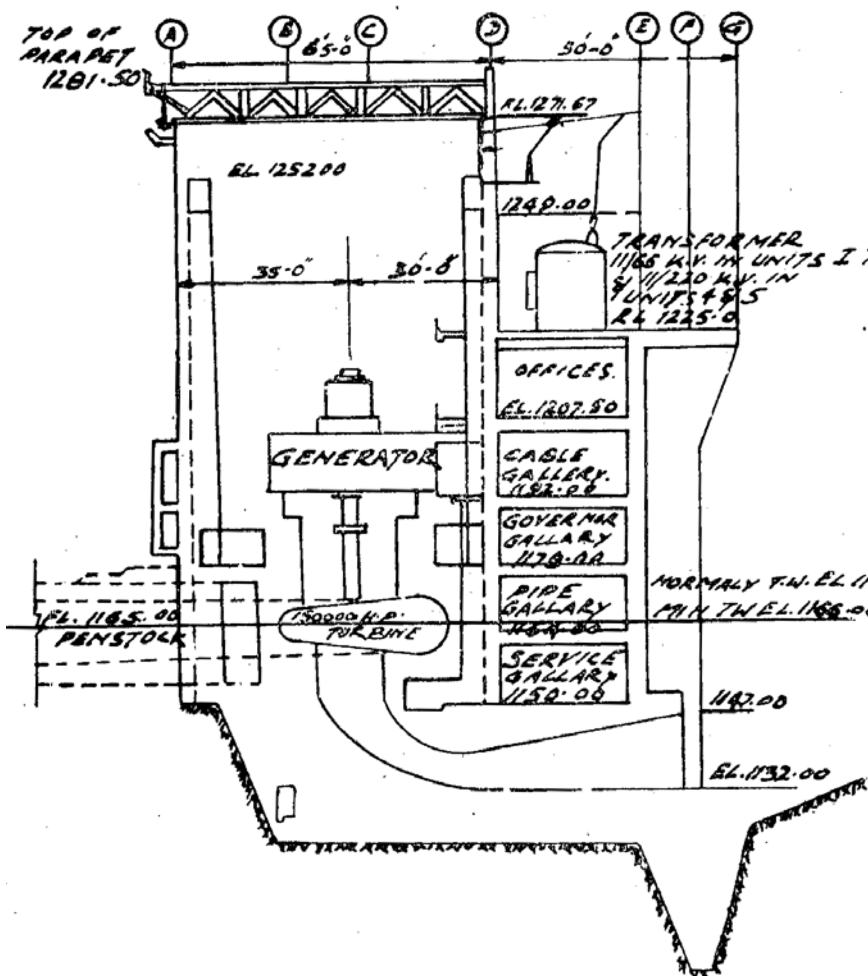


Figure 3.3 (a) Bhakra Left bank Power Plant No. 1 Transverse Section (1960) (Hitachi Turbines) (Dimensions in feet & inches)

Turbine – Vertical Francis Type	Max. head (m)	Rated & Design Head (m)	Min. head (m)
Net Head (m)	156.06	121.92	87.79
Output (h.p.)	150,000 (112 MW)	150,000(112 MW)	71,000 (53 MW)
Efficiency at 100% output	91.1%	91.1%	86.3%
Discharge Rated M^3/sec.		102.3	
Speed r.p.m.	338 (runaway)	166.7	166.7
Runner			
Normal dia. (mm)	4157		
No. of blades	17		
Weight	29.46 (Tonnes)		
Setting H_s (ft.)	- 1		
Spiral Casing	Inlet dia. mm 3962.4		

Note: Unit Capacity after Renovation, Modernization and updating was increased to 108 MW and propose further updating to 126 MW.

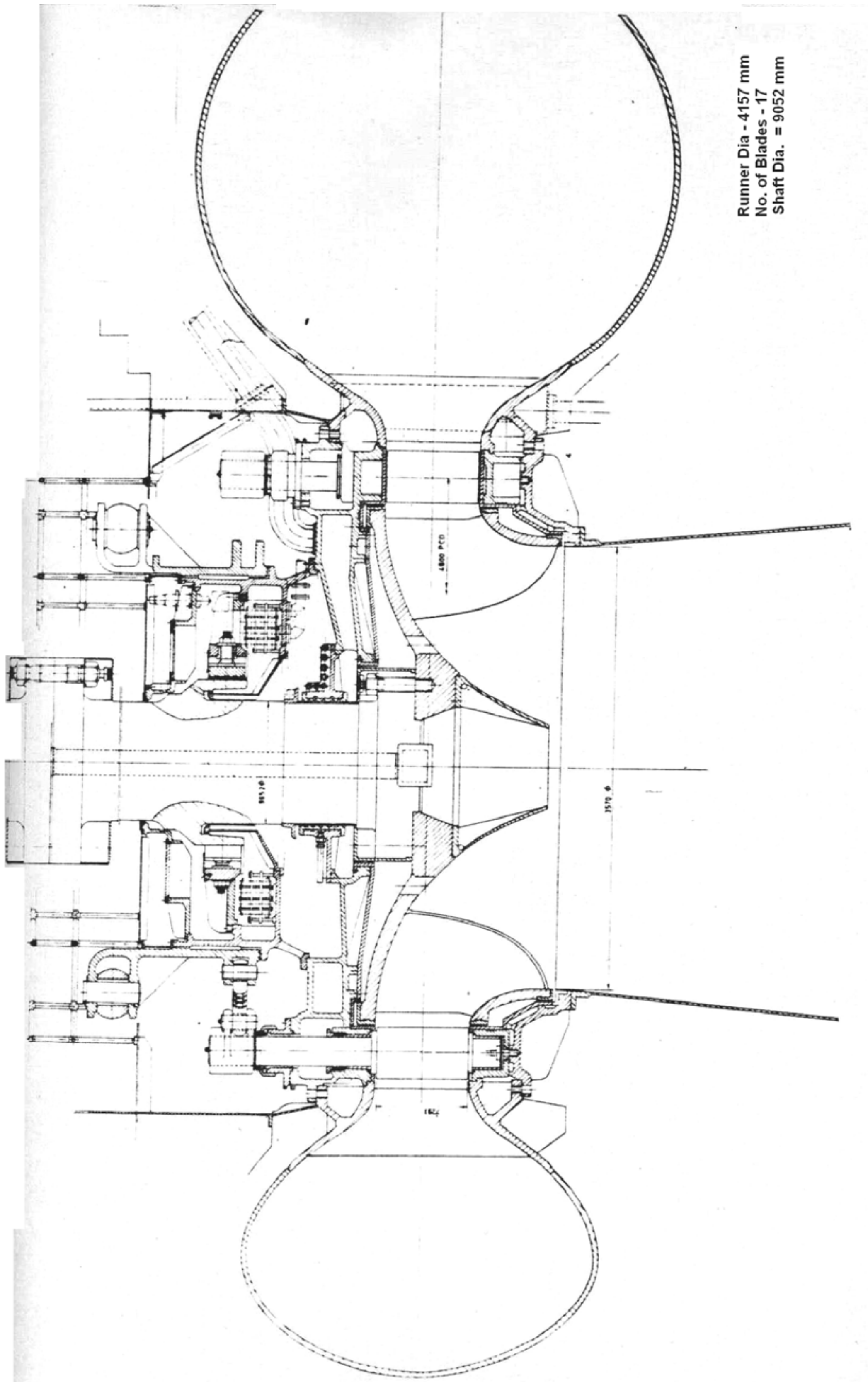


Figure 3.3 (b): Bhakra Left Bank Francis Turbine (Section through Turbine)
(Source: Notes compiled from uprating as Member uprating committee)

The efficiency curve of a typical fixed blade Propeller turbine forms a sharp peak, more abrupt than a Francis turbine curve. For variable pitch blade units the peak efficiency occurs at different outputs depending on the blade setting. An envelope of the efficiency curves cover the range of blade pitch settings forms the variable pitch efficiency curve. This efficiency curve is broad and flat. Fixed blade units are less costly than variable pitch blade turbines; however, the power operating ranges are more limited.

Turbine manufacturers have developed runner designs for a head range of 3 to 40 meters. Four blade designs may be used up to 12 meters of head, five blade designs to 20 meters and six blade designs to 35 meters. In general, peak efficiencies are approximately the same as for Francis turbines.

Kaplan turbines may be operated at power outputs with flow from 40-105% of the rated flow. Discharge rates above 105% may be obtained; however, the higher rates are generally above the turbine and generator manufacturers' guarantees. Many units are in satisfactorily operation from 60 to 140% of design head. Efficiency loss at higher heads drops 2 to 5% points below peak efficiency at the design head and as much as 15% points at lower heads.

Kaplan (variable pitch blade) turbines are mounted with a vertical shaft. Horizontal and slant settings will be discussed separately. The vertical units are equipped with a wicket gate assembly to permit placing the unit on line at synchronous speed, to regulate speed and load, and to shutdown the unit. The wicket gate mechanism units are actuated by hydraulic servomotors. Small units may be actuated by electric motor gate operators. Variable pitch units are equipped with a cam mechanism to coordinate the pitch of the blade with gate position and head. Digital control envisages Control of wicket gates and blade angle by independent servomotors coordinated by digital control. The special condition of constant flow, as previously discussed for Francis turbines, can be applied to propeller turbines. For this case, elimination of the wicket gate assembly may be acceptable.

The advantage and disadvantages discussed above with regard to vertical versus horizontal settings for Francis turbines apply also to propeller turbines.

The water supply case is generally concrete. Either an open flume or a closed conduit type of construction may be used. Open flume construction may be economical when heads are below 13 meters. At higher heads the turbine shaft length becomes excessive. Also open flume construction is disadvantageous with regard to maintenance costs. The wicket gate assembly and guide bearing are water lubricated causing additional maintenance particularly when silt or debris is in the water

Table 3.3: Typical Indian Project Data of Kaplan/Propeller Turbine
Source: - Bharat Heavy Electrical Ltd. India Publication Entitled "Hydro-Electric Installation"

S. No	Power Station	Agency	No. of units x size (MW)	Head (M)	Speed (RPM)	Year of Commissioning (expected)	Specific speed (N_s)	Type of turbine	Specific speed H marked in Figure 3.12
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1.	Ukai	GEB	4 x 75	47.8	150	1974	395.82	Vertical Kaplan	58
2.	Sardar Sarovar (CHPH)	SSNNL	5 x 50	36	136.4	2004	418.88		59
3.	Garhwal Risikesh Chilla	UPSEB	4 x 36	32.5	187.5	1980	555.22		60
4.	Obra	UPSEB	3 x 33	20.4	115.4	1970	285.59		61
5.	Baliamela	APSEB	2 x 30	35.8	187.5	2008	449.13		62
6.	Balimela Dam	APSEB	2×30	35.8	187.5	2008	449.13		28.
7.	Donkarai	APSEB	1×25	21.0	136.4	1983	580.99		29.
8.	Mukerian Phase-III & IV	PSEB	6×19.5	22.0	166.7	1989	591.68		30.
9.	SYL Phase-I	PSEB	2×18	15.3	136.4	2010	732.41		31.
10.	UBDC Stage-II	PSEB	3×15	17.1	166.7	1989	711.05		32.

11.	UBDC	PSEB	3×15	17.1	150.0	1971	639.82		33.
12.	Mukerian Phase-I & II	PSEB	6×15	16.8	150.0	1983	654.13		34.
13.	Bansagar Phase-II	MPEB	2×15	21.0	166.7	2002	550.01		35.
14.	Kabini	SP&ML	2×10	18.0	200.0	2003	653.29		36.
15.	Pochampad	APSEB	3×9	21.4	250.0	1987	624.04		37.
16.	Mukerian Stage-II	PSEB	2×9	8.23	125.0	2009	1030.26	Bulb turbine	38.
17.	Singur	APSEB	2×7.5	18.29	250.0	1999	693.22	Vertical Kaplan	39.
18.	Teesta Canal	WBSEB	4×7.5	8.0	142.9	1999	1113.95		40.
19.	Bhadra R.B.	KPCL	1×6	17.0	214.0	1998	581.56		41.
20.	Narayanpur	MPCL	2×5.8	6.5	111.1	1999	987.31		42.
21.	Suratgarh	RSEB	2×2	8.66	187.5	1992	683.57		43.
22.	Mangrol	RSEB	3×2	7.27	166.7	1992	756.31		44.
23.	Sone Western Canal	BSHPC	4×1.65	3.7	120.0	1993	1150.37		45.
24.	Dhupdal	FORBES Gokak Mills	2×1.4	4.8	158.0	1997	1107.71		46.
25.	Nidampur	PSEB	2×0.5	3.0	136.4	1985	935.54	Horizontal Propeller/Kaplan	47.
26.	Dauhar	PSEB	3×0.5	3.5	136.4	1987	771.58		48.
27.	Ganekal	KPCL	1×0.35	3.69	136.4	1994	604.27		49.
28.	Kakatiya (19th Mile)	APSEB	3×0.23	3.3	166.7	1987	688.37		50.
29.	Kakroi	University of Roorkee	1×0.1	1.9	125.0	1988	678.63		51.

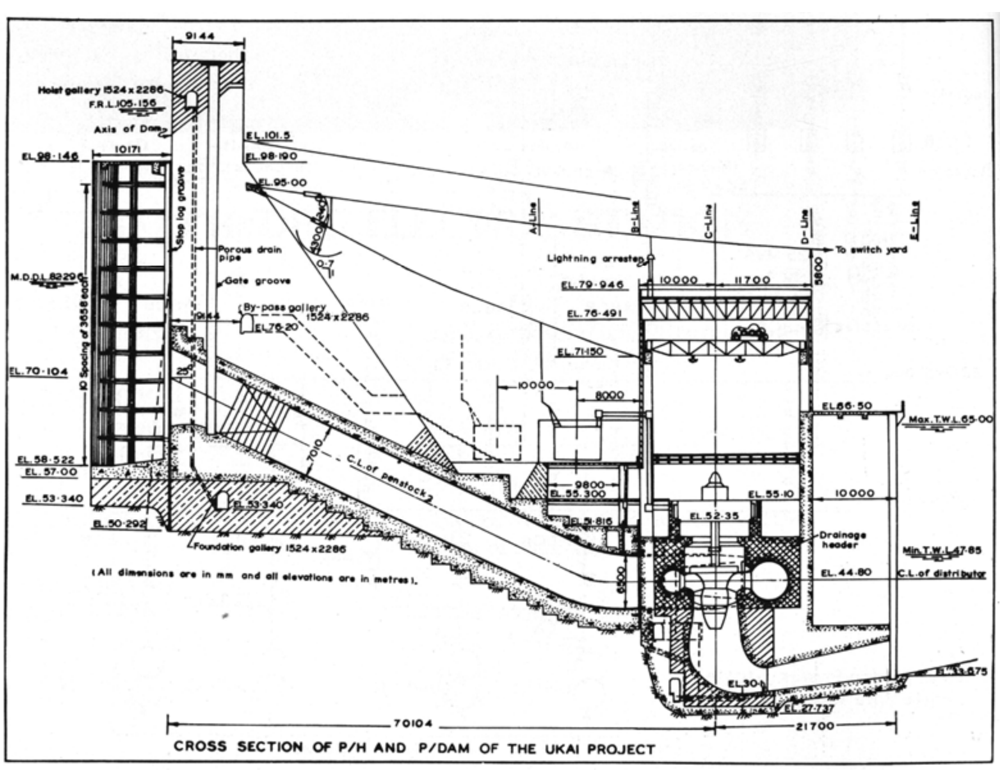


Figure 3.4: UKAI Power House – Transverse Section – Vertical Kaplan (Gujarat)
(Source: CBI & P Publication No. 288))

Water Turbines

a)	Numbers	4
b)	Type	Vertical Kaplan
c)	Net Head (Rated)	47.8 m
d)	Rated output of each unit	1, 05,000 MHP (75 MW)
e)	Normal speed	150 rpm
f)	Runaway speed	300 rpm

At capacities above 1500 kW, wicket gate and guide bearing loading are such that an open flume may not be a satisfactory choice. For closed conduits, spiral cases of steel or concrete may be used. The concrete case is generally less costly. The cross-section of a concrete case, taken in a direction radial to the shaft is usually rectangular.

The draft tube designs discussed for Francis turbines apply also to propeller turbines.

Typical large and small hydro projects with Indigenous Kaplan/Propeller turbine in the country is given in table 3.3. Typical transverse section of large vertical Kaplan turbine is shown in figure 3.4.

Tubular Turbines: Tubular or tube turbines are horizontal or slant mounted units with propeller runners. The generators are located outside of the water passageway. Tube turbines are available equipped with fixed or variable pitch runners and with or without wicket gate assemblies.

Performance characteristics of a tube turbine are similar to the performance characteristics discussed for propeller turbines. The efficiency of a tube turbine will be one to two % higher than for a vertical propeller turbine of the same size since the water passageway has less change in direction.

The performance range of the tube turbine with variable pitch blade and without wicket gates is greater than for a fixed blade propeller turbine but less than for a Kaplan turbine. The water flow through the turbine is controlled by changing the pitch of the runner blades.

When it is not required to regulate turbine discharge and power output, a fixed blade runner may be used. This results in a lower cost of both the turbine and governor system. To estimate the performance of the fixed blade runner, use the maximum rated power and discharge for the appropriate net head on the variable pitch blade performance curves.

Several items of auxiliary equipments are often necessary for the operation of tube turbines. All tube turbines without wicket gates should be equipped with a shut off valve automatically operated to provide shut-off and start-up functions.

Tube turbines can be connected either directly to the generator or through a speed increaser. The speed increaser would allow the use of a higher speed generator, typically 750 or 1000 (1500) r/min, instead of a generator operating at turbine speed. The choice to utilize a speed increaser is an economic decision. Speed incresers lower the overall plant efficiency by about 1% for a single gear increaser and about 2% for double gear increaser. (The manufacturer can supply exact data regarding the efficiency of speed increasers). This loss of efficiency and the cost of the speed increaser must be compared to the reduction in cost for the smaller generator. It is recommended that speed increaser option should not be used for unit sizes above 5 MW capacity.

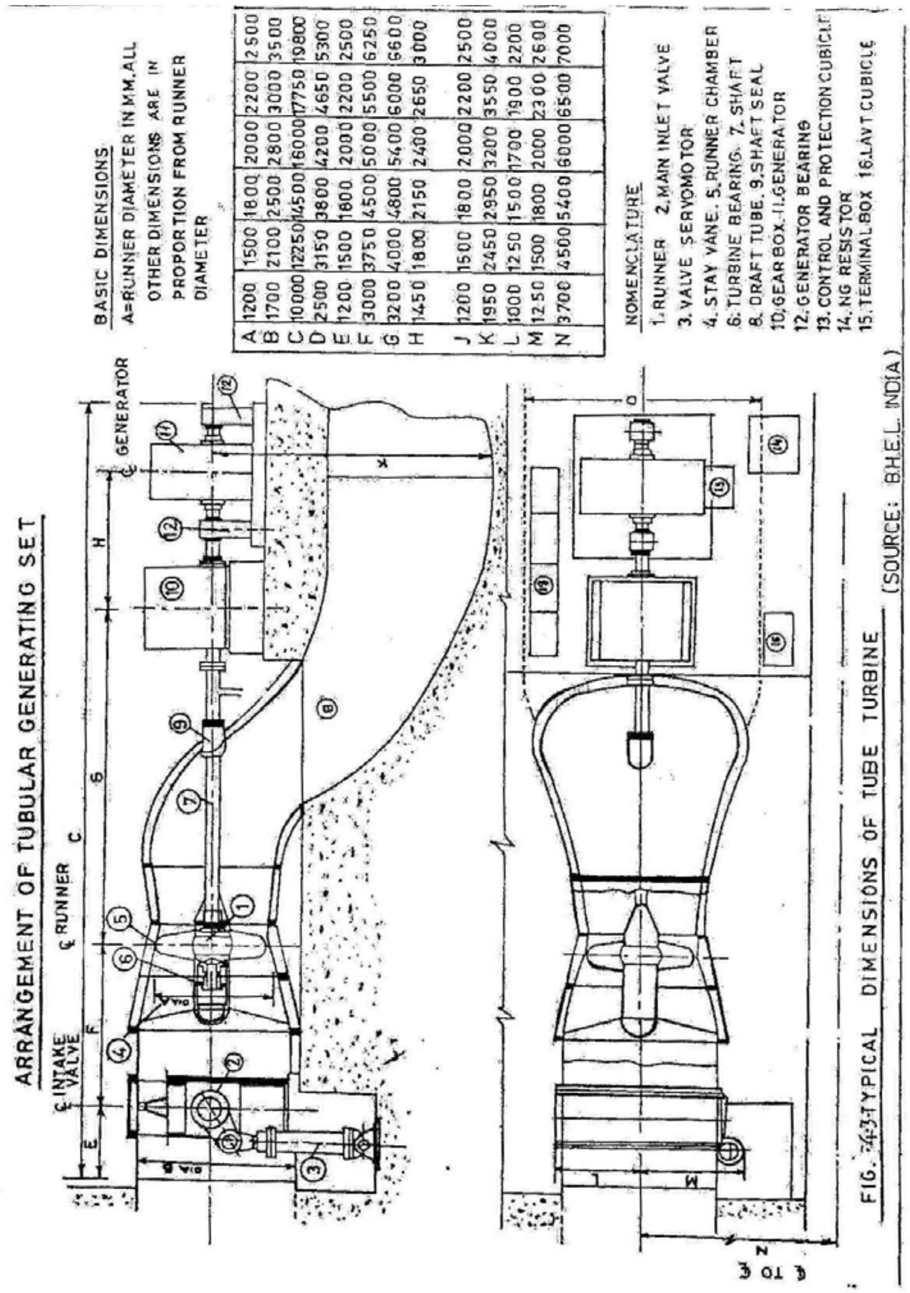


Figure 3.5 Typical Dimension of Tube Turbine (Source: BHEL India)

The required civil features are different for horizontal units than for vertical units. Horizontally mounted tube turbines require more floor area than vertically mounted units. The area required may be lessened by slant mounting, however, additional turbine costs are incurred as a large axial thrust bearing is required. Excavation and powerhouse height for a horizontal unit is less than that required for a vertical unit. Standard Tube turbines of Bharat Heavy Electricals based on runner diameter is shown in Figure 3.5. A large number of these turbines are installed in the country. First ultra low head (1.9 m) 100 kW tubular turbine indigenous made by (BHEL) on a branch canal was installed as an experimental measure to demonstrate economic viability of a large no. of such falls in the country. This is discussed in detail in chapter 13.

Bulb Turbines: Bulb Turbines are horizontal, axis having propeller runners directly connected to the generator. The generator is enclosed in a water-tight enclosure (bulb) located in the turbine water passageway. The bulb turbine is available with fixed or variable pitch blades and with or without a wicket gate mechanism. Performance characteristic are similar to the vertical and Tube type turbines previously discussed. The bulb turbine will have an improved efficiency of approximately 2% over a vertical unit and

1% over a tube unit because of the straight water passageway. Due to the compact design, powerhouse floor space and height for Bulb turbine installations are minimized. Maintenance time due to accessibility, however, may be greater than for either the vertical or the tube type turbines.

Figure 3.6 shows bulb turbine installation proposed for Mukerain SHP 2 x 9 MW at rated and design head 8.23 m.

Comparison between Vertical Kaplan and Horizontal Bulb -Water Passage:
The main difference between the Bulb turbine and the vertical Kaplan turbine is the water passage. In case of a vertical turbine the direction of flow of the water changes several times, first in the spiral case, then in the space between guide vanes and runner and lastly in the draft tube for reaching the horizontal direction into the tail water. In case of a Bulb turbine the water passes the flow canal nearly straight lined. Strong changes in direction of flow are avoided by arranging the unit shaft horizontally or slightly inclined. From these differences in the two types of turbines many advantages in use of bulb turbines occur.

Hydraulic Features of Bulb Turbines: Due to the higher flow velocity in a Bulb turbine the hydraulic losses from the intake to the guide vanes are somewhat higher than those of a Kaplan turbine; this is the same for the inlet and outlet losses. However, the flow between guide vane and runner is nearly free of changes of direction and the draft tube efficiency due to the straight draft tube with a uniform velocity distribution at the outlet is more favourable than that of a Kaplan turbine. These advantages cause an improvement of the hydraulic efficiency of the bulb turbine at full discharge in the range of overload and compared with the Kaplan turbines a flatter efficiency curve is obtained.

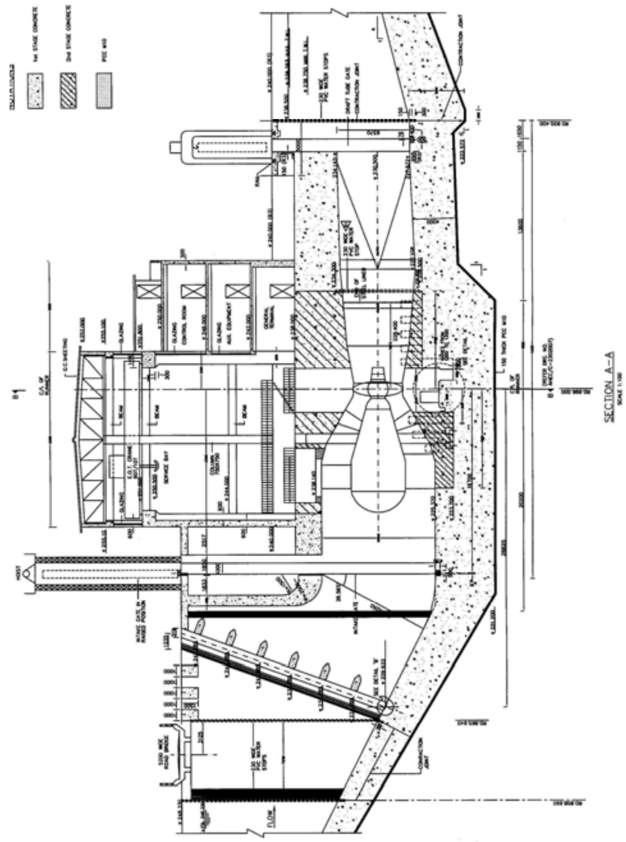


Figure 3.6 Bulb Turbine for Mukerian SHP 2 x 9 MW
(Source: AHEC Specification)

The discharge of a bulb turbine is higher with the same efficiency than the discharge of Kaplan turbine. Comparisons shows that due to these reasons the bulb turbine can be designed with a runner diameter 15 percent smaller and be rated with a higher speed of 20-25 percent to reach the same output and efficiency as the Kaplan turbine at given technical data of the plant.

During one revolution each point of a runner blade of a Vertical Kaplan turbine moves in a Horizontal plane, that means under the same suction head and thus under the same cavitation conditions. In case of the horizontally arranged bulb turbine, however, one blade during one revolution passes several suction heads.

Caused by the changing cavitation along the runner diameter a periodic cavitation noise or periodic pressure fluctuations may occur. The most endangered range of cavitation is the periphery of the blades in its topmost position. Each blade, however, passes the range within a short time. With regard to economic reasons this extent of cavitation condition is permitted without impairing the operating conditions or endangering the turbine.

If a bulb turbine and a Vertical Kaplan turbine have the same velocity of flow in the runner, the cavitation behaviour of the bulb turbine is better. That means that either a higher installation or higher speed is possible with the same unit power.

Advantages in Civil Works: From the hydraulic conditions of bulb turbines considerable advantages result for the civil engineering. Turbine intake and draft tube are easy to form, the spiral can be completely omitted. The straight-lined design of the turbine inlet permits a reduction of the distance between the units of above 30 percent and thus saving in the width of the power plant. The longitudinal distance from the turbine inlet to the draft tube outlet is about the same as for vertical units. The height of the power plant can also be reduced. Besides the essentially reduced volume of civil work also the simple sheeting due to the omission of the elbows reduce the cost of civil works considerably.

Vertical Semi-Kaplan Turbine with Syphon Intake: These are Low specific speed Vertical semi-Kaplan turbine set above maximum tailrace level with Syphon intake with adjustable runner blade and fixed guide vane. As the name suggests, the Vertical Turbine with Syphon Intake operates on the Syphon Principle i.e. the intake flume chamber valve is closed and made water tight and vacuum is created by a vacuum pump which enables water to enter flume chamber and energize the runner. Shut down is brought about by following the reverse procedure i.e. by breaking vacuum. Since turbine operates on a Syphon Principle, it is not necessary to have Intake and Draft gates thereby reducing the cost. The Syphon Intake semi Kaplan Vertical Turbine part load efficiency at about 30% load is about 76%. Turbine is suitable for variable head also. Dewatering and drainage arrangements are also not required.

This type of turbine has been found to be very economical for canal drop falls (up to 3-4 m head). The turbine is set above maximum tailrace water level and hence lower specific speed. A typical installation is shown in figure 3.7. A list of such typical installation is given in table 3.4.

Table 3. 4: Projects on canal falls with Vertical Semi Kaplan Turbines with Syphon Intakes (AHEC Project)

Sl. No	Power Station	Sponsorer/ Manufacturer	No. of Units x Size (MW)	Head (M)	Speed (RPM)	Year/ Likely year of Commissioning	Specific Speed (Ns)	Type of Turbine	Type of Generator
BIHAR									
1.	Shirkhinda SHP	HPP Energy (India) Pvt. Ltd.	2x0.350	3.186	135	2010	744.89	Vertical Semi Kaplan with Syphon Intake	Synchronous Generator Vertical
2.	Belsar SHP	HPP Energy (India) Pvt. Ltd.	2x0.500	3.22	129	Under commissioning/construction	763.22	Vertical Semi Kaplan with Syphon Intake	Synchronous Generator Vertical
3.	Tejpura SHP	HPP Energy (India) Pvt. Ltd.	2x0.750	3.46	107	Under commissioning/construction	770.77	Vertical Semi Kaplan with Syphon Intake	Synchronous Generator Vertical
4.	Rajapur SHP	HPP Energy (India) Pvt. Ltd.	2x0.350	4.78	190	Under commissioning/construction	798.55	Vertical Semi Kaplan with Intake Gate	Synchronous Generator Vertical
5.	Amethi SHP	HPP Energy (India) Pvt. Ltd.	1x0.500	3.218	114	Under commissioning/construction	745.97	Vertical Semi Kaplan with Syphon Intake	Synchronous Generator Vertical
6.	Arwal SHP	HPP Energy (India) Pvt. Ltd.	1x0.500	2.926	103	Under commissioning/construction	757.83	Vertical Semi Kaplan with Syphon Intake	Synchronous Generator Vertical
7.	Walidad SHP	HPP Energy (India) Pvt. Ltd.	1x0.700	3.44	116	Under commissioning/construction	751.36	Vertical Semi Kaplan with Syphon Intake	Synchronous Generator Vertical

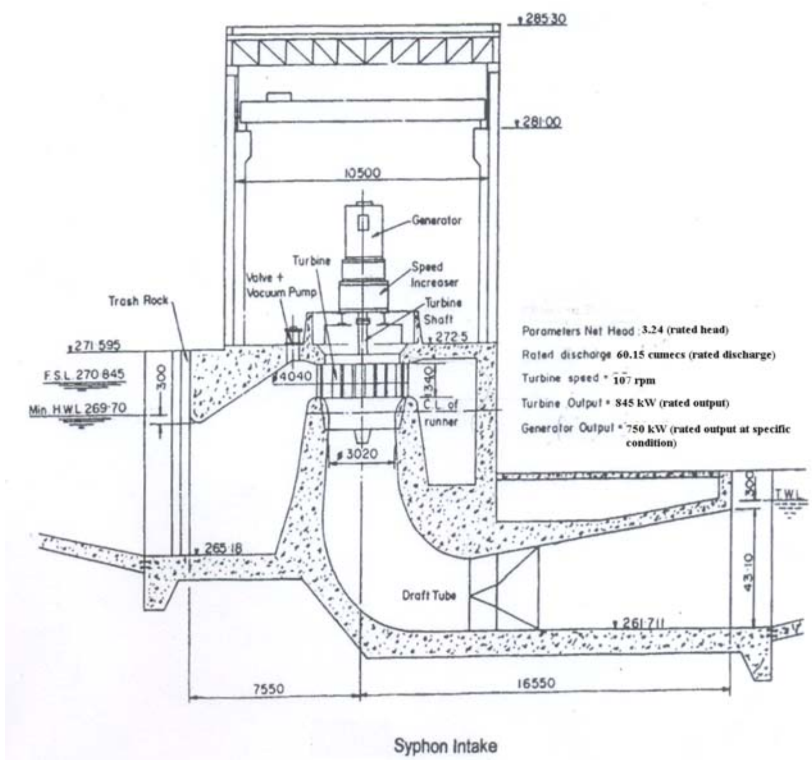


Figure 3.7- Syphon Intake for Tejpura project
(AHEC Project)

Pit Type Bulb Turbine: Pit type turbine is a variation of S-type arrangements. Typical pit Turbines coupled to standard high speed generator through step up bevel/helical gears are generally used. Overall efficiency is lower because of gear box. Maximum size depends upon gear box and is generally limited to 5 MW. Higher sized unit up to 10 MW have been recently installed. Performance data of these units is not available. Typical installation is shown in figure 3.8(a) and figure 3.8 (b)

3.3.3 Impulse Turbine

Pelton Turbines: An impulse turbine is one having one or more free jets discharging into an aerated space and impinging on the buckets of a runner. Efficiencies are often 90% and above. In general, an impulse turbine will not be competitive in cost with a reaction turbine in overlapping range. However, certain hydraulic conditions or surge protection requirements may warrant investigation into the suitability of an impulse turbine in the overlapping head range.

Single nozzle impulse pelton turbine has a very flat efficiency curve and may be operated down to loads of 20% of rated capacity with good efficiency. For multi-nozzle units, the range is even broader because the number of operating jets can be varied.

Control of the turbine is maintained by hydraulically operated needle nozzles in each jet. In addition, a jet deflector is provided for emergency shutdown. The deflector diverts the water jet from the buckets to the wall of the pit liner. This feature provides surge protection for the penstock without the need for a pressure relief valve because load can be rapidly removed from the generator without changing the flow rate.

Control of the turbine may also be accomplished by the deflector alone. On these units the needle nozzle is manually operated and the deflector diverts a portion of the jet for lower loads. This method is less efficient and normally used for speed regulation of the turbine under constant load.

Runners on the modern impulse turbine are a one-piece casting. Runners with individually attached buckets have proved to be less dependable and, on occasion, have broken away from the wheel causing severe damage to powerhouse. Integral cast runners are difficult to cast, costly and require long delivery times. However, maintenance costs for an impulse turbine are less than for a reaction turbine as they are free of cavitation problems. Excessive silt or sand in the water however, will cause more wear on the runner of an impulse turbine than on the runner of most reaction turbines.

Draft tubes are not required for impulse turbines. The runner must be located above maximum tailrace water to permit operation at atmospheric pressure. This requirement entails an additional head loss for an impulse turbine not required by a reaction turbine.

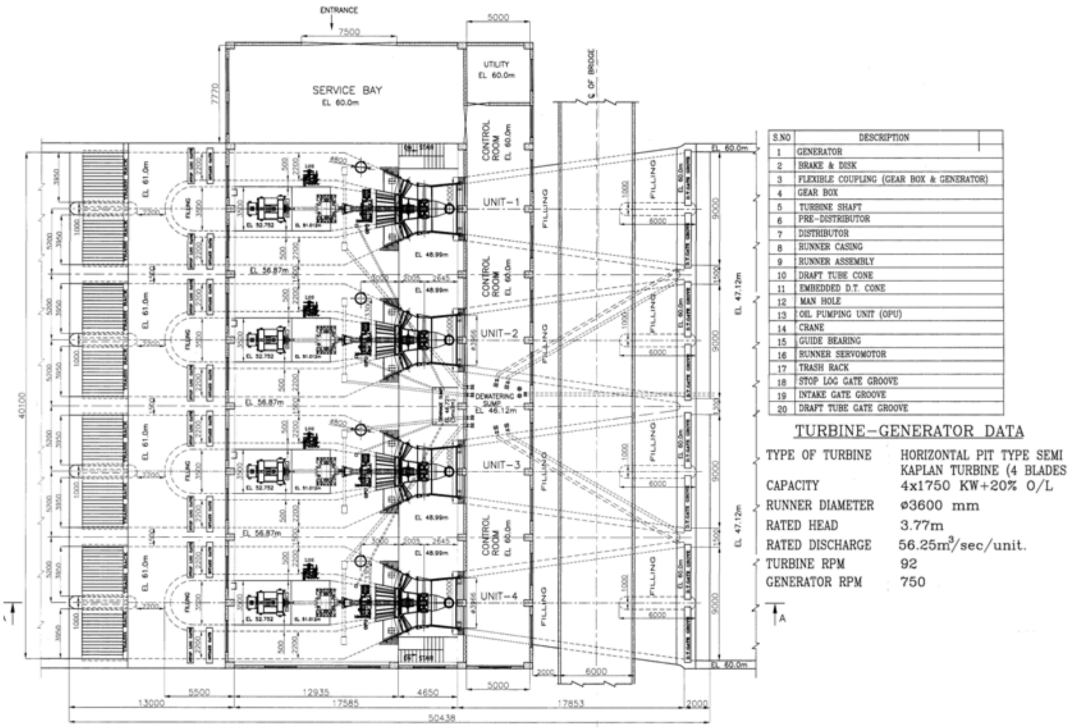


Figure 3.8 (a): Longitudinal Section of Powerhouse Pit Turbine– Nirmali Project (Source: Alternate Hydro Energy Centre, IIT Roorkee)

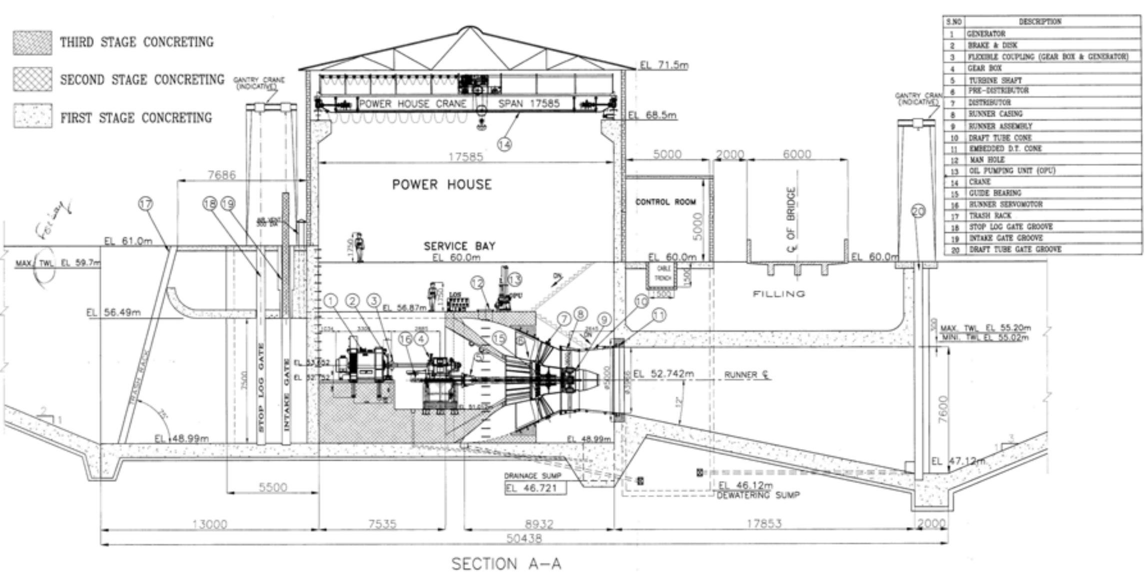


Figure 3.8 (b): Transverse Section of Powerhouse Pit Turbine – Nirmali Project (Source: Alternate Hydro Energy Centre, IIT Roorkee)

Impulse turbines may be mounted horizontally or vertically. The additional floor space required for the horizontal setting can be compensated for by lower generator costs on single nozzle units in the lower capacity sizes. Vertical units require less floor space and are often used for large capacity multi-nozzle units.

Vertical shaft multi-jet turbines are generally selected for large flow installations, whereas horizontal shaft turbines are suitable for those applications that have less water available.

Multi-jet turbines are slightly more costly than single jet turbines; however, the more rapid accumulation of stress cycle alternations justifies a more conservative runner design. Abrasive material entrained in the water will erode the buckets of a multi-jet turbine more rapidly than in the case of a single jet per runner.

For the same rated head and flow conditions, increasing the number of jets results in a smaller runner and a higher operating speed. Therefore, whether vertical or horizontal, multi-jet turbines tend to be less costly for comparable outputs because the cost of the runner represents up to 20% of the cost of the entire turbine.

Table 3. 5: Indian Project Data of Pelton Turbine

Source: - Bharat Heavy Electrical Ltd. India Publication Entitled "Hydro-Electric Installation"/AHEC Projects

Sl. No.	Power Station	Agency/ Manufacturer	No. of Units× Size (MW)	Head (M)	Speed (RPM)	Year Of Comm'ing	Specific Speed (NS)	Type of Turbine	Specific speed H marked in Figure 3.12
1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**
1.	Parbati Stage-II	NHPC	4×200	789.0	375.0	2006	48.57	Pelton Turbine	1
2.	Varahi	KPCL	2×115	460.0	250.0	1989	48.20		2
3.	Sharavathy	KPCL	2×89.1	439.5	300.0	1976	56.55		3
4.	Chukha	Chukha project Authority, Bhutan	4×84	435.0	300.0	1986	53.00		4
5.	Tillari	GOM	1×60	628.8	500.0	1986	47.11		5
6.	Bihai	Taiwan Power Co. Taiwan	1×62.5	416.8	495.0	2005	79.58		6
7.	Kuttiyadi AES	KSEB	2×50	625.0	500.0	2005	43.33		7
8.	Pykara Ultimate	TNEB	3×50	1027.0	600.0	2005	27.95		8
9.	Malana	MPCL	2×43	480.0	500.0	2001	55.89		9
10.	Lower Sungai piah	National Electricity Board, Malaysia	2×27.68	400.0	428.6	1993	48.28		10
11.	Bassi	HPSEB	4×15	335.7	500.0	1970	51.61		11
12.	Kitpi-II	Guglor Hydro Energy gmbh Germany	2x1.5	200	600			Pelton 2 Jet Horizontal	Synchronous Generator Horizontal

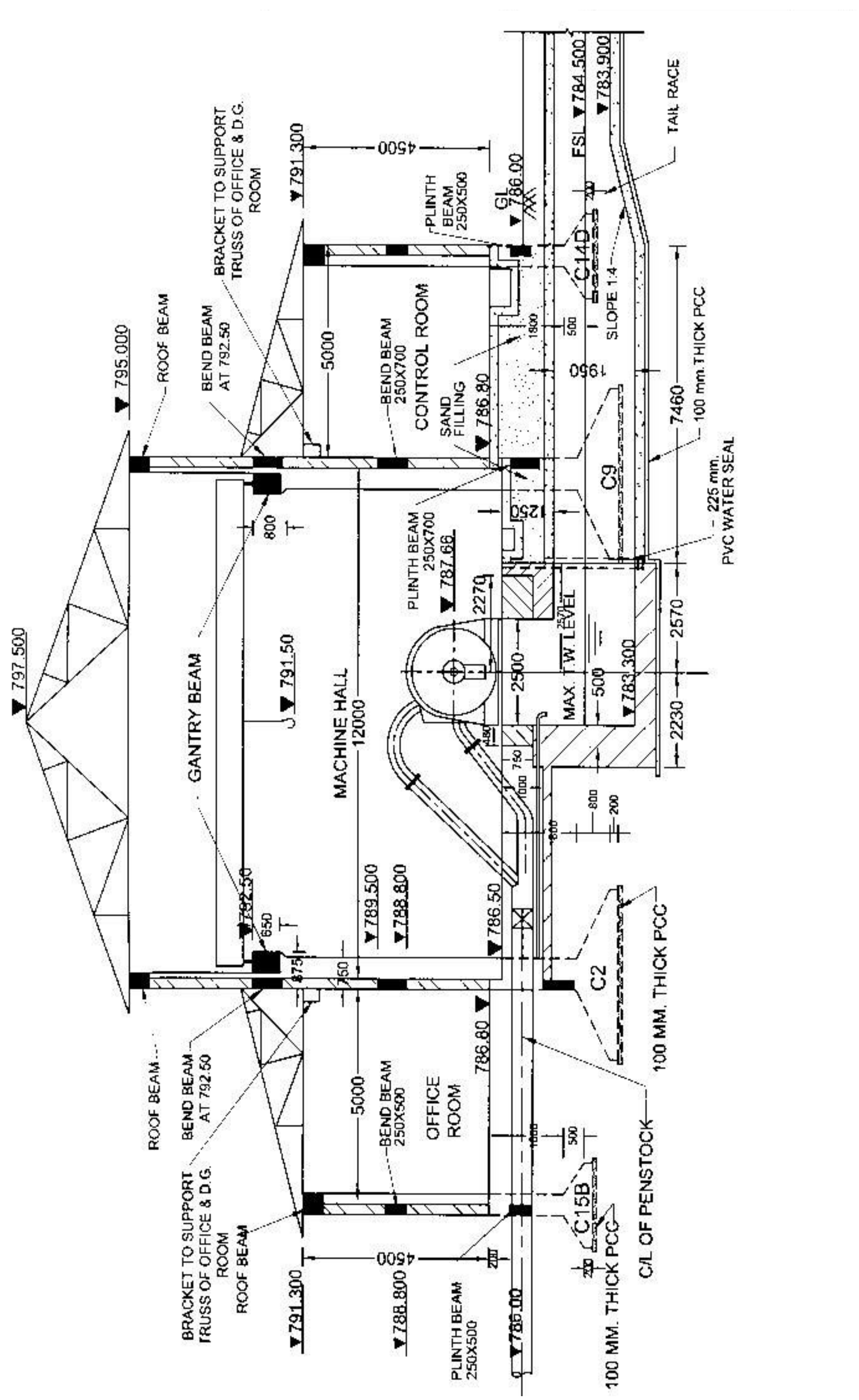


Figure 3.9: Impulse Turbine for Kitpi Project (2 x 1500 kW) Arunachal Pradesh (Source: - Alternate Hydro energy Centre, IIT, Roorkee)

A deflector is normally used to cut into the jet when rapid power reduction is required such as a complete loss of connected-load. The deflector is mounted close to the runner on the nozzle assembly and is typically provided with its own servomotor.

A typical installation is shown in figure 3.9. A list of typical large and small hydro projects with indigenous turbines is shown in table 3.5.

Turgo Impulse Turbines: Another type of impulse turbine is the Turgo impulse. This turbine is higher in specific speed than the typical impulse turbine. Eric Crewdson originally patented this turbine in 1920. The difference between a Pelton unit and a Turgo is that, on a Turgo unit, the jet eneters one side of the runner and exits the other side. The Turgo unit operates at a higher specific speed, which means for the same runner diameter as a Pelton runner, the rotational speed can be higher. The application head range for a Turgo unit is 15 meters to 300 meters. Turgo units have been used for application up to 7,500 kW. Efficiency of a Turgo impulse turbine is about 82 – 84%.

Cross Flow Turbine: A cross flow turbine is an impulse type turbine with partial air admission.

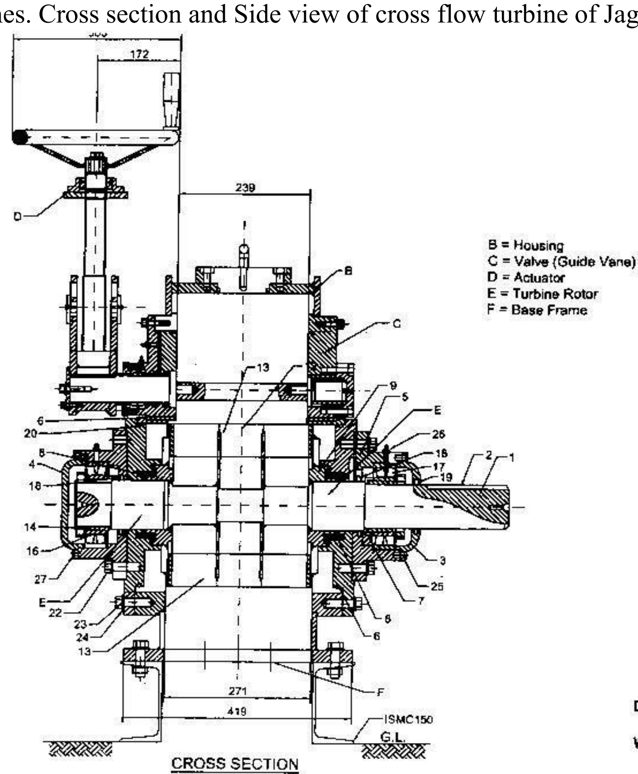
Performance characteristics of this turbine are similar to an impulse turbine, and consist of a flat efficiency curve over a wide range of flow and head conditions. The wide range is accomplished by use of a guide vane at the entrance, which directs the flow to a limited portion of the runner depending on the flow. This operation is similar to operation of multi-jet impulse turbine.

Peak efficiency of the cross flow turbine is less than that of other turbine types previously discussed. Guaranteed maximum efficiency seldom exceeds 80%. Efficiency of indigenous available turbines is about 60-65%.

The largest size runner of cross flow is about 1.2 meter in diameter. This limits unit capacity but multi-unit installations can be used. Allowable heads range from 2 meter to 180 meter.

Cross flow turbines are sometimes equipped with a conical draft tube creating a pressure below atmosphere in the turbine chamber. Therefore the difference between the turbine centerline elevation and the tail water is not lost to Cross-flow turbines as is the case for an impulse turbine. Air is admitted into the chamber through an adjustable air inlet valve used to control the pressure.

Cross flow turbines are free from cavitation, but are susceptible to wear when excessive silt or sand particles are in the water. Runners are self-cleaning and, in general, maintenance is less complex than for the other types of turbines. Cross section and Side view of cross flow turbine of Jagthana SHP is at figure 3.10 (a) & figure 3.10 (b).



Turbine Rotor	
1	Rotor Shaft
2	Rotor Key
3	Bearing cover Dw=80 Drive End (DE)
4	Bearing Cover Dw=80 Non Drive End (NDE) (axial loose)
5	Bearing Housing (include M allen key shaft screws)
6	Rotor Flange
7	Labyrint seal (left threat) Labyrint seal (right threat)
8	Distance Ring for Bearing
9	Shaft Reinforcement
10	Side disk Reinforcement Flange
11	Side disk
12	Intermediate disk
13	Rotor Blades (made from pipe sections)
14	Adadter slev (NDE)
15	Adadter slev (DE)
16	Bearing (NDE closed side)
17	Bearing Shaft side (Optional locating Ring 2FBR 12.5/160)
18	Felt Ring Seal
19	Felt Ring Seal
20	O Ring seal
21	O ring for Protection
22	Screw
23	Spring Washer
24	Washer
25	Screw
26	Grease Nipple

DIAMETER OF RUNNER 300mm

WIDTH OF RUNNER 230mm

Figure 3.10 (a) Cross section view of Jagthana Cross Flow SHP (2 x 50 kW) – AHEC Project (Source: Alternate Hydro Energy Centre, IIT Roorkee)

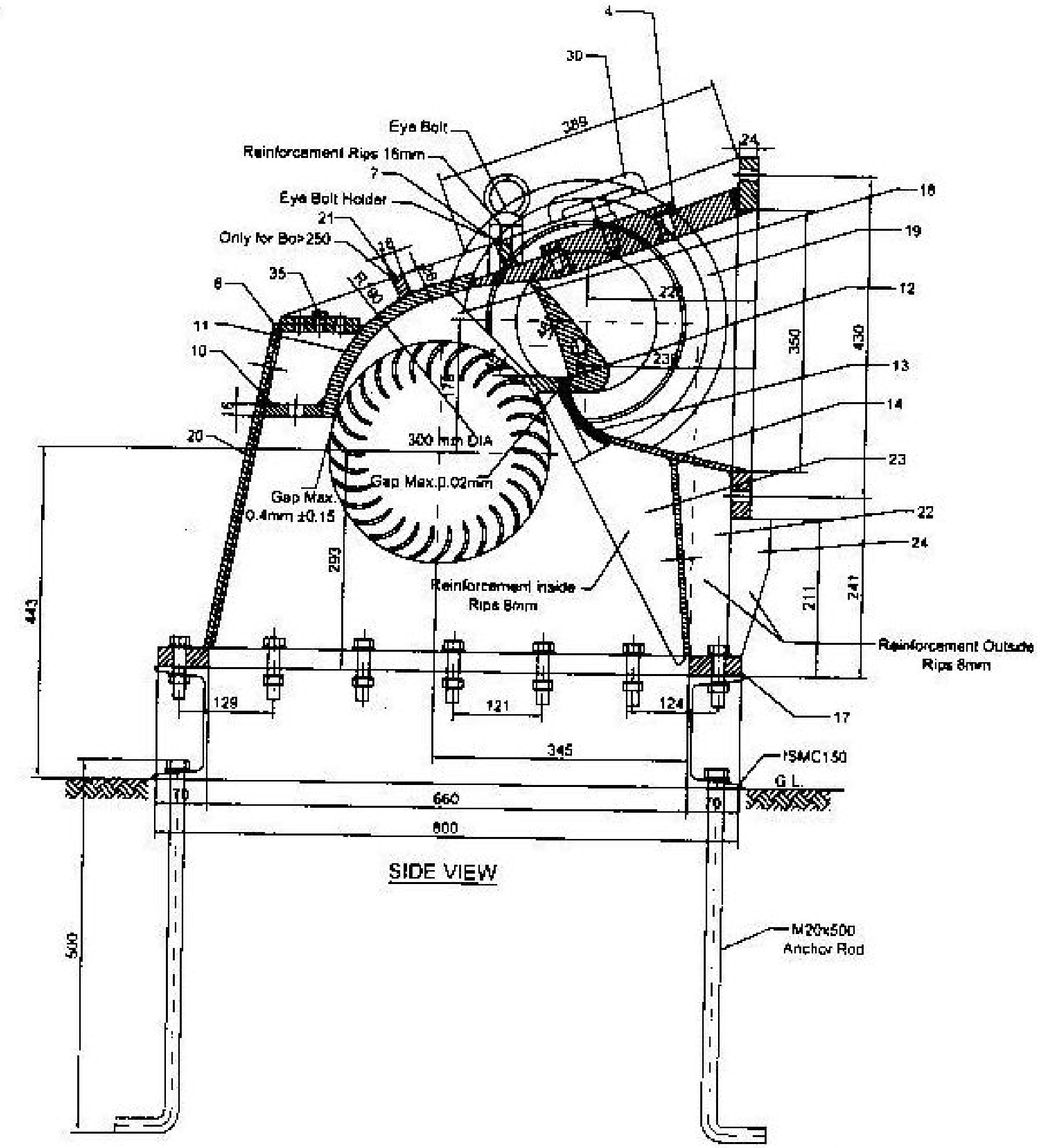


Figure 3.10 (b) Side view of Jagthana SHP (2 x 50 kW) with cross flow turbine (AHEC project)
(Source: Alternate Hydro Energy Centre, IIT Roorkee)

3.3.4 Deriaz Turbine

Francis turbine operating below 40% of rated discharge is prone to vibration and/or power surges. To overcome this Deriaz turbine was developed. These turbines have mixed flow runner with variable pitch blade (as in Kaplan runners) used for medium heads up to 200 m. Conventional guide and gate mechanism of Francis reaction turbine are used. These are not common in India one installation of Deriaz runner is reversible turbine at Kadana pumped storage scheme in Gujarat State of India (table 3.6) and transverse section shown in figure 3.11.

3.3.5 Reversible Turbines Pumped Storage Projects

A pumped storage unit is a turbine/generator that can be reversed to pump water upstream when operating as a pump; the generator becomes a motor, which now supplies power to the turbine.

Starting the unit in the pumping mode requires a means of accelerating the generator/motor in the pump direction. Regardless of how it is done, the motor is started with gates closed and tailrace water depressed. Once the unit is at full speed and on line, the depressing air is vented and the pump is primed. The gates are then opened and pumping begins. Six of the most common methods of starting are as follows:

a) Full voltage, Across – the – line starting
b) Reduce voltage, Across – the – line starting
c) Synchronous starting semi- synchronous starting
d) Motor starting
e) Static starting

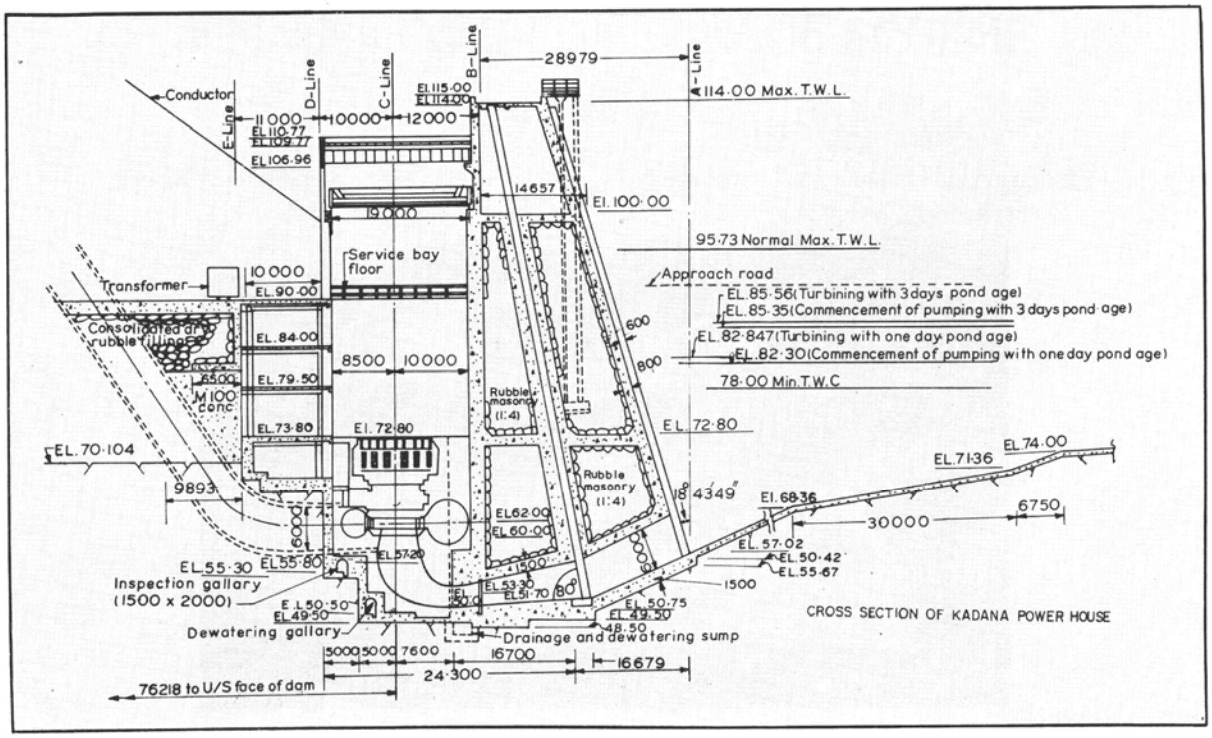


Figure 3.11: Kadana Pumped Storage reversible Units 4 x 60 MW (Deriaz Units)
(Source: CBI&P Publication No. 288)

A typical transverse section of Kadana pumped storage scheme in Gujarat State with reversible turbines with Deriaz runners is shown in figure 3.11.

<u>Water Turbines</u>

a)	Numbers	4	
b)	Type	reversible pump/turbine, diagonal,	
	8 DR 35 with adjustable blade		
c)	Net head	Turbine	pumping
	Maximum	48.2 m	51.0 m
	Minimum	30.77 m	35.0 m
	Rated	43.5 m	47.0 m
d)	Rated output of each unit	60 MW	
e)	Normal speed	142.86 rpm	
f)	Runaway speed	283 rpm	

Typical starting time is less than ten minutes. List of notable pumped storage unit with reversible turbine and their types is given in table 3.6

Table 3.6: Indian Project Data of Reversible Pump/Turbine
Source: - Bharat Heavy Electrical Ltd. India Publication Entitled "Hydro-Electric Installation"

S. No.	Power Station	Type of turbine	No. of Unit Size (MW)	Head (m) Turbine/pump	Speed (RPM)	Yearly commissioning
1.	Sardar Sarovar	Francis	2 x 200/220	116.6/114.0	136.4	2006
2.	Srisailam LBPH	Francis	2 x 150/170	82.8/107.1	136.4	2003
3.	Ghatghar	Francis	1 x 125/142	410/425	500.0	2004
4.	Kadamparai	Francis	4 x 100/200	341.0/381.0	500.0	1987
5.	Nagarjunsagar	Francis	3 x 100.8/106	93.0/97.0	157.8	1982
6.	Kadana	Deriaz	4 x 60/66.5	43.5/47.0	142.8	1990

3.4 SELECTION OF HYDRAULIC TURBINE- GENERAL CONSIDERATION

3.4.1 General

Various types of turbines have already been explained in Para 3.3. Selection of hydraulic turbine up to 5 MW units size (including micro hydros) is generally based on IEC: 1116. Selection of turbines above 5 MW or those in overlapping range is carried out by a more detailed procedure. In any case standard turbines are generally used up to 5 MW unit size. Hydraulic turbine above 5 MW unit size are generally tailor made and selection criteria is more specific. Head, discharge and efficiency play most important role in selection of turbine.

Specification requires that the manufacturer be responsible for the mechanical design and hydraulic efficiency of the turbine. Objective of these guidelines is to prepare designs and specification so as to obtain a turbine that result in the most economical combination of turbine, related water passages, and structures. Competitive bidding for the least expensive turbine that will meet specification requirements is required. In evaluating the efficiency of a proposed turbine, the performance is estimated on the basis of experience rather than theoretical turbine design. The peak efficiency point of a Reaction turbine is established at 90% of the rated capacity of the turbine. In turn, the peak efficiency at 65% of rated head will drop to near 75%.

To develop a given power at a specified head for the lowest possible first cost, the turbine and generator unit should have the highest speed practicable. However, the speed may be limited by mechanical design, cavitation tendency, vibration, drop in peak efficiency, or loss of overall efficiency because the best efficiency range of the power efficiency curve is narrowed. The greater speed also reduces the head range under which the turbine will satisfactory operate.

The selection of speed and setting (from cavitation considerations) described in these guidelines is satisfactory for conditions normally found at most sites and will usually result in a balance of factors that will produce power at the least cost.

Impulse turbines have application in high head hydropower installations. Application of impulse turbine in low head range is limited to very small size units.

3.4.2 Head: Selection of rated and design head for reaction turbine requires special attention. Definition of these heads is given in Para 3.2.2.

Permissible range of head for reaction turbines for optimum efficiency and cavitation characteristics based on experience data is given in table 3.1.

It is important that these operating head ranges are not exceeded. A typical example is of 120 MW Bhakra Right Bank on River Satluj in Punjab/Himachal State Border. Where vertical Francis Turbines were installed. In order to utilize additional water available due to construction of Beas Satluj Link Project subsequent to construction of Bhakra Dam and injection of additional water upstream of Bhakra Dam.

Rated, maximum and minimum head were specified as follows in table 3.4.1 in order to obtain more power in low head period.

Table 3.7 Bhakra Right Bank 1966

Maximum net head	158.5 m	(520 ft.)
Minimum net head	79.86 m	(262 ft.)
Rated head	121.92 m	(400 ft.)
Rated output at rated head	150,000 BHP	(150,000 – 170,000 BHP) at 90% gate
Rated generator	120,000 Kw	120,000 kW at 0.9 pf
Speed	187.5 rpm	

The turbine rating is given at rated head. Selection of head for 120 MW Bhakra Right Bank power plant (commissioned in 1966) is an example of poor selection as later reviewed. The turbine were rated 170,000 BHP at not more than 90% full gate opening under an effective head (rated head) of 121.92 m (400 ft.) The point of best efficiency of turbine (design head) was also specified as 121.92 m (400 ft.) Net head variation was specified 158.5 m (520 ft.) maximum to 79.86 m (262 ft.) minimum. The turbine was coupled to 120 MW generator. An oversized turbine runner was installed with effective rated/design head at about 355 ft. Part load operation was not possible vibration and surges were noticed. The turbine gave rated output at about 84% gate opening at rated head. Turbines mostly operated at net heads of 400 ft. and above resulting in further maloperation. Generating units were uprated to 132 MW in 1975 for smooth operation by encroaching on safety margins. The units were later on replaced by higher sized properly rated machines at higher rated head. Accordingly determination of rated head, design head and maximum and minimum net head is important. Permissible departure from design head for reaction turbines for optimum efficiency and cavitation characteristics based on experience data is given in table 3.1 and is shown in figure 3.1.

3.4.3 Discharge and Plant Rating

Available discharge and its variation is also important for checking plant rating and capacity limitations for part load operations. Performance curve for various types of reaction turbines for part load operations are discussed in chapter 5. Figures 5.2.1 & 5.2.2 and could be used for preliminary selection of reaction turbines. Exact figures can only be given by turbine manufacturer.

Plant kilowatt rating = 9.804 X (rated discharge in m^3/sec.) X (rated head in meters) X (plant efficiency)

1 megawatt = 1000 kW

Plant factor = average plant output/plant capacity

3.4.4 Specific Speed (Ns) – The term specific speed used in classifying types of turbines and characteristics of turbines within types is generally the basis of selection procedure. This term is specified as **t**he speed in revolutions per minute at which the given turbine would rotate, if reduced homologically in size, so that it would develop one metric horse power at full gate opening under one meter head. Low specific speeds are associated with high heads and high specific speeds are associated with low heads. Moreover, there is a wide range of specific speeds which may be suitable for a given head.

Selection of a high specific speed for a given head will result in a smaller turbine and generator, with savings in capital cost. However, the reaction turbine will have to be placed lower, for which the cost may offset the savings. The values of electrical energy, plant factor, interest rate, and period of analysis enter into the selection of an economic specific speed. Commonly used mathematically expression in India for specific speed is power based (English System) is as follows:

Power Based Specific Speed N_{sp}

$$N_{sp} = \frac{N(P)^{0.5}}{(H)^{1.25}}$$

Where N = revolutions per Minute

P = power in metric horse power/kW at full gate opening
H = rated head in m.

The specific speed value defines the approximate head range application for turbine type and size. Low head units tend to have a high specific speed, and high-head units to have a low specific speed.

Ns, kW Units = 0.86 Ns metric horse power unit

<u>Flow Based Specific Speed Nq</u>

Flow based metric system for specific speed (Nq) used in Europe is given by equitation below. This can be derived from Nq as P α QH

$$Nq = \frac{NQ^{0.5}}{H^{0.75}}$$

Where Nq = Specific Speed
N = Speed in rpm
Q = Flow in cubic meters/second
H = Net Head in meters

The net head available to the turbine and unit size dictates the selection of type of turbine suitable for use at a particular site. The term specific speed is generally used in classifying types of turbines and characteristics within type as shown in figure 3.12. This figure is based on ASME guide to design of hydropower mechanical design 1996 and modified by Indian Projects data given from table 3.2 to table 3.6. Relationship between head and specific speed for preliminary selection of turbine types as per Indian Standard 12837 is given in figure 3.13. Overlapping range of the three types of turbine is shown in figure 3.12.

$$N_s = \frac{N\sqrt{P}}{(H_d)^{5/4}}$$ N_s (Specific Speed) Based on Optimum Point

N = Speed (rev./min.)
P = Turbine full gate capacity in HP (metric)
H = Head (m)

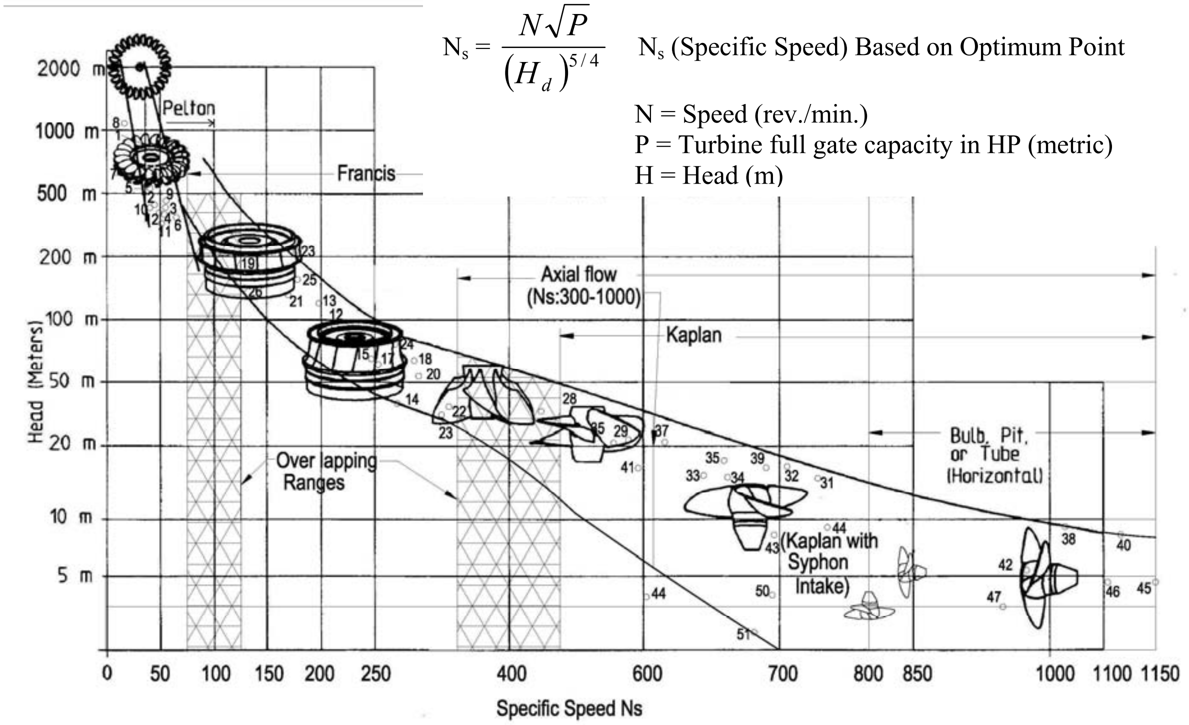
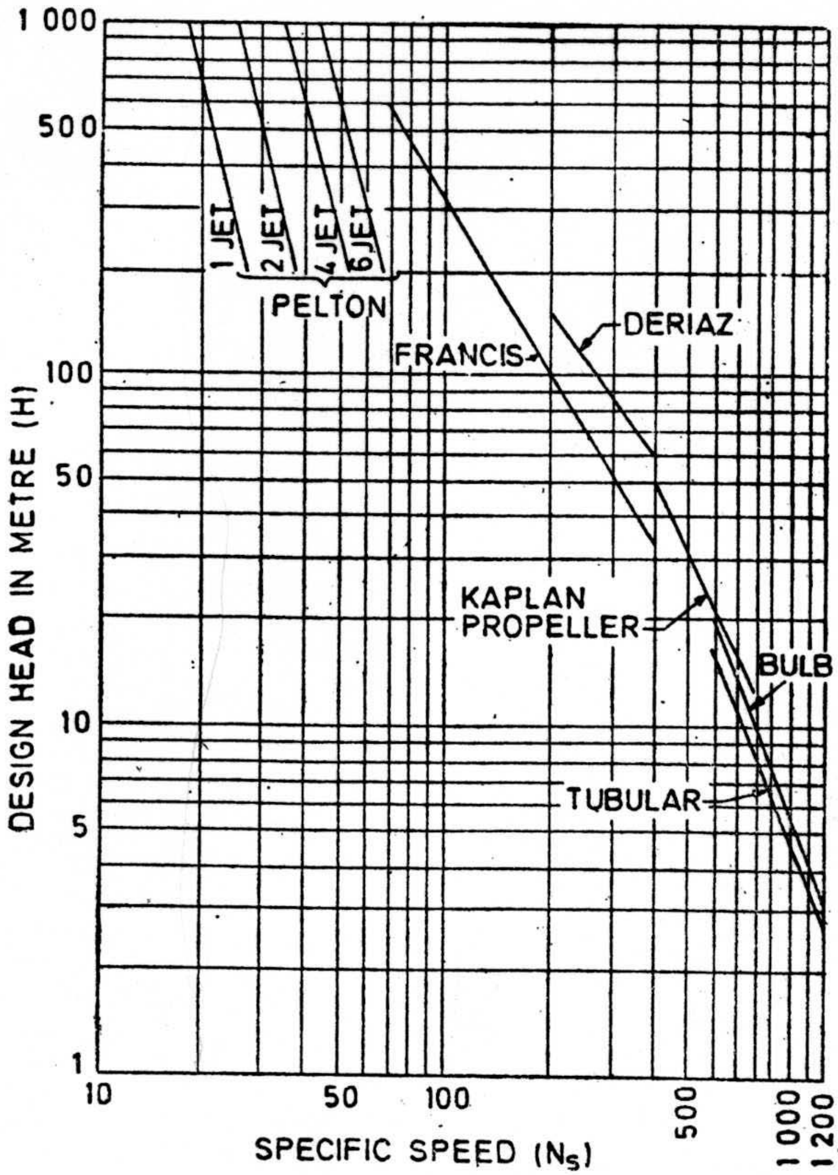


Figure 3.12 Ns versus Head.- This figure shows the various turbine type as a function of specific speed (Ns) and head. This figure should be used a guideline, as there is overlap between the various turbine types with respect to their operating ranges.

Note: Details of turbine marked on the chart refer (Table 3.2 – Francis Turbine; Table 3.3 – Kaplan/Propeller Turbine and Table 3.5 for Pelton Turbine).



$$Ns = \frac{RPM\sqrt{MHP}}{(HEAD)^{5/4}}$$

Figure 3.13 Relationship between Head and Specific Speed
(Source – IS: 12837)

3.5 SELECTION CRITERIA OF HYDRO TURBINE ABOVE 5 MW UNIT SIZE

Factors Influencing Selection of a Turbine and Specific Speed are as follows:

a) Head available to the turbine
b) Turbine efficiency
c) Speed in rpm
d) Cavitataion and plant setting
e) Part load operation
f) Runaway speed
g) Machine size – runner diameter

Selection of turbines for a particular site is determined by trial and error process and in consultation with manufacturers for optimum determination of the type, size, setting and efficiency.

Criteria for selection of hydro turbine based on specific speed as per Indian standard IS: 12837 is given in table 3.8.

Table: 3.8

Type of machine	Head variation % of rated head	Load variation % of rated output	Specific speed (m-mhp)	Peak efficiency in %
Pelton	120 to 80	50 to 100	15 to 065	90
Francis	125 to 65	40 to 100	60 to 400	93
Deriaz	125 to 65	50 to 100	200 to 400	92
Kaplan	125 to 65	40 to 100	300 to 800	92
Propeller	110 to 90	90 to 100	300 to 800	92
Bulb	125 to 65	40 to 100	600 to 1200	92

Prior to issue of Indian standards, Engineering Mono graph No. 20 (USBR) was mostly used for selection of reaction turbines.

3.5.1 Head, Output and Type of Turbine

Determine Type of turbine from figure 3.12; figure 3.13 and table 3.8 for the design head determined from site data. In case of overlapping ranges turbine types applicable may be noted and approximate range of Specific speed applicable to the turbine may be determined from the figures and table mentioned above for detailed economic analysis. This analysis is based on speed, efficiency, part load operation, setting and size of a turbine.

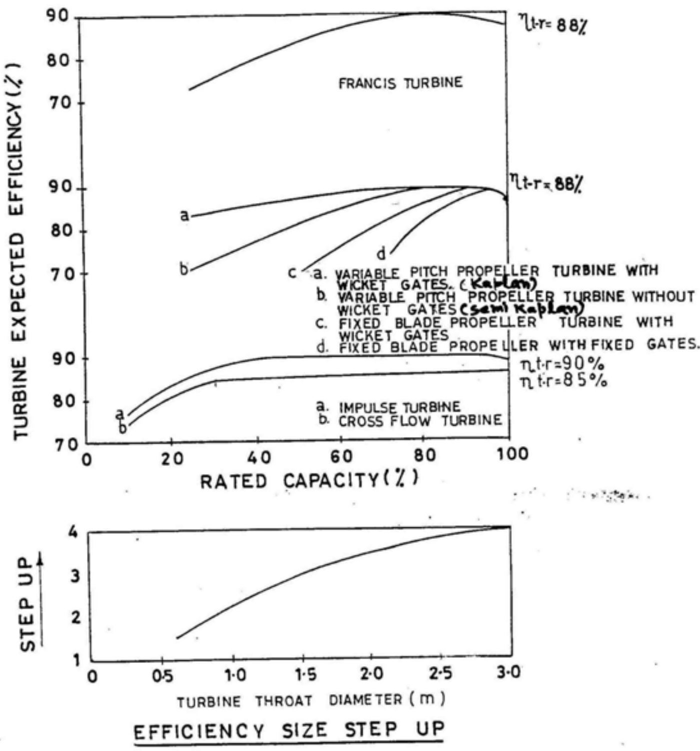
USBR monograph recommends that except for unusual circumstances, the trial specific speed for reaction turbines may be based on specific speed near about (2334/$\sqrt{h_d}$ metric). This figure in earlier edition of the monograph was much lower. This indicates trend for higher speed reaction turbine. Present trend is to select higher trial specific speed (see chapter 14).

Head Variations: Performance of the turbine is ideal at design head. Turbine efficiency falls at head higher and lower than the design head. Normal range of head variations for various type of turbines is given in table 3.8.

3.5.2 Efficiency

Relative efficiency of different type of units as per IS: 12800 is shown in figure 3.8.

Relative Francis versus full Kaplan (Variable blades and wicket gates) efficiency curve is shown in figure 3.15.



NOTES:

1. ηt.r =Turbine Efficiency at rated output (Pr) and head (hr)
2. The values shown are typical for a turbine with 300 mm diameter runner. The values shown in the size set up curve may be added to the ηt.r values for larger units. Values apply for Francis, fixed and variable pitch propeller,tube,bulb and rim turbine.Do not apply step up on impulse or cross flow turbine.
3. Efficiency of indigenous cross flow turbine is about 60 - 70%.
4. Peak efficiency at design head and rated output is about 2-5% higher.

Figure 3.14 Turbine Efficiency Curves (Source IS: 12800)

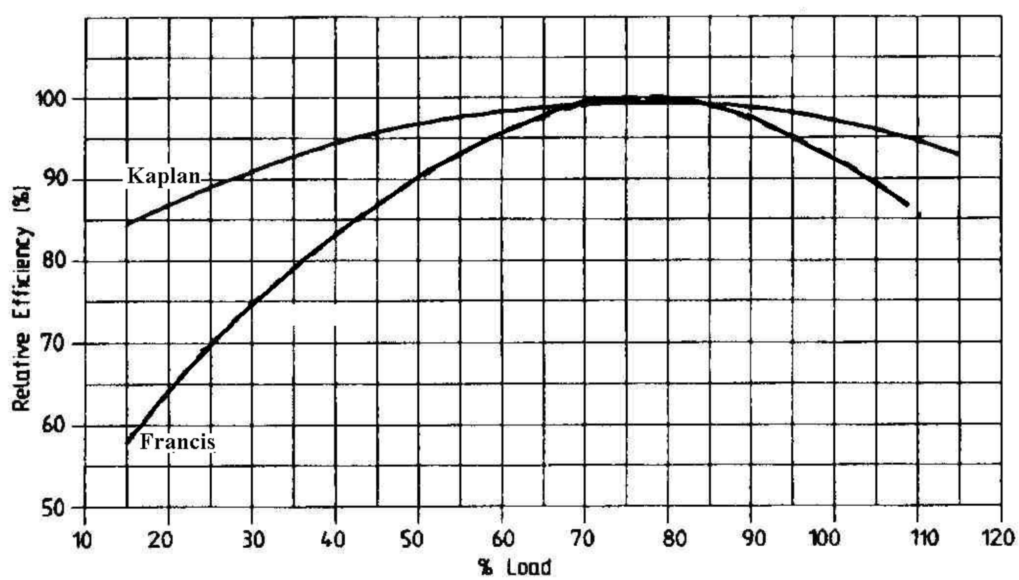


Figure 3.15: Francis Versus Kaplan Relative Efficiency. Kaplan turbine has much better part load efficiency than propeller or Francis turbines (Typical)

3.5.3 Load variations

Turbine efficiency varies with load. Necessity of operating turbine at part loads influences choice of turbines in the overlapping head ranges. Minimum load up to which the turbine may be operated without undue cavitation and vibration is dictated by type of turbine and given in table 3.8.

3.5.4 Runner Size

Runner size determines turbine size, the civil engineering cost and hence is important for selection of turbines.

Actual runner size is determined by the manufacturer in accordance with model tests data. For preliminary selection of turbine and layout purposes following formula can be used as per IS: 12800.

Francis Turbine:

$$\theta_s = 0.0211\left(n_s\right)^{2/3}$$

Runner diameter, D = $\dfrac{84.6\,\theta_s\left(H_r\right)^{1/2}}{n}$

Where θ_s is the velocity ratio at discharge diameter of runner.

Propeller Turbine:

$$\theta_s = 0.0233\left(n_s\right)^{2/3}$$

Runner diameter, D = $\dfrac{84.6\,\theta_s\left(H_r\right)^{1/2}}{n}$

Impulse Turbine:

$$\theta_s \frac{d}{D} = 0.0019\, n_s$$

Where
d = diameter of jet

D = $\dfrac{84.6\,\theta_s\left(H_r\right)^{1/2}}{n}$

Practical values of $\dfrac{d}{D} = 0.04\, to\, 0.1$

Normal diameter ratio is = 0.0555

3.5.5 Transport Consideration

In case of large unit rating machines, this criteria plays important role in selecting of turbine size. Normally runner is one of the costliest and most critical parts which should be preferably handled in one piece. Reliability of assembled large Kaplan size runner is much less on account of possibility of removing runner blades easily as they are fixed by bolts and keys. In case of Francis turbines, necessity of limiting runner size during transport, requiring manufacture of runner in two pieces increases cost of the turbine by about 10%. Pelton turbine runner as a rule is transported in one piece.

Bhakra Right Bank power unit size was fixed on the basis of maximum runner size cast in one piece that could be manufacture and transported to site.

3.5.6 Turbine Setting and Excavation Requirement

Setting of reaction turbine with reference to minimum tail water level is dictated by requirement from cavitational considerations. Further in view of bent draft tube, excavation up to bottommost point of knee that is much deeper than runner centre line is required. In general cavitation co-efficient for Francis turbines is much less than that for Kaplan turbine necessitating relatively lesser submergence and excavation for Francis turbine. Pelton turbines are installed above maximum tail water level, thus requiring minimum excavation cost.

Highest speed practicable at specified head is required for lowest possible cost. In addition greater speed requires the reaction turbine (Francis and Propeller/Kaplan) to be placed lower with respect to the tailrace water to avoid cavitation. This generally increases excavation and structural costs.

Cavitation results from sub-atmospheric pressure at places on runner and runner chamber. To minimize this problem the turbine runner is set at depths below the minimum tail water to obtain a countering pressure. The appropriate value of the depth of setting for runner of different specific speed is computed using a characteristic 'cavitation coefficient' for the particular specific speed, as follows:

$$Z = (H_a - H_v) - \sigma H$$

Where,

Z = Depth of centre line of runner below minimum level of tail water
H_a = Atmospheric pressure in meter (m) water column at plant elevation
H_v = Vapour pressure in meters at plant location temperature
H = head on turbine, meters
σ = Plant sigma or cavitation coefficient for the turbine specific speed
The value for σ for selection purposes may be found from the expression which is as follows (IS: 12800):

$$\sigma = \frac{(n_s)^{1.64}}{50327}$$

The value of σ can also be taken from the curves relating n_s and σ shown in USBR Enguineering Monograph No. 20.

The value of σ for Francis turbine is lower than those for Propeller or Kaplan turbines. The setting level for the latter is consequently lower than for Francis turbine. Many low n_s Francis turbines will yield setting levels above minimum tail water level and same may be the case with Kaplan/ Propeller turbines of very low heads. Pelton turbines are set above the maximum tailrace water level.

Atmospheric pressure and vapour pressure (meter) is given in table 3.9 and setting of the turbine is based on the cavitation coefficient.

Table 3.9

Atmospheric Pressure

Altitude meters	H_a mm of H_g	H_a m of H_2O
0	760.00	10.351
500	715.99	9.751
1000	674.07	9.180
1500	634.16	8.637
2000	596.18	8.120
2500	560.07	7.628
3000	525.75	7.160
3500	493.15	6.716
4000	462.21	6.295

Water Properties

Temp ^{0}F	H_v Meter	Temp ^{0}C
40	0.089	5
50	0.125	10
60	0.174	15
70	0.239	20
80	0.324	25

H_a = Atmospheric pressure for altitude (m)
H_v = Vapour Pressure of water, use highest expected temperature, (m)
$H_b = H_a – H_v$, Atmospheric pressure minus vapor pressure , (m)

3.5.7 Other Considerations

Other considerations for selection of the type of large turbine are as follows:

i) Performance of turbine is ideal, at design head. Fall of efficiency in case of pelton, Kaplan and Bulb is much less in comparison to Francis and propeller types. Therefore in overlapping head ranges selection of type of turbine is affected by head variation existing at site.

ii) Turbine efficiency varies with load. Fall of efficiency at part load for Francis and propeller is much steeper in comparison to that for Kaplan and Pelton turbines, therefore, necessity of operating turbines at part loads for longer time influences choice of turbines in the overlapping head ranges. Thus in the head ranges where both Kaplan and Francis are suitable, requirement of large head and load variation, Kaplan turbine is superior to Francis turbine from considerations of higher power generation on account of better overall efficiency. Similarly, in the overlapping head ranges where both Francis and Petlon could be used, Pelton has advantages over Francis in overall performance level when variation of load is higher.

iii) Highest specific speed of turbine results in higher speed of rotation for generator with consequent reduction in cost of generator. This criteria is very important for resulting type of turbine from cost consideration in the overlapping head ranges (see figure 3.12 & figure 3.13

3.6 SELECTION PROCEDURE FOR TURBINES ABOVE 5 MW UNIT SIZE

The practice for preliminary selecting of large turbines (reaction turbine mostly used) is based on trial and error method and United States Department of the Interior, Bureau of Reclamation, Engineering Monograph no. 20 entitled Selecting Hydraulic Reaction Turbines and in consultation with manufacturer of the equipment.

(i)Trial specific speed $n_{s;}$

Select from figure 3.12 or figure 3.16 trial specific speed. For reaction turbines trial specific speed is revised from $\frac{2010}{\sqrt{H}}$ to $\frac{2334}{\sqrt{H}}$ as per USBR monograph no. 20. High trial specific speed is recommended as shown in figure 3.16. See also chapter 14 for modern trends.

(ii)Trial speed N' (rev./min.)

$$N' = \frac{N_s \times (H_d)^{5/4}}{\sqrt{P}}$$

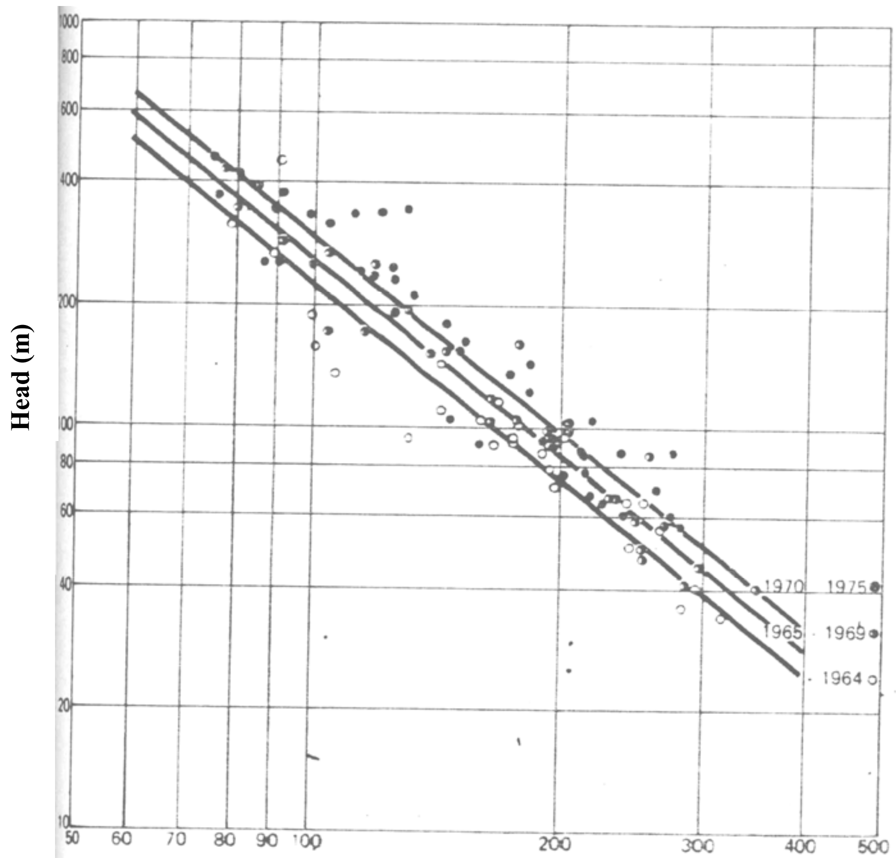
Where,
N' = Trial rotational speed
N'_s = Trial specific speed
H_d = Design head
P = Turbine full gate capacity at H_d (metric horse power)

(iii) Rotational speed or design speed, n:

The rotational synchronous speed nearest the design speed is selected subject to the following considerations:

a. A multiple of four poles is preferred, but standard generators are available in some multiples of two poles.

b. If the head is expected to vary less than 10% from design head, the next greater speed may be chosen. A head varying in excess of 10% from design head suggest the next lower speed.



Specific Speed (power based)
Figure 3.16: Specific Speed

3.6.1 Examples of Medium and Large Turbine Selection

Some examples of selecting hydraulic turbines especially in the overlapping range are given below:

3.6.1.1 Turbine Selection of Dehar Powerhouse (4 x 165 MW) of Beas Satluj link Project

The Turbines were selected in consultation with Bharat Heavy Eelctricals Ltd. (BHEL), the supplier of equipment.

Basic data for the turbine selection is as follows:

Rated head (H)	-	341.4 m
Rated output (P)	-	23000 HP
Generator Output	-	165000 kW

This falls within the overlapping range of Francis and Pelton turbine range (Figure 3.12).

$$N_s = \frac{N\sqrt{P}}{(H)^{5/4}}$$

$$N = \frac{N_s (H)^{5/4}}{\sqrt{P}}$$

$$N = \frac{N_s \times (341.4)^{5/4}}{\sqrt{230,000}}$$

N = 3.06 N_s

The value of N_s form figure 3.12 lies approximately in following limits for rated head 341.4m

Pelton Turbine – 50 to 100
Francis turbine - 100 to 125

Choosing a six jet pelton turbine (N_s = 20 per jet) and reaction francis turbine with $N_s = \frac{2010}{\sqrt{H}}$ = 109 (based on USBR monograph no. 20) for trial purpose and comparison is shown in table 3.6.1.

Reaction Turbine

Trial specific speed $N_{sp} = \frac{2010}{\sqrt{H}} = \frac{2010}{\sqrt{341.4}}$ = 109.2 (based on USBR monograph No. 20-1954)

Trial Speed N' (rpm)

$$N' = \frac{N_s \times (H)^{5/4}}{\sqrt{p}} = \frac{109 \times (341.4)^{5/4}}{\sqrt{23000}} = \frac{109 \times 1467.5}{479.6} = 333 \text{ RPM}$$

Nearest synchronous speed for even no. of pairs of pole (20) = 150 RPM (6 jet pelton)
(10) = 300 RPM (reaction turbine)
(8) = 375 RPM (reaction turbine)

Table 3.10

S. No.	Type of Turbine	N_s	n (rpm) = 3.06 N_s	Synch. Speed
1.	6 jet pelton	20 per jet	149	150
2.	Francis a)	100	306	300
	Francis b)	120	367	375

300 rpm Francis turbine were chosen because of following reasons.

i) 6 jet pelton turbine having 150 rpm speed with very large runner diameter was considered uneconomical
ii) 375 rpm Francis turbine requires lower setting of the runner which was very costly because of hard rock
iii) The turbine was proposed to be directly coupled to umbrella synchronous generator. Peripheral speed of the rotor for 150 rpm speed is very high for the size of the generator. This was not permissible for the steel available at that time.
iv) Manufacturers recommended
v) Higher specific speed machines were being used in 1975 (Figure 3.16).

Comparison of Francis and Pelton turbine in general terms is given below:

Advantage of a Francis turbine

i) Higher specific speed and higher rotational speed and, therefore, smaller generator;
ii) Higher peak efficiency
iii) Higher effective head

Advantages of a Pelton Turbine

i) Excavation cost will be less
ii) Often better for applications with erosive water – easier to maintain
iii) Better part – load efficiency – very flat efficiency curve for approximately 25% to 100 % load, particularly with multi jet units.
iv) Less sensitive to changes in head
v) Wider operating range – particularly with multi jet units.
vi) Rapid operation of deflectors minimizes water hammer and may, therefore, eliminate the need for a surge tank. A Francis turbine needs longer closing time, resulting in longer and higher over speeds.
vii) It is simple with fewer moving parts and may have lower maintenance costs.

Francis turbines 300 RPM directly coupled to synchronous generators were chosen in consultation with the manufacturers.

3.6.1.2 Example of Turbine Selection of 20 MW Unit Size (Matnar Project, Chhatisgarh)

1.Turbine Selection Basic Data

i)	Rated design head	:	57.75 m
ii)	Rated Turbine Discharge	:	41.57 cumecs
iii)	Total discharge	:	124.72 cumecs
iv)	Maximum tailrace level	:	468.25 m
v)	Rated output at rated head and rated discharge	:	20 MW (at generator terminals)

As per figure 3.12 turbine falls within the range of Francis turbine.

Net design head (h_d) = 57.75 m

Turbine full gate capacity at rated load (10% overload on generator 96% generator efficiency and 5% margin.

Generator rated output = 20,000 kW
(10% overload capacity) = 22,000 kW

Turbine rated output required = $\dfrac{20000 \times 1.10 \times 1.05}{0.96 \times 0.86}$ = 27980 MHP

Trial Specific Speed (n_s') = $\dfrac{2334}{\sqrt{h_d}}$ (metric)

= $\dfrac{2334}{\sqrt{57.75}}$ =307 (Graph 3.4.1 shows n_s ~ 200-300)

Trial Rotational Speed (n') = $\dfrac{n'_s \times (h_d)^{5/4}}{\sqrt{P_d}}$ (based on USBR monograph No. 20-1974)

= $\dfrac{307 \times (57.75)^{5/4}}{\sqrt{27980}}$ = 292.2 $\cong$ 300 or 250

Design Speed

Head is expected to vary less than 10% from design head and the next greater speed may be chosen.
Accordingly 10 pole (5 pairs pole) generator with design speed of 300 rpm is optimum choice.

Design Specific Speed (n_s)

$$n_s = \frac{n\sqrt{P_d}}{(h_d)^{5/4}}$$

$$= \frac{300\sqrt{27980}}{(57.75)^{5/4}} = 315.21$$

$$= 315$$

Discharge Diameter (D) (as per 3.5.4)

$$\text{Velocity ratio} \quad (\phi) = 0.0211\,(n_s)^{2/3}$$

$$= 0.0211\,(315)^{2/3} = 0.9768$$

$$D = \frac{84.6 \times \Phi \times \sqrt{h_d}}{n}$$

$$= \frac{84.6 \times 0.9768 \times \sqrt{81.37}}{300}$$

$$= 2.09 \text{ m}$$

<u>Manufacturer</u>

M/s BHEL intimated following parameters for the turbine of Matnar project

Design head	=	57.75 m
Turbine output	=	20000 kW (without 10% overloads)
Rated speed	=	300 rpm
Runner dia.	=	2.08 m

3.6.1.3 Example of Turbine Selection for Medium size Low Head Schemes (Mukerian & SBC Canal Fall Projects)

For low head large size units equipment costs are high.

Selection Criteria

For a small/medium low head power station, the operating and installation costs are comparatively much higher with respect to large installations. This means that greater consideration must be given to the following points:

1. The Civil Engineering work needs to be kept to a minimum.
2. The site erection of the units has to be kept to a minimum.
3. The power station must be automatically controlled to reduce the attendant personnel.
4. The equipment must be simple and robust with easy accessibility to essential parts for maintenance.
5. Indian experience & Indigenous availability

For low heads, vertical Kaplan/ Bulb turbine is suitable for these requirements. The main advantage of the bulb unit derives from its hydraulic simple and straight water passage. The consequence of this is a smaller turbine and a reduced civil works cost.

The turbine is smaller because the bulb unit has a higher specific speed and a higher specific output than other types of turbines while maintaining or even improving the efficiencies and cavitation characteristics.

Selection of turbines is discussed with special reference to Mukerian & SBC Canal Projects.

Turbine Selection Basic Data

	Mukerian	SBC
Rated/design head	8.23 m/8.23 m	11.20/11.20 m
Rated output	2 x 9000 kW	2 x 8000 kW

Power House Dimensions for Vertical Kaplan and Kaplan Bulb Turbine

		Mukerian	**SBC**
Design Head (H)	=	8.23 m	11.20 m
Rated Power (P)	=	2 x 9,000 kW	2 x 8,000 kW

Specific Speed (ns) is related to rotational speed (n):

Mukerian / **SBC**

$$ns = \frac{n\sqrt{P}}{H^{5/4}} = \frac{n \times (9{,}000)^{1/2}}{(8.23)^{5/4}} \Big/ \frac{n \times (8{,}000)^{1/2}}{(11.20)^{5/4}}$$

$$n = 0.1477ns \;/\; 0.229\ ns$$

Runner diameter (D) and speed for possible values of ns for vertical Kaplan based on U.S.B.R. Monograph no. 20 taken as 2334/ $\sqrt{H}$ 1 and bulb turbines taken as about 15-25 percent higher is worked out in Table-4.8. Nearest synchronous speed is chosen. The runner diameter and setting is calculated as per U.S.B.R. Design Monograph No. 20 (titled selection of hydraulic turbines). Comparison of the figures for the two types is shown in Table-3.11.

Table – 3.11

Types of Turbine	ns (Trial)		n (rpm)		Actual ns		Runner Diameter (meter)		Setting above Tail race (meter)
	SBC	**Mukerian**	**SBC**	**Mukerian**	**SBC**	**Mukerian**	**SBC**	**Mukerian**	**SBC**
Vertical Kaplan	a) 700	850	166.7	125	730	800	3.210	4.06	- 3.50
	b) 700	-	187.5	-	819	-	3.080	-	- 5.60
Bulb Turbine	a) 850	1000	187.5	150	819	1020	3.080	3.82	- 8.16
	b) 850	-	200	-	873	-	3.015	-	- 8.27

*Assuming 1 m as safety margin for vertical Kaplan and 0.5 m for Bulb units.

Vertical Kaplan turbines can be coupled directly to 166.7/125 r.p.m. (18/24 pole) generators for SBC/Mukerain and Bulb turbines can be coupled to 187.5/200/136.5 r.p.m. (16/15/22 pole) generators for SBC/Mukerian.

Following reputed manufacturers of equipment responded to our enquiries for the generating equipment (turbine and generator) selection for SBC turbine.

(1) M/s Bharat Heavy Electricals Ltd. INDIA
(2) M/s Fuji Electric JAPAN
(3) M/s Sulzer Flovel Hydro Ltd. INDIA
(4) M/s Jyoti Ltd. INDIA

Table – 3.12

Sl. No	Manufacturer	Type of Offered turbine	Synchronous Speed	Runner Diameter	Draft Head
1.	Bharat Heavy Electricals Ltd.	Horizontal Bulb 7500 kW Output at 10.9 m head	150 r.p.m.	--------	
2.	M/s Fuji	Horizontal Bulb 7500 kW Output at 10.9 m head	200 r.p.m.	3150 mm	- 8 m
3.	M/s Sulzer	Vertical Shaft Kaplan 7980 kW Coupling to 7500 kW Gen. at 10.9 m head	166.7 r.p.m.	3400 mm	

M/s Jyoti Ltd. offered 3 x 5000 kW units tubular type of Kaplan units. They further indicated capability of making Kaplan units up to 10000 kW unit size. For the purpose of comparison of similar unit size data supplied by the manufacturers for 7500 kW unit size (Vertical Kaplan or Bulb type) are given in table 3.12.

Experience with Bulb Turbines

1. Indigenous Experience - A large number of Bulb units have been installed in India and have been in satisfactory operation for quite some time. List of some of these installations is given in Table 3.13.

Table 3.13: Some recent Bulb Turbine Installations in India

S. No.	Developer	Location	Turbine size (kW)	Head/Speed (m/rpm)	Generator	Rema-rks
1.	Bihar State Hydro-Electric Power Corporation	Eastern Gandak Canal	i. 5155 ii. 5155 iii. 5155	7.1 / 107 5.3 / 107 4.97 / 107	5670 kVA, 6.6 kV 50 Hz each	3 Sets
2.	Tamil Nadu State Electricity Board	Cauvery River Mettur Dam Power House I Power House II Power House III Power House IV	i. 17,200 ii. 15,600 iii. 4,400	9.0 / 75 6.5 / 75 3.0 / 75	18,333 kVA, 6.6 kV, 50 Hz	Total 8 Sets
3.	Haryana Sate Electricity Board	Western Yamuna Hydro electric Project Power House I Power House II Power House III Power House IV	i. 9,350 ii. 7,310	12.8 / 1875 11.5 / 1875	10440 kVA, 6.6 KV, 50 Hz each	Total 8 Sets
4.	Murudeshwar Power Corporation Ltd., Karnataka	Narayanpur Left Branch Canal	4500 kW	7 m/111 rpm	6000 kVA	Two sets

(2) More than 100 bulb units of unit output more than 5 MW, designed and manufactured by M/s Neyperic are Operating satisfactorily. Largest unit size is 53 MW and cost reduction recommended is reproduced below (Refer proceedings of water Power International Conference, 1985 (pp 749 - 755)).

The specific speed increase reaches at least 20%. This means that for a given head and output the use of a Bulb unit allows a turbine diameter about 10% smaller than with a conventional turbine.

Moreover, the main advantage of the Bulb turbine is the reduction in civil works. When compared to a Vertical Kaplan unit, the inlet width is at least 50% smaller, all these together bringing to a total gain of about 25 to 35% of the civil costs. When compared to a tubular unit, the smaller runner diameter of the bulb unit and its simplicity in design and installation result in an overall reduction in the cost of civil works.

(3) A comparison of vertical Kaplan and Kaplan Bulb units for Idaho falls in USA was made by International Engineering Co. of USA for Department of Energy. Unit size is 7.2 MW and head 5.8 estimated saving in cost was as follows:

Estimated saving in equipment cost = 10%
Reduction in cost of Civil Engg. Works = 50%
Bulb units supplied by M/s Voest Alpine are working satisfactorily.

Conclusions and Recommendations Bulb Turbines were recommended for both the powerhouse.

3.7 SELECTION OF SMALL HYDRO TURBINE UP TO 5 MW UNIT SIZE

Factor Affecting Selection of Turbines are as follows:

a) Type of scheme
b) Use of standard turbines
c) Turbine Efficiency
d) Turbine performance
e) Runner diameter

3.7.1 Type of Scheme

3.7.1.1 High Head Scheme

A typical high head small hydro scheme is shown in figure 4 (overview). Selected turbine efficiency and speed is of paramount importance for cost effective installation as illustrated below:

Cost Elements: in small and micro hydro power projects as per National Consultants recommendations UNDP – GEF Hilly Projects is shown in figure 3.17.

These cost elements are for type of small hydro in hilly area. Efficiency of indigenous turbines in small hydro range is approx. as follows:

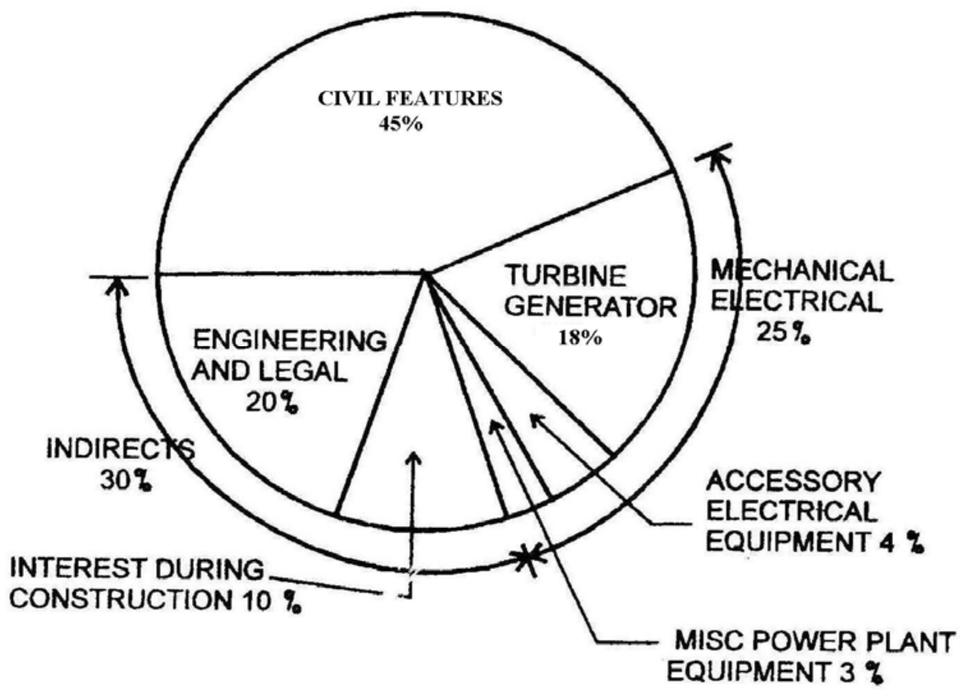


Figure 3.17 Maximum Civil Features Cost (High Head Scheme)

Pelton	-	90%
Turgo Impulse	-	80%
Cross flow	-	60%
High Head Francis	-	90% (Peak Efficiency at 90%)

Cost/kW Comparison of 100 kW 60 m head, Run of the river scheme using different type of turbine based on cost element as per figure 3.17 is given in table 3.14. The civil works i.e. intake weir, settling tank, canal, penstock and power house costs is dependent upon quantity of water required for generation i.e. proportional to efficiency. Rough cost comparison between cross flow; Turgo Impulse and Pelton/Francis turbine is based on indigenous available turbines.

Table 3.14

Item	Cross flow	Turgo Impulse	Francis	Remarks
Civil works 45% (For Francis turbine)	35100	29700	27000	
Electro-mechanical i) Turbine ii) Generator and other equipment	 3940 11220	 4320 10200	 4800 10200	1000/1500 rpm generator for Francis and turgo impulse and 750 rpm gen. For cross flow
Direct cost	50260	44220	42000	
Engineering and Indirect cost	21540	18951	18000	
Total cost/kW	71800	63172	60000	

Francis turbines costs although higher by 20% reduce cost/kW by 20%.

3.7.1.2 Low Head Scheme

Cost element in a low head project such as in canal fall projects is shown in figure 3.18 Accordingly equipment cost predominate. Cost of generators is reduced by providing speed increasing gears and accordingly selection of turbine is important for cost affective installation. Accordingly only high specific speed (Axial flow) is possible. Selection procedure is therefore is to select type and configuration of axial flow turbine as clarified in example. Most of the canal falls in the country are below 4 – 5 meter head. Canal schemes in the range lower that 3 meters are designed as ultra low head schemes. Ultra low head scheme are discussed in chapter 13.

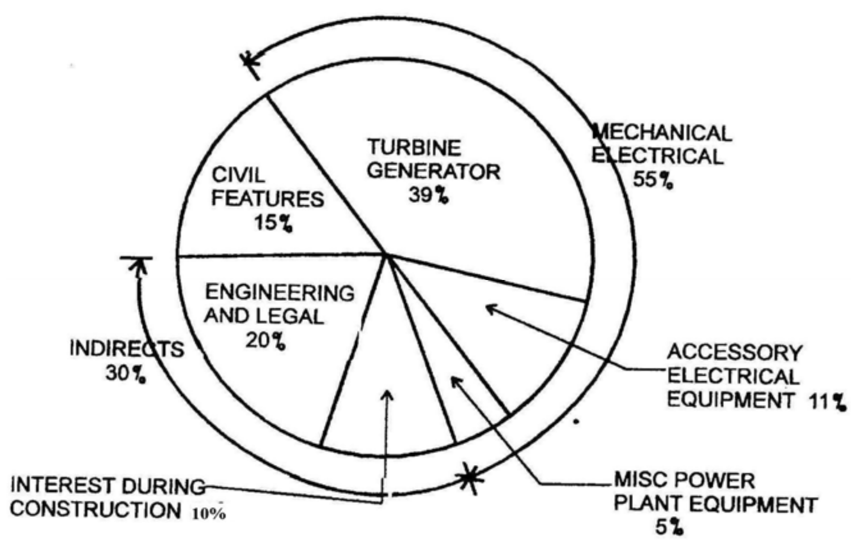


Figure 3.18 – Minimum Civil Feature (Low Head Scheme)

3.7.2 Use of Standard Turbine

Cost constraints require use of turbines for which model test data is available. The capacity to be installed could be adjusted as per this data. Typical/Standard turbines available for discharge and head in the country as per data given by some manufacturers (table 3.15) is based on AHEC/MNRE/SHP Standards/E & M Works entitled "Guidelines for Selection of Turbine and Governing System for Hydroelectric Projects" and listed below for guidance. These lists provide following information for the turbine.

Rated head; discharge; unit size and runner diameter and configuration.

Range of head and discharge not available in the list may be asked from the manufacturer. Runner diameter may be used for preliminary layout of the turbine as per IS 12800 part (3) for economic evaluation.

Table 3.15

Standard Turbine by some of the manufacturers in India

3.7.2-A1	BHEL – Standard Tubular Turbines
3.7.2-A2	BHEL – Standard Kaplan Turbine
3.7.2-A3	BHEL – Standard Francis Turbine (Horizontal Shaft)
3.7.2-A4	BHEL – Standard Pelton Turbine (Single Jet – Horizontal Shaft)
3.7.2-B1	Flovel – Standard Tubular Turbines – Semi Kaplan
3.7.2-B2	Flovel – Standard Tubular Turbines – Full Kaplan
3.7.2-B3	Flovel – Standard Pit Type Francis Turbine
3.7.2-B4	Flovel – Standard Francis Turbine (Spiral Casing Type)
3.7.2-C1	Jyoti – Standard Tubular Turbines
3.7.2-C2	Jyoti – Standard Francis Turbines
3.7.2-C3	Jyoti – Standard Pelton Turbines
3.7.2-C4	Jyoti – Standard Turgo Impulse Turbine
3.7.2-D1	HPP – Standard Vertical Kaplan Turbines

Table 3.16A1: BHEL – Standard Tubular Turbines

Runner Dia. (mm)		**1200**	**1500**	**1800**	**2000**	**2200**	**2500**
Head (m)		**Unit Output Pt (kW) and Discharge Q m^3/sec.**					
3.0	Pt	75 to 150	150 to 225	225 to 325	325 to 400	400 to 500	500 to 625
	Q	3.18 to 6.36	6.36 to 9.54	9.54 to 13.78	13.78 to 16.96	16.96 to 21.20	21.20 to 26.50
4.0	Pt	120 to 250	250 to 375	375 to 525	525 to 650	650 to 825	825 to 1050
	Q	3.82 to 7.95	7.95 to 11.92	11.92 to 16.69	16.69 to 20.67	20.67 to 26.23	26.23 to 33.38
5.0	Pt	175 to 335	335 to 525	525 to 750	750 to 925	925 to 1125	1125 to 1450
	Q	4.45 to 8.52	8.52 to 13.35	13.35 to 19.08	19.08 to 23.53	23.53 to 28.62	28.62 to 36.88
6.0	Pt	225 to 425	425 to 650	650 to 950	950 to 1175	1175 to 1450	1450 to 1875
	Q	4.77 to 9.00	9.00 to 13.78	13.78 to 20.14	20.14 to 24.91	24.91 to 30.73	30.73 to 39.74
7.0	Pt	280 to 525	525 to 800	800 to 1175	1175 to 1450	1450 to 1775	1775 to 2300
	Q	5.09 to 9.54	9.54 to 14.53	14.53 to 21.35	21.35 to 26.34	26.34 to 32.25	32.25 to 41.79
8.0	Pt	310 to 525	525 to 825	825 to 1200	1200 to 1450	1450 to 1800	1800 to 2300
	Q	4.93 to 8.35	8.35 to 13.12	13.12 to 19.08	19.08 to 23.05	23.05 to 28.62	28.62 to 36.56
9.0	Pt	370 to 625	625 to 1000	1000 to 1450	1450 to 1775	1775 to 2150	–
	Q	5.23 to 8.83	8.83 to 14.13	14.13 to 20.49	20.49 to 25.08	25.08 to 30.38	–
10.0	Pt	425 to 740	740 to 1175	1175 to 1675	1675 to 2050	–	–
	Q	5.41 to 9.41	9.41 to 14.94	14.94 to 21.30	21.30 to 26.07	–	–
12.0	Pt	565 to 850	850 to 1350	1350 to 1950	1950 to 2400	–	–
	Q	5.99 to 9.01	9.01 to 14.31	14.31 to 20.67	20.67 to 25.44	–	–
14.0	Pt	675 to 1100	1100 to 1700	1700 to 2475	–	–	–
	Q	6.13 to 9.99	9.99 to 15.44	15.44 to 22.48	–	–	–
16.0	Pt	800 to 1250	1250 to 2000	–	–	–	–
	Q	6.36 to 9.94	9.94 to 15.90	–	–	–	–

Table 3.16 A2: BHEL – Standard Kaplan Turbine

Runner dia. (mm)		1200	1500	1800	2000	2200	2500
Head (m)		Unit Output Pt (kW) and discharge Q (m^3/sec.)					
16	Pt	875-1250	1250-1950	1950-2800	2800-3500	3500-4200	4200-5000
	Q	6.8-9.7	9.7-15.2	15.2-21.8	21.8-27.3	27.3-32.7	32.7-39.0
18	Pt	1050-1500	1500-2350	2350-3375	3375-4200	4200-5000	-
	Q	7.3-10.4	10.4-16.3	16.3-23.4	23.4-29.1	29.1-34.6	
20	Pt	1240-1750	1750-2750	2750-3950	3950-4875	4875-5000	-
	Q	7.7-10.9	10.9-17.7	17.7-24.6	24.6-30.4	30.4-31.2	
22.5	Pt	1350-1850	1850-2900	2900-4175	4175-5000	-	-
	Q	7.5-10.25	10.25-16.1	16.1-23.1	23.1-27.7		
25	Pt	1600-2175	2175-3375	3375-4875	4875-5000	-	-
	Q	8.0-10.8	10.8-16.8	16.8-24.3	24.3-25.0		

Table 3.16 A3: BHEL – Standard Francis Turbine (Horizontal Shaft)

Runner dia. (mm)		450	500	560	640
Head (m)		Unit Output Pt (kW) and discharge Q (m^3/sec.)			
45	Pt	400-500	500-620	620-775	775-1000
	Q	1.00-1.30	1.30-1.65	1.65-2.05	2.05-2.65
60	Pt	600-775	775-950	950-1200	1200-1550
	Q	1.20-1.55	1.55-1.88	1.88-2.40	2.40-3.10
75	Pt	850-1075	1075-1300	1300-1700	1700-2000
	Q	1.35-1.70	1.70-2.10	2.10-2.70	2.70-3.17
90	Pt	875-1100	1100-1350	1350-1700	1700-2000
	Q	1.25-1.55	1.55-1.90	1.90-2.40	2.40-2.80
120	Pt	825-1050	1050-1300	1300-1600	1600-2000
	Q	0.80-1.05	1.05-1.30	1.30-1.6	1.6-2.00
150	Pt	750-950	950-1150	1150-1450	1450-1900
	Q	0.6-0.75	0.75-0.90	0.90-1.15	1.15-1.50
180	Pt	950-1150	1150-1450	1450-1800	1800-2000
	Q	0.65-0.75	0.75-0.95	0.95-1.20	1.20-1.35

Table 3.16 A4: BHEL – Standard Pelton Turbine (Single Jet – Horizontal Shaft)

Runner dia. (mm)		A	B	C	D	E	F	G
Head (m)		**Unit Output Pt (kW) and discharge Q (m^3/sec.)**						
150	Pt	140-170	170-215	215-265	265-320	320-380	380-450	450-500
	Q	0.08-0.1	0.1-0.117	0.117-0.13	0.13-0.145	0.145-0.157	0.157-0.17	0.17-0.176
200	Pt	210-260	260-325	325-400	400-500	500-580	580-680	680-800
	Q	0.13-0.16	0.16-0.178	0.178-0.20	0.20-0.225	0.225-0.240	0.240-0.26	0.26-0.28
250	Pt	290-360	360-460	460-565	565-685	685-825	825-950	950-1100
	Q	0.175-0.22	0.22-0.25	0.25-0.28	0.28-0.31	0.31-0.34	0.34-0.36	0.36-0.39
300	Pt	380-475	475-600	600-750	750-900	900-1075	1075-1250	1250-1450
	Q	0.23-0.29	0.29-0.325	0.325-0.37	0.37-0.405	0.405-0.44	0.44-0.48	0.48-0.51
350	Pt	480-600	600-760	760-940	940-1150	1150-1350	1350-1580	1580-1850
	Q	0.30-0.37	0.37-0.42	0.42-0.46	0.46-0.515	0.515-0.555	0.555-0.60	0.60-0.65
400	Pt	600-730	730-925	925-1150	1150-1400	1400-1650	1650-1930	1930-2000
	Q	0.36-0.45	0.45-0.50	0.50-0.57	0.57-0.625	0.625-0.680	0.680-0.73	0.73-0.70
450	Pt	700-875	875-1100	1100-1350	1350-1650	1650-1975	1975-2000	
	Q	0.43-0.54	0.54-0.60	0.60-0.67	0.67-0.74	0.74-0.81	0.81-0.76	-
500	Pt	820-1025	1025-1300	1300-1600	1600-1950	1950-2000		
	Q	0.50-0.63	0.63-0.715	0.715-0.79	0.79-0.875	0.875-0.820	-	-

Table 3.16 B1: **Flovel – Standard Tubular Turbines – Semi Kaplan**

Runner Dia (mm)	900	1150	1400	1650	1900	2150	2400	2650	2900	3200
Head (m)	**Turbine/Generator Output (kW)**									
3	100	125	175	280	350	425	550	650	800	1000
4	100	175	275	380	500	650	800	1000	1250	1500
5	150	225	350	500	650	825	1100	1350	1600	1900
6	200	320	450	625	875	1200	1450	1700	2000	2400
7	240	380	550	800	1100	1400	1750	2000	2400	3000
8	275	420	700	950	1250	1650	2000	2375	2900	3500
9	320	520	800	1150	1500	1900	2250	2750	3400	4000
10	380	600	850	1250	1650	2100	2600	3250	3800	4500
12	420	750	1100	1450	1850	2600	3200	4000	4800	6000
14	500	800	1200	1600	2100	3000	3700	4600	5600	6500
16	500	800	1200	1700	2750	3150	4100	4600	5600	6700

Table 3.16 B2: Flovel – Standard Tubular Turbines – Full Kaplan

Runner Dia. (mm)	1450	1650	1900	2150	2400	2650	2900	3200
Head (m)	**Turbine/Generator Output (kW)**							
3	200	300	400	500	650	800	1000	1200
4	300	420	550	725	900	1050	1300	1500
5	400	550	750	925	1160	1450	1700	2000
6	500	700	950	1200	1500	1800	2150	2500
7	600	850	1200	1500	1750	2150	2500	3200
8	750	1000	1400	1725	2050	2500	3000	3600
9	800	1200	1600	1950	2400	3050	3600	4300
10	1000	1300	1700	2250	2750	3400	4000	4900
12	1150	1500	1900	2750	3400	4200	5000	6200
14	1200	1650	2100	3200	3850	4600	5650	7000
16	1200	1650	2220	3300	4200	4900	6200	7500

Table 3.16 B3: Flovel – Standard Pit Type Francis Turbine

Runner dia. (mm)		800	1100	1400
Head (m)		**Turbine/generator output P (kW) and Turbine Speed N (rpm)**		
3	P	36	75	125
	N	170	120	100
4	P	60	100	200
	N	220	170	120
6	P	100	175	350
	N	280	210	150
8	P	175	300	500
	N	300	230	180
10	P	250	450	750
	N	350	250	200

Note: Recommended generator speed – 1000 to 1500 rpm

Table 3.16 B4: Flovel – Standard Francis Turbine (Spiral Casing Type)

Runner dia. (mm)	450	650	800	1000	1200	1400	1600
Head range (m)	15 to 250	15 to 300	20 to 200	20 to 150	20 to 90	20 to 70	20 to 50
Output (kW)	100 to 1500	200 to 3000	500 to 6000	1000 to 7000	1500 to 8000	2000 to 8000	3000 to 8000
Range of speeds (rpm)	1000 1500	500 750 1000	400 500 600 750	375 420 500 600	300 375 428 500	250 300 333	200 250 300

Table 3.16 C1: Jyoti – Standard Tubular Turbines

Runner dia. (mm)	**260**	**600**	**750**	**1000**	**1200**	**1400**	**1650**	**1900**	**2200**	**2500**
Head (m)	**Turbine output Pt (kW)**									
3	5	28	45	75	125	175	240	330	430	550
4	8	45	80	130	200	280	380	520	730	925
5	11	65	115	190	300	400	560	800	1050	1350
6	15	90	150	250	400	540	750	1000	1400	1800
7	17	115	190	300	460	700	900	1200	1650	2150
8	19	130	210	340	525	750	1000	1400	1900	2500
9		150	240	400	600	825	1150	1600	2150	2900
10		165	270	450	650	920	1250	1750	2350	3200
12.5		205	320	545	800	1200	1600	2200	3100	4000
15		240	380	650	1000	1400	1850	2750	3700	4700
20		320	480	830	1300	1800	2450	3550	4600	6000
25		400	560	900	1450	2250	3150	4200	5900	7200

Table 3.16 C2: Jyoti – Standard Francis

Runner dia. (mm)	**350**	**375**	**450**	**525**	**600**	**750**
Head (m)	**Turbine Output in Kilowatts**					
10	25	31	45	65	90	-
15	45	55	80	115	145	230
20	70	85	125	170	225	355
25	100	120	180	240	320	500
30	135	165	240	330	435	680
35	160	200	295	405	530	835
40	130	157	360	500	650	1000
45	160	200	400	390	520	1250
50	180	225	490	680	600	1450
55	320	410	580	530	700	1660
60	375	470	690	940	800	1950
70	305	370	545	725	960	1530
80	360	440	645	890	1180	1830
90	440	540	780	1080	1400	2240
100	500	635	900	1275	1650	2620
110	600	740	1080	1480	1950	3100

Table 3.16C3: Jyoti – Standard Pelton Turbines

Runner dia. (mm)	425	600	750	850	1100
Head (m)	Turbine Output in Kilowatts				
100	40	90	120	170	275
110	50	105	140	195	320
120	55	120	160	224	366
130	60	130	180	250	410
140	70	150	205	285	465
150	80	165	225	315	515
160	85	180	245	345	570
170	95	200	270	380	625
180	100	215	295	415	675
190	110	235	325	450	740
200	120	255	345	485	790
225	140	300	415	575	940
250	165	355	485	675	1100
275	190	410	560	780	1275
300	215	465	635	890	1450
325	245	525	715	1000	1635
350	275	585	800	1120	1825
375	305	650	890	1245	2030
400	-	-	975	1360	2235
425	-	-	1080	1510	2465
450	-	-	1165	1630	2660

Note: Pelton will be double of above figures for two jet pelton

Table 3.16 C4: Jyoti – Standard Turgo Impulse Turbine

Runner dia. (mm)	350	425	525	600	675	750
Head (m)	Turbine Output in Kilowatt					
40	41	61	100	131	168	207
50	57	86	140	184	233	290
60	75	113	185	241	308	382
70	94	141	232	304	388	481
80	115	174	284	373	473	587
90	137	207	338	444	564	702
100	161	242	397	521	622	822
110	186	279	458	601	764	948
120	212	319	521	684	868	1078
130	239	359	589	772	982	1217
140	267	404	658	862	1097	1360
150	295	446	727	956	1212	1509
160	325	491	801	1053	1336	1636
170	356	537	878	1152	1465	1822
180	388	585	957	1255	1596	1986
190	421	635	1038	1367	1731	2153
200	455	687	1126	1475	1879	2327

Table 3.16 D

HPP - STANDARD VERTICAL KAPLAN TURBINE											
RUNNER DIA (mm)	**1200**	**1400**	**1700**	**1850**	**2000**	**2100**	**2300**	**2700**	**2900**	**3000**	**3600**
HEAD (m)						**TURBINE / GENERATOR OUTPUT (KW)**					
1.75	60	80	120	145	170	185	225	300	350	380	550
2	80	110	160	200	225	250	300	400	475	500	725
3	160	200	300	360	420	465	560	770	885	950	1350
4	225	300	450	535	625	690	825	1140	1315	1400	2025
5	325	440	650	770	900	990	1190	1640	1900	2025	2915
6	400	550	815	965	1130	1245	1500	2050	2375	2550	3660
7	500	685	1015	1200	1400	1550	1850	2550	2950	3160	4550
8	550	750	1100	1300	1500	1675	2000	2770	3200	3420	4925
9	675	920	1350	1600	1875	2060	2480	3420	3950	4225	6080
10	775	1050	1550	1850	2150	2375	2850	3925	4530	4850	7000
12	850	1165	1715	2030	2375	2620	3140	4325	5000	5350	7700
14	1120	1520	2240	2650	3100	3420	4100	5650	6520	6980	10050

3.7.3 Turbine Efficiency

Typical efficiency curves of the various types of turbines are shown for comparison in Figure 3.14. These curves are shown to illustrate the variation in efficiency of the turbine through the load range of the design head. Approximate efficiency at rated capacity for the reaction turbines are shown for a turbine with a throat diameter of 0.3 m. Rated efficiency will increase as the size of the turbine increases. The bottom curve in figure 3.14 shows the relationship of efficiency to throat diameter. The rated efficiency for turbines with throat diameters larger than 0.3 m may be calculated in accordance with this curve. The efficiency curves shown are typical expected efficiencies. Actual efficiencies vary with manufacturer and design.

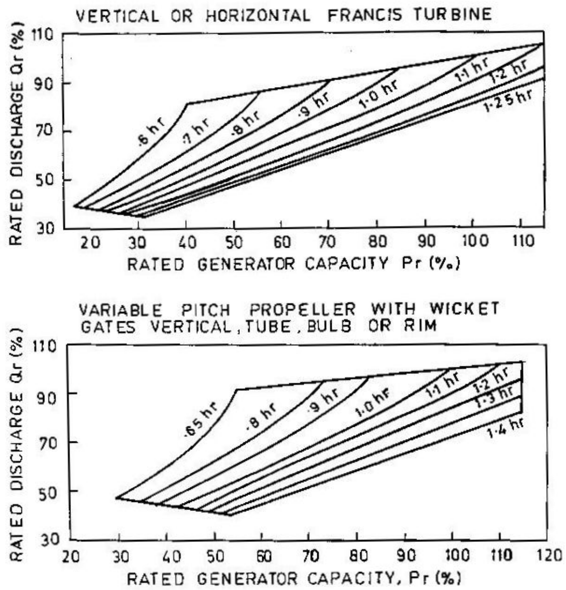
Size step up efficiency factors do not apply to impulse or cross flow type turbines. The values as shown may be used. Note, that these curves can only be used when the head on the turbine does not vary and less precise results are warranted. In micro hydro range turbine efficiencies are lower.

3.7.4 Turbine Performance

Figure 3.19 and figure 3.20 (AHEC/MNRE/SHP Standards/E & M Works entitled “Guidelines for Selection of Turbine and Governing System for Hydroelectric Projects”) show performance characteristics for Francis, Kaplan (variable pitch blade propeller with wicket gates). Propeller (fixed blades with wicket gates) and Tube (variable pitch blades without wicket gates) type turbine. These curves were developed from typical performance curves of the turbines of a special speed that was average for the head range considered in the guidelines. Comparison of performance curves of various specific speed runners was made and the average performance values were used. The maximum error occurs at the lowest Pr and was approximately three percent. These curves may be used to determine the power output of the turbine and generator when the flow rates and heads are known. The curves show percent turbine discharge, percent Qr versus percent generator rating, percent Pr throughout the range of operating heads for the turbine.

3.7.5 Runner Diameter and Turbine Setting

Runner diameter may be used for preliminary layout of the turbine as pre IS 12800 part (3) for economic evaluation. Approximate runner diameter may be determined form Francis turbine from Figure 3.21 & for propeller turbine from figure 3.22. All other dimensions for preliminary layout are given in the IS: 12800 as a factor of diameter. The civil engineer cost of the powerhouse building for the particular turbine type may affect choice of selection of turbine.

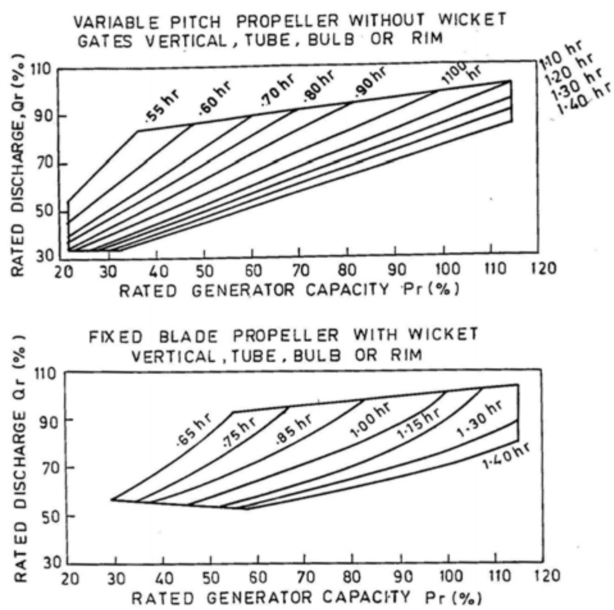


$Pr = \gamma w,\ hr,\ Q r,\ \eta\ t.r\ \ \eta\ g$ (kW)

Where,

Pr = Rated capacity at hr
Hr = Selected Design Head
Qr = Turbine Discharge at h r ε Pr
η t. r = Turbine efficiency at h r ε Pr
η g = Generator efficiency , (%)

Figure 3.19: Francis and Kaplan performance curves

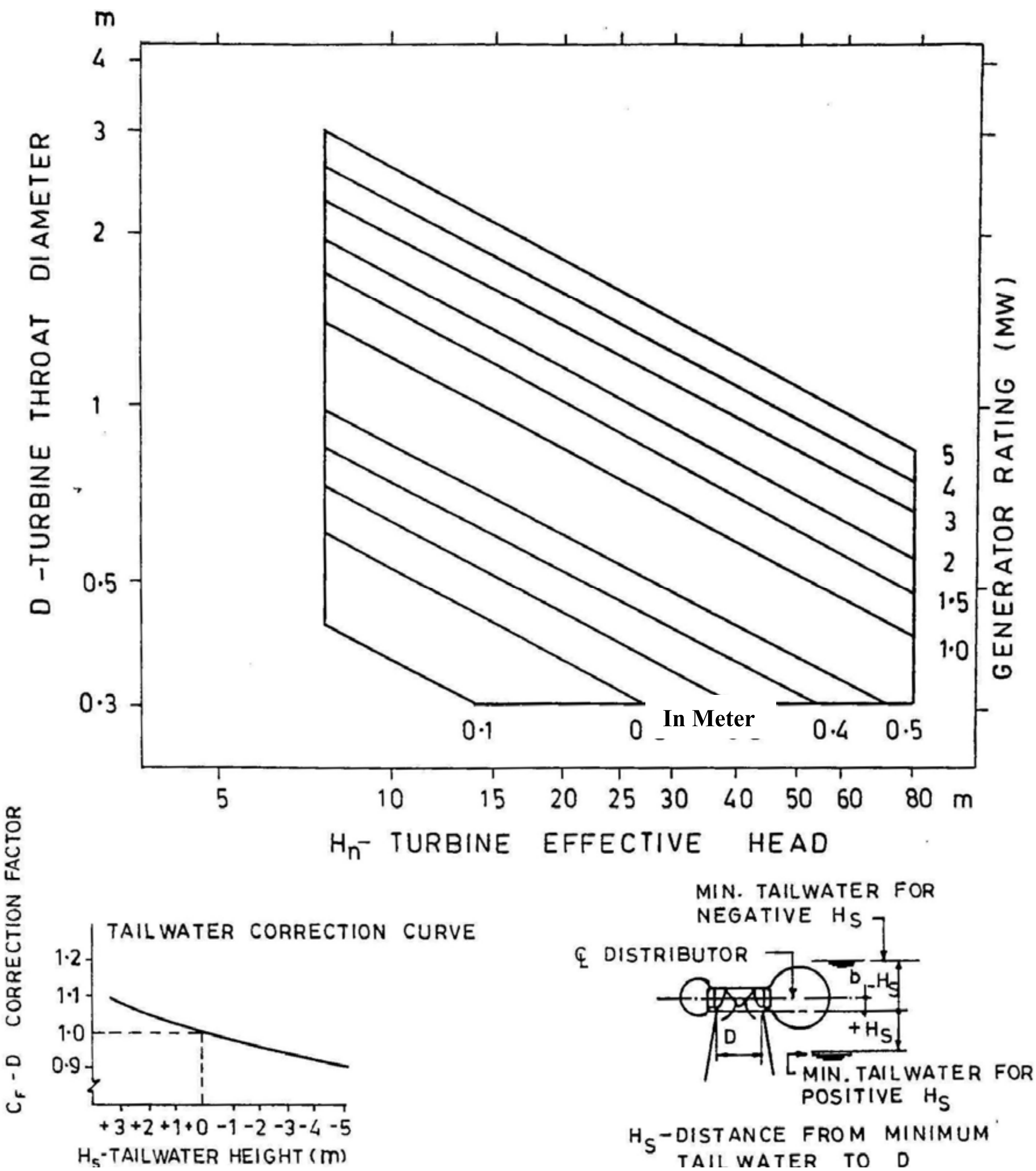


$Pr = \gamma w,\ hr,\ Q r,\ \eta\ t.r\ \ \eta\ g$ (kw)

Where,

Pr = Rated capacity at hr
Hr = Selected Design Head
Qr = Turbine Discharge at h r ε Pr
η t. r = Turbine efficiency at h r ε Pr
η g = Generator efficiency , (%)
γ w = specific density of water in N/m^2 and may be taken 9.804

Figure 3.20: Propeller turbine performance curves



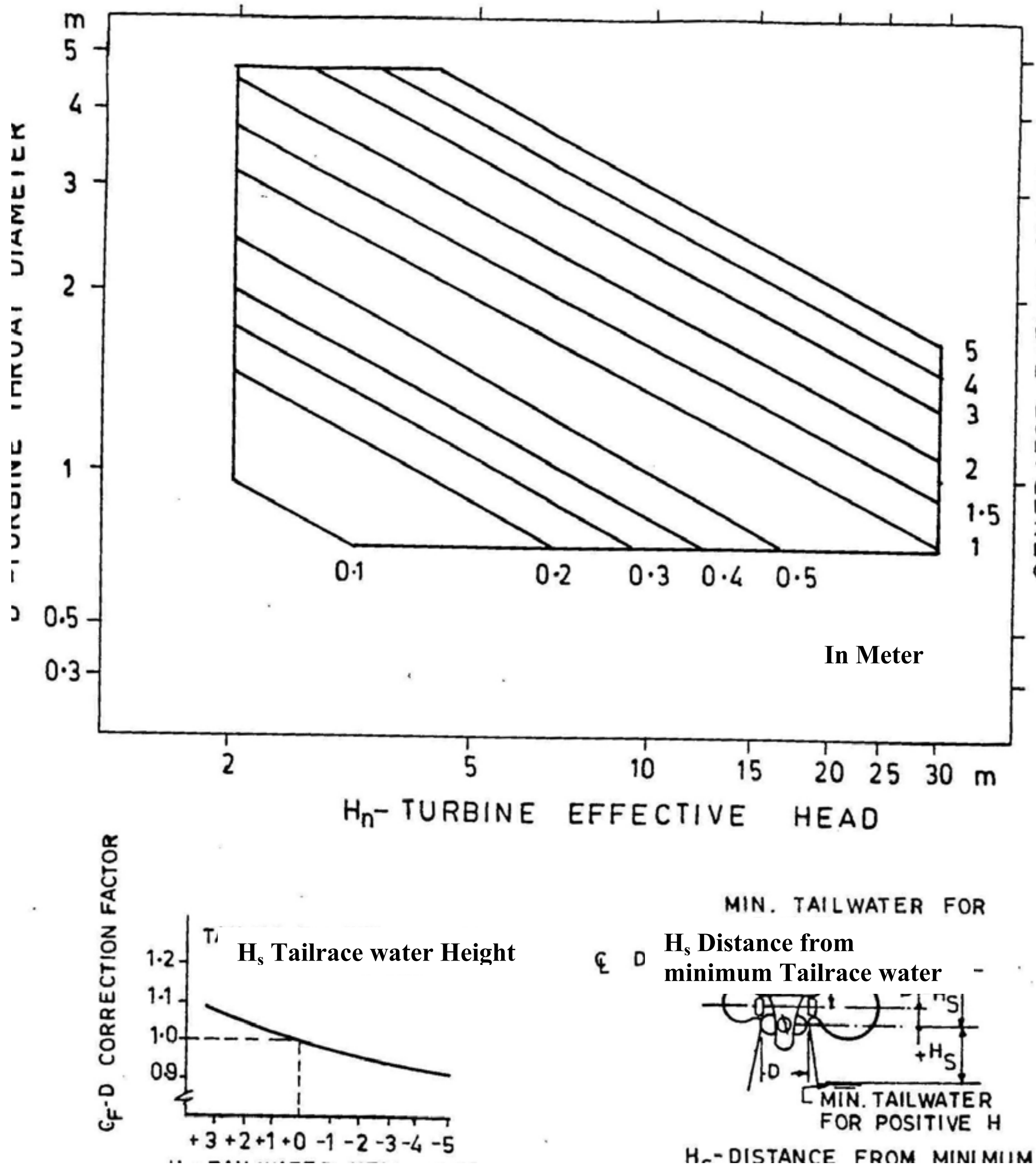
NOTES:

1. Estimated turbine runner diameters D are based upon a plant elevation of 600 m. and a tailrace water height (Hs) of zero. Where Hs = distance between minimum tail water level and exit of runner blades.

2. The estimated runner diameters may be used for both vertical and horizontal Francis turbines.

3. For plant elevations higher than 600 m add 1% to D for each 300 m. Subtract 1% from D for each 300 m. slower than the 600 m plant elevation.

Figure 3.21 Francis turbine runner diameters
(Source: IS 12800)



NOTES:

1 Estimated turbine runner diameters D are based upon a plant elevation of 600 m. and a tailrace water height (Hs) of zero. Where Hs = distance between minimum tail water level and exit of runner blades.

2 The estimated runner diameters may be used for both vertical and horizontal Francis turbines.

3 For plant elevations higher than 600 m add 1% to D for each 300 m. Subtract 1% from D for each 300 m. lower than the 600 m plant elevation.

Figure 3.22: Propeller turbine runner diameters
(Source: IS 12800)

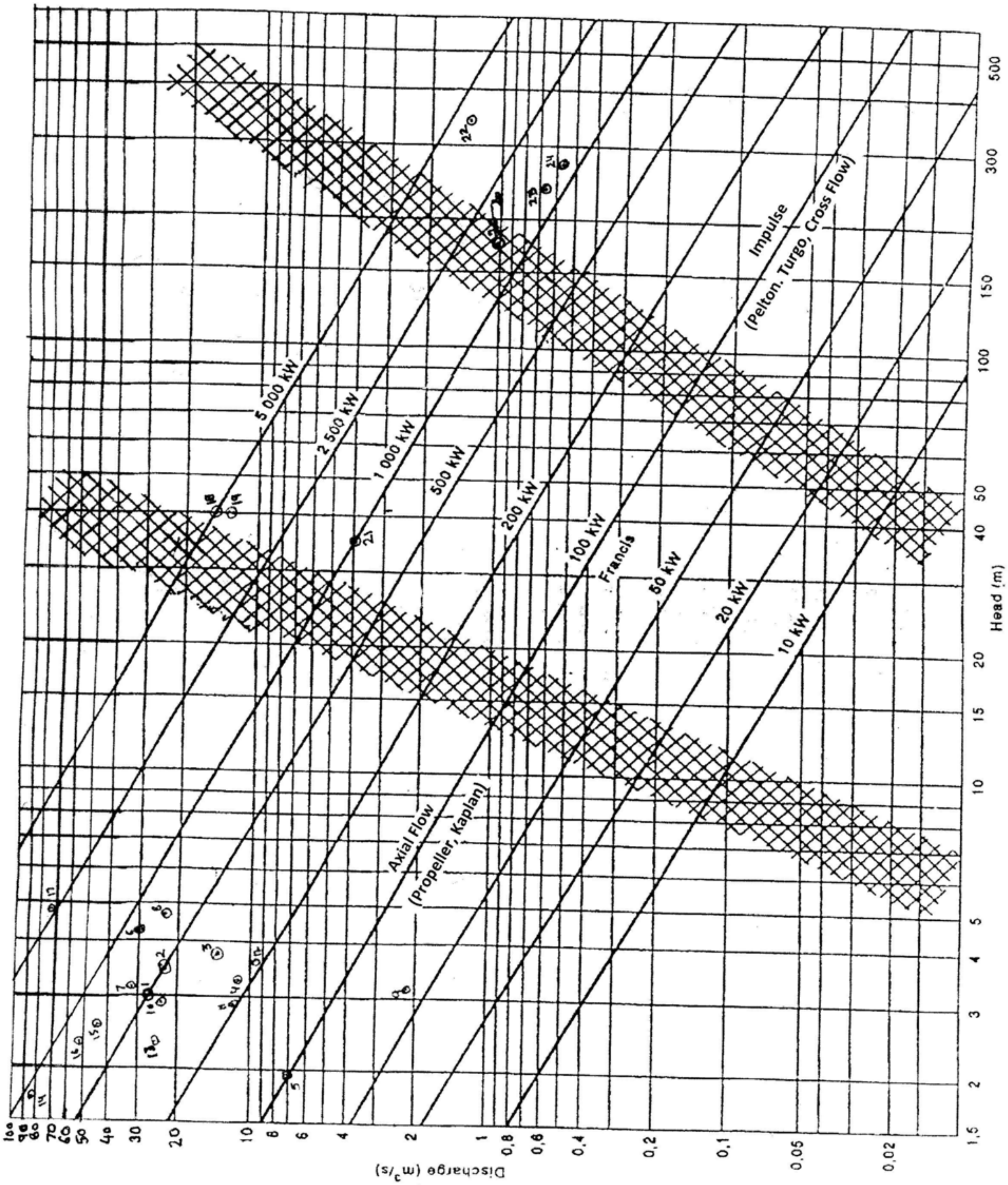
3.8 SELECTION PROCEDURE OF SMALL HYDRO TURBINE UP TO 5 MW UNIT SIZE

Preliminary selection for type of small hydro turbine can be made from selection chart (figure 3.23) which is based on IEC –1116 – 1992 as modified by actual data of small hydro installed in the country (table 3.17). Kind (within type) and configuration (horizontal or vertical) may be based on economic consideration including cost of civil works, efficiency etc. and Typical/Standard turbines available for discharge and head in the country as illustrated in the examples.

Table 3.17

Sl. No	Power Station	No. of Units× Size (MW)	Head (M)	Discharge (M/s)	Year of Coming	Specific Speed Ns in (MHP)
Axial Turbine (Kaplan Turbine)						
1.	Nidampur	2x0.500	3.000	-	1985	935.54
2.	Dauhar	3x0.500	3.500	-	1987	771.58
3.	Ganekal	1x0.350	3.690	-	1994	604.27
4.	Kakatiya	3x0.230	3.300	-	1987	688.37
5.	Kakroi	1x0.100	1.900	-	1988	678.63
6.	Jainagra SHP	2x0.500	4.180	29.62	Under Construction	-
7.	Shirkhinda SHP	2x0.350	3.186	31.40		739.37
8.	Rajapur SHP	2x0.350	4.780	23.00		791.80
9.	Amethi SHP	1x0.500	3.218	2.17		740.44
10.	Arwal SHP	1x0.500	2.926	24.40		752.21
11.	Rampur SHP	1x0.250	2.940	11.97		-
12.	Natwar SHP	1x0.250	3.569	9.87		-
13.	Mautholi SHP	1x0.400	2.350	25.94		-
14.	Katanya SHP	4x0.250	1.780	81.12		-
15.	Agnoor SHP	2x0.500	2.744	41.90	2005	-
16.	Dhelabagh SHP	2x0.500	2.400	51.80	2006	-
17.	Triveni SHP	2x1.500	4.940	72.52	Under Construction	-
Francis Turbine						
18.	Gumti	3x5.000	40.00	-	1976	283.73
19.	Devighat (Through NHPC)	3x4.800	40.00	-	1983	278.00
20.	Gumma	2x1.500	176.75	-	2000	109.17
21.	Karnah	2x1.000	36.00	-	1991	325.72
Pelton Turbine						
22.	Chenani	2x4.600	365.8	-	1975	30.81
23.	Thirot	3x1.500	245.0	-	1995	36.29
24.	Yazali	3x1.500	277.0	-	1991	31.13

MHP: - Metric horse power units.



Note: *Details of SHP marked on the chart are given in table 3.17*

Figure 3.23 Preliminary Turbine Selection Chart for SHP
(Based on IEC: 1116 and Indian Projects Data)

3.8.1 Small Hydro in the Range 0.1 MW to 5 MW

1) Field Data Required

a) Discharge data - Q cumecs
b) Head - H in meter
c) Voltage Net work (415 volts 11 kV/33kV)
d) Nearest grid sub-station (optional) – kV and length of interconnecting line

2) **Compute kW capacity (P)** (from field Data)

$$P = Q \times H \times 9.804 \times 0.8$$

3) Fix unit size, number and installed capacity based on data collected.
4) Using kW; H and Q per unit select usable turbine from figure 3.23.
5) In case of turbine in overlapping range determine speed and specific speed relation and determine synchronous speed based on applicable range of specific speed as per table 3.8. Higher speed machine is cost effective.
6) Select standard/typical available turbine with highest synchronous speed and best efficiency range (table 3.15).

3.8.2 Example of turbine selection (SHP range)

3.8.2.1 Sobla Power House (high head)

Site Data

A common penstock bifurcating at the powerhouse into a wye branch for each power unit is proposed. The length of the penstock system including Y-branch length is 340 meters.

Detail of hydraulic system and basic data for design of turbine as extracted from the specifications is given below:

(1)	Full reservoir/max. Forebay level (m)	1935
(2)	Minimum draw down level (m)	1934
(3)	Maximum gross head (static) (m)	198
(4)	Maximum net head (m)	185
(5)	Minimum net head (m)	184
(6)	Rated head (m)	185
(7)	Elevation of centre line (m)	1737
(8)	Maximum tail race level (m)	1734
(9)	Diameter of each penstock (m)	1200
(10)	Length of penstock (m)	340
(11)	Permissible speed rise	45%
(12)	Permissible pressure rise	20%

Discharge Data

Stream discharges available for diversion for generation of power at Sobla are given in Table 3.18. There is no storage. Inter connection of power plant implies utilisation of entire power generated for feeding into the grid besides supplying local loads at Sobla and Dharchulla. Accordingly, power generation based on minimum inflows and loading of turbine as percentage of installed capacity is shown in Table-3.19. It is clear that at no time the part load operation is below 67%. Average plant factor during water shortage critical months (December-April) is about 73%.

Inter connection and load characteristics

The powerhouse was proposed to be interconnected by 33 kV lines to Kanchauti and Dharchulla in a ring main for interconnection with Uttarakhand Grid sub-station at Dharchulla.

Table –3.18

SOBLA SMALL HYDRO SCHEME DISCHARGES (m^3/sec)

S.No.	Month	1978	1981	1982	1983	1986	1987
1.	January	3.00		3.13	3.49	-	3.10
2.	February			3.08		-	3.05
3.	March			3.00	3.17	-	2.77 2.85
4.	April	4.21		4.16		-	3.16
5.	May	5.19		4.50		-	>5.0
6.	June	9.48				-	>5.0
7.	July		24.00			-	9.10 8.25
8.	August			13.65		11.35	11.90
9.	September			8.00		~ ≥.8	12.10
10.	October			6.20		7.71	7.90 8.00
11.	November			5.20		≥.4.8	7.05
12.	December			3.10		3.40	5.67

Table –3.19

PART LOAD OPERATION OF SOBLA UNITS

Installation = 2 x3 MW; Rated Head = 185 m

S.No.	Month	Discharge (Cumecs)		Minimum available Power = 9.81 x Q.HE kW	Average plant factor during month
		Average	Minimum		
1.	January	3.18	3.00	4356	71%
2.	February	3.06	3.05	4428	73.8%
3.	March	3.00	2.77	4022	67%
4.	April	3.84	3.16	4588	76.4%
5.	May	4.89	4.50	6533	100%
6.	June	7.00	5.00	7259	100%
7.	July	9.00	8.25	6000	100%
8.	August	12.30	11.35	6000	100%
9.	September	9.30	8.00	6000	100%
10.	October	7.27	6.20	6000	100%
11.	November	5.68	4.80	6969	100%
12.	December	4.05	3.10	4501	75%

NOTE: Overall Efficiency assumed 80%

A small 250 kVA transformer to feed local loads at Sobla was also proposed.

Accordingly, it was considered essential to design the turbines for standalone isolated operation as well as for parallel operation with grid.

Turbine Selection

Rated Head (H)	=	185 m
Rated Power (P) per unit	=	3000 kW
Discharge	=	2.06 cumecs
Installation	=	2 x 3000 kW

As per Figure 3.23 it is seen that either an impulse or Francis Turbine may be suitable. Pelton turbines were originally proposed.

Specific speed (n_s) is related to rotational speed (n) by specific speed n_s

$$n_s = n\sqrt{P}/H^{5/4}$$
$$= n\sqrt{3000}/(185)^{5/4}$$
$$n = 12.45\ n_s$$

Runner diameter (D) and speed for various possible values of n_s are computed and compared in Table 3.20.

For Pelton Turbine upper practical limit of jet diameter D_j and runner diameter ratio $D_j/D = 0.1$, then D is 2.1 m which corresponds to a unit with specific speed $n_s = 21$ for single jet pelton and about 30 for two jet turbine. Accordingly, synchronous speed of 375 RPM pelton 2 jet turbine having runner dia of about 1.3 m is possible in case Pelton turbines is used.

Pelton turbines can be coupled directly to 375 r.p.m. (16 pole) generator or 750 r.p.m. (8 pole) generator through speed increasing gears.

For Francis turbine a 6 pole machine 1000 r.p.m. can be set 0.7 m above minimum tailrace water and may be economical to use. Four pole, 1500 r.p.m. generators coupled to 120 (n_s) turbines are also feasible and are cavitation free but not recommended due to high speed low inertia in generators and lower setting.

Table 3.20

<table>
<tr><th>S. No.</th><th>Type of Turbine</th><th>N_s (metric)</th><th>n(r.p.m.) =12.4 n_s (nearest synchronous)</th><th>Runner dia (m)</th><th>Setting of runner above tailrace</th><th>Remarks</th></tr>
<tr><td>A.</td><td>Single Jet Pelton</td><td>10
15
20</td><td>125
187.5
250</td><td>4.11
2.74
2.06</td><td rowspan="2">Above maximum T.W. level</td><td rowspan="2">Speed nearest Synchronous</td></tr>
<tr><td>B.</td><td>Double Jet Pelton</td><td>15
20
30</td><td>187.5
250
375</td><td>2.74
2.06
1.30</td></tr>
<tr><td rowspan="4">C.</td><td rowspan="4">Francis</td><td>60</td><td>750</td><td>0.675</td><td>+4.0 m</td><td rowspan="4">i. Nearest synchronous speed
ii. Allow 1 m as margin for atmospheric variation for runner setting</td></tr>
<tr><td>80</td><td>1000</td><td>0.54</td><td>+2.2 m</td></tr>
<tr><td>100</td><td>1250 (Synchronous speed not possible)</td><td></td><td></td></tr>
<tr><td>120</td><td>1500</td><td>0.4</td><td>-2.4 m</td></tr>
</table>

Comparison of 375 r.p.m. Pelton Turbine and 1000 r.p.m. Francis Turbine

1. Cost of directly coupled Pelton turbine generator set will be more (about 2.5 times that of Francis Turbine coupled generators) and those coupled through speed increasers by about 1.5 – 2 times.
2. Selection of low specific speed Francis turbine (1000 r.p.m.) with a setting of 0.7 m above minimum tailrace water level is possible and is liable to be cavitation free.
3. Excessive silt or sand in the water will cause more wear on the runner of an impulse turbine than on the runners of most reaction turbines.
4. Powerhouse size is liable to be bigger by about 70% for Pelton units. Thereby increasing Civil Engineering cost.
5. Setting for Pelton turbine nozzle center line is proposed at EL 1737 m and maximum tail water E.L. is 1734 m. Accordingly, if Francis turbine is used, a minimum increase in head of 3 meters is possible. Available head will be further increased during water shortage winter months when tail water is at lower level.
6. Peak efficiency of Pelton turbine is slightly lower than peak efficiency of Francis turbine but part load efficiencies of Pelton turbines are higher. The units do not run below 70% load (Annexure-I) and 80% of the time the units are running above 80-90% load. Accordingly, it is considered that Francis units will generate more energy.

7. Penstock length (L) is 340 meter and head (H) is 185 m. According L/H ratio is about 1.8 indicating no water hammer problem for stable speed regulation for Francis turbines and no special advantage for Pelton turbines.

Conclusion & Recommendations

Originally Proposed Pelton turbines were replaced by Francis Turbines and large economies in cost (25-30%) were made.

3.8.2.2 Tejpura SHP (Bihar) (Canal Fall Scheme)

Site Data

Discharge Q	=	61.05 cubic meters
Net head H	=	3.46 meters
Power P	=	9.80 x 61.05 x 3.46 x 0.85
	=	1759 kW
Installation	=	2 x 750 kW

Efficiency SHP range of turbine and generator has been taken as 0.85.

Turbine Selection

As per figure 3.23 only Kaplan/Propeller Axial flow turbine is feasible.

Available standard turbine (table 3.15 A1) is Tubular turbine S type (Full Kaplan) or Semi Kaplan turbine with runners dia. About 2500 meter (BHEL standard Tubular Turbine Figure 3.17) is feasible. This type of turbines requires intake valve for shut off (emergency) as well as draft tube gates for dewatering. It also requires dewatering and drainage arrangement.

Semi Kaplan vertical turbines with siphon intake as shown in figure 3.7 was selected as cheapest and cost effective alternatives (efficient) which does not require intake and draft gates and dewatering arrangements. Detailed comparison of S type tubular turbine with vertical syphon intake turbine is given in table 3.21.

Table 3.21

Comparison of Tubular type and vertical axis siphon intake for ultra low head (below 3 to 4 meter head)

S. No.		Tubular turbine (semi Kaplan)	Vertical axis Siphon intake	Remarks
1.	Inlet valve	Required	Not required	
2.	Draft tube gate	Required	Not required	
3.	Drainage pump	Required	Not required as setting is above maximum tailrace	
4.	Dewatering pump	Required	Not required as setting is Above tailrace	
5.	Cost of civil Work	High (setting is low)	Low	
6.	Efficiency	Tubular turbine efficiency is 1% higher		

Guaranteed technical Particulars of the Tejpura Mini HP

Turbines ordered are as follows:

Type of turbine – vertical semi Kaplan with siphon intake

Rated Head (H)	=	3.24 m
Rated power (P)	=	845 kW (10% overload)

Rated discharge (Q) = 30.075 Cumecs
(for rated output
generator terminal)

Efficiency at rated Head & output = 88.92 %
Synchronous Gen. Efficiency at rated output = 96.4 %

3.9 MICRO HYDRO

3.9.1 Micro Hydro Range (up to 100 kW): A large number of micro hydro in remote hilly areas are being installed to supply power to remote villages. To meet basic needs as follows:

- Electricity for lighting and appliances (fan, radio, TV, computer, etc), in homes and public buildings such as schools and clinics
- Electrical or mechanical power for local service and cottage industries
- Electrical or mechanical power for agricultural value-adding industries and labour saving activities
- Electricity for lighting and general uses in public spaces and for collective events

The electricity provided is in the form of 415/240-volt AC line connections to users, with 11 kV sub transmission, if required.

Table 3.22: Micro Hydro Turbine Selection as per Micro Hydro Standards (AHEC)

	Description	**Category (Installed Capacity in kW)**		
		Category A (Up to 10 kW)	**Category B (Above10kW and up to 50 kW)**	**Category C (Above 50 kW and up to 100 kW)**
Turbine	Types	• Cross Flow • Pump as turbine • Pelton • Turgo • Axial Flow • Turbine • Any other turbine meeting the technical requirement	• Cross Flow • Pelton • Turgo Impulse • Axial Flow Turbine • Francis • Pump as Turbine • Any other turbine meeting the technical requirement	• Cross Flow • Pelton • Turgo Impulse • Axial Flow Turbine • Francis • Any other turbine meeting the technical requirement
	Rated Output at rated head (at Generator output)	Up to 10 kW	(Above10kw and up to 50 kW**) as specified**	**(**Above 50 kW **and up to 100 kW) as specified**
	Bid evaluation – equalization for shortfall in overall weighted average efficiency	NIL	Each 3% for every 1 percent difference by which rated average efficiency (computed) is lower than the highest weighted average efficiency	Each 3% by which rated average efficiency (computed) is lower than the highest weighted average efficiency
Generator	Types	Synchronous/ Induction -Single Phase/3 phase	Synchronous/ Induction 3 Phase	Synchronous 3 Phase
	Terminal Voltage, frequency	240 V, 1 –phase, 50 Hz	415 V 3 phase, 50 Hz	415 V, 3 phase, 50 Hz
	Make and Runaway withstand	Standard / Special generators designed to withstand against continuous runaway condition.		
	Insulation and Temperature Rise	Class F/H insulation and Class B Temperature rise		

	Description	Category (Installed Capacity in kW)		
		Category A (Up to 10 kW)	Category B (Above10kW and up to 50 kW)	Category C (Above 50 kW and up to 100 kW)
Overall Efficiency	Minimum required Weighted Average Efficiency of the turbine Generator set (ηT Av) $0.50 \times \eta T_{100} + 0.50\ \eta T_{50}$	45%	50%	60%

3.9.2 Step by step procedure for selection of turbine is detailed below:

1) Obtain Field Data as follows:

   a) Discharge data - Q cumecs
   b) Head - H head in meter
   c) Voltage Net work (415 volts or 11 kV)
   d) Nearest grid sub-station (optional) – kV and length of interconnecting line

2) **Compute kW capacity** (P) with available data from site

   P = Q x H x 9.804 x 0.8

3) Fix unit size, number and installed capacity based on data collected and requirement.
4) Using kW; H and Q per unit select usable turbine from figure 3.23.
5) In case of turbine in overlapping range determine speed and specific speed relation and determine synchronous speed based on applicable range of specific speed as per Para 3.7. Higher speed machine is cost effective.
6) Review turbine limitation and fix turbine type as per micro hydro standard (table 3.22)

Table 3.23: Typical List of Cross Flow Turbine Installed/Proposed in Remote Areas of Uttarakhand

Sl. No.	Power Station	Sponsorer/ Manufacturer	No. of Units x Size (MW)	Head (M)	Speed (RPM)	Year/ Likely year of Commissioning	Specific Speed (Ns)	Type of Turbine	Type of Generator
1.	Dokti	Nepal Hydro & Electric Pvt. Ltd.	1x0.02	62.0	1575			Cross Flow	Synchronous Generator Horizontal, Kirloskar
2.	Kanolgod	Nepal Hydro & Electric Pvt. Ltd.	2x0.05	24.5	990			Cross Flow	Synchronous Generator Horizontal, Kirloskar
3.	Karmi-II	Nepal Hydro & Electric Pvt. Ltd.	2x0.025	70	1673			Cross Flow	Synchronous Generator Horizontal, Kirloskar
4.	Ramgarh	Jyoti Ltd.	2x0.05	50	750			Cross Flow	Horizontal Jyoti Ltd.
5.	Ratmoli	Nepal Hydro & Electric Pvt. Ltd.	2x0.025	39	1250			Cross Flow	Synchronous Generator Horizontal, Kirloskar
6.	Gangotri-I	Vodini Check Republic	2x0.050	23.6	836			Cross Flow	AVK

3.9.3 Examples of Turbine Selection (micro hydro range)

Napalchyo MHP (Uttarakhand)

Site Data

Q = 0.674 cumecs
H = 62 m

P = 9.80 x 0.674 x 62 x 0.80
= 327.61 kW

Installation proposed based on load survey = 2 x 100 kW

Turbine selection (with following particulars)

Power (P) = 100 kW
Head = 62 m

i) As per Figure 3.23 Francis turbine requiring a discharge of 0.2 cumec per turbine is feasible. Peak efficiency of Francis turbine as per figure 3.5.1 is 90% (at 90% gate).

ii) Available standard turbine (table 3.15)

	Type	Runner dia.	Speed	Peak Approved Efficiency
Flovel	Francis	450 mm	1000 to 1500 rpm	90% (table 3.15 B4)
Jyoti	Turgo Impulse	425 mm	1000 rpm	85% (table 3.15 C4)

According Francis turbine requiring a discharge of 0.2 cumecs per turbine and 0.4 cumecs for 2 turbines required. Civil work may be designed for 0.45 cumecs (10% + 5% margin). Pumps as turbine (mixed flow) can also be used. Check for part load efficiency.

Rong Kong MHP (Uttarakhand)

Site Data

Q = 0.441 cumecs
H = 51.0 m
Power required = 1 x 50 kW

Available power = 9.80 x 0.441 x 51 x 0.8
= 176.32 kW

Installation Proposed - 1 x 50 kW

Turbine Selection (with following particulars)

Power (P) = 50 kW
Head = 51 m

i) As per Figure 3.17) Francis Turbine requiring a discharge of 0.1 cumec per turbine is feasible. Peak efficiency of Francis turbine as per figure 3.14 is about 90% (at 90% gate) for

ii) Available standard turbine (CBI & P- table: 3.15)

	Type	Runner dia.	Speed	Peak Approved Efficiency
Flovel	Francis	450	1000 to 1500 rpm	90%
Jyoti	Turgo Impulse	350	1000 rpm	85%

According Francis turbine requiring a discharge of 0.1 cumec per turbine, civil work may be designed for 0.25 cumec (10% + 5% margin) for two turbine (one for future). Check for part load efficiency.

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