VERSION 3

STANDARDS / MANUALS / GUIDELINES FOR SMALL HYDRO DEVELOPMENT

SPONSOR:

MINISTRY OF NEW AND RENEWABLE ENERGY
GOVERNMENT OF INDIA

GUIDELINES FOR SELECTION OF TURBINE AND GOVERNING SYSTEM FOR HYDROELECTRIC PROJECT

LEAD ORGANISATION:

ALTERNATE HYDRO ENERGY CENTRE
INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE

Guide for Selection of Turbine and Governing System for Hydroelectric Generating Units Upto 25 MW

1. Overview

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. 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 unit size, selection on the basis of typical turbine data furnished by manufacturers is recommended. For units above 5 MW size information exchange with turbine manufacturers is recommended for turbine 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.

1.1 Purpose

The purpose of this guide is to provide guidance for application of hydroelectric turbines and governing systems by developers, manufacturers, consultants, regulators and others. The guide includes, planning, investigation, design and execution, manufacture of equipment and test at work.

2. References

This guide shall be used in conjunction with the following publications. When the following specification are superseded by an approved revision, the revision shall apply.

IS: 12800 (Part 3) – 1991, Guidelines for selection of hydraulic turbine, preliminary dimensioning and layout of surface hydroelectric powerhouses.

IS: 12837 – 1989, Hydraulic turbines for medium and large power houses – guidelines for selection

IEC: 1116 – 1992, Electromechanical equipment guide for small hydroelectric installations.

IEC: 41 – 1991, Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines

IEC: 193 – 1965, International code for model acceptance tests of hydraulic turbines.

IEC: 60308 – 1970, International code for testing of speed governing system for hydraulic turbines.

IEC: 545 – 1976, Guide for commissioning, operation and maintenance of hydraulic turbines.

IEC: 609 – 1978, Cavitation pitting evaluation in hydraulic turbines, storage pumps and pump-turbines.

IEEE: 1207 – 2004, Guide for the application of turbine governing system for hydroelectric generating units.

IEEE: 125 – 1996, Recommended practice for preparation of equipment specifications for speed governing of hydraulic turbines intended to drive electric generators

United states department of the - Selecting Hydraulic Reaction Turbine
Interior Bureau of Reclamation
Engineering Monograph No. 20,

Central Board of Irrigation & - Small Hydro Stations Standardization
Power India Publication No.
175 - 1985,

Central Board of Irrigation & - Manual on Planning and Design of Small
Power India Publication No. Hydroelectric Schemes
280 - 2001,

Alternate Hydro Energy Centre – 2005, Micro Hydro Quality Standard
Indian Institute of Technology
Roorkee

ASME – 1996, Guide to Hydropower Mechanical Design (Book)

3. Site Data

It is presumed that the data with regard to design head, design discharge, number and types of units and capacity are known. Departure from these guidelines may be necessary to meet the special requirements and conditions of individual sites.

3.1 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. Definition of these heads are given in Para 1.5 and shown in figure 1.1. 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 1.1.

3.2 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 tailwater level at the outlet, less the hydraulic losses of the water passage as shown in Fig. 1.1. 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 resulting from the difference in elevation between the maximum forebay 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 nay be disregarded.

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

Table 1.1

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

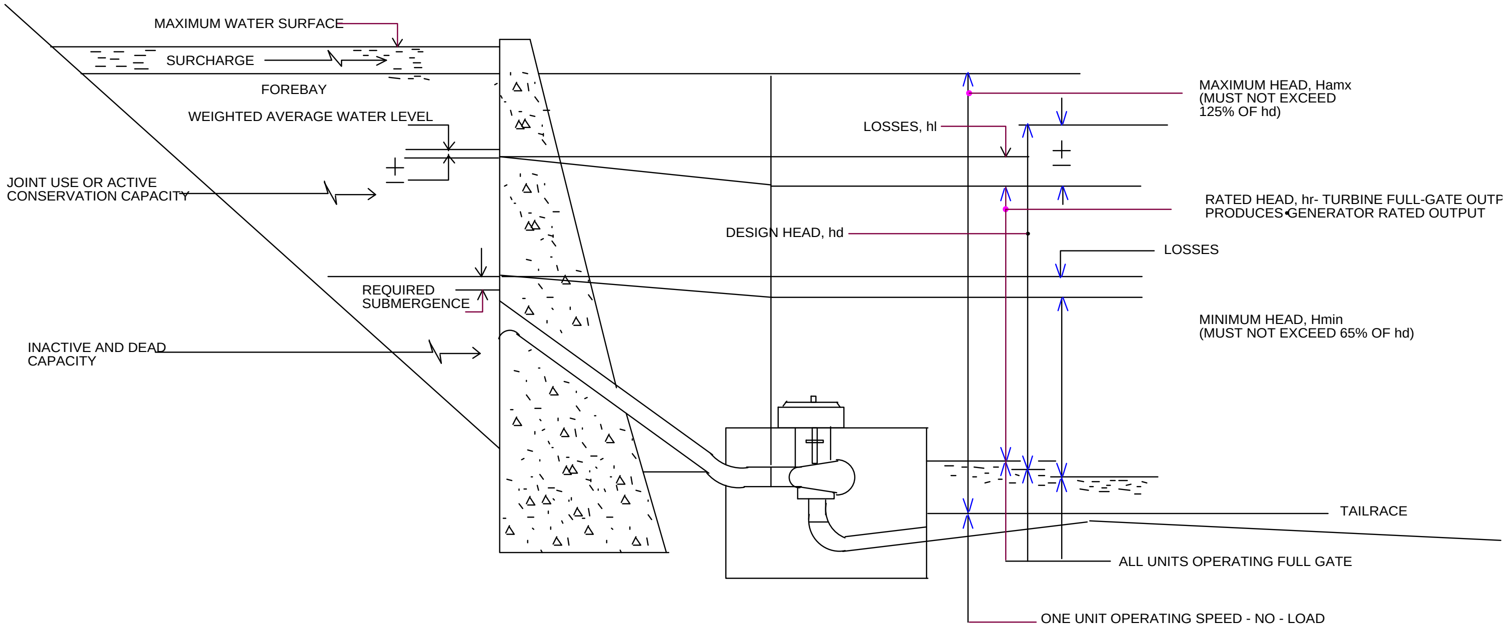


Fig. 1.1

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 as follows in table 1.1.

4. 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.

4.1 FRANCIS TURBINES

A Francis turbine is one having a runner with fixed blades (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.

A Francis turbine may be operated over a range of flows approximately 40 to 110% 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 maximum 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 Hydel range (upto 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. Synchronising is done by manual load control to adjust speed.

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 tailwater elevation locating the turbine below tailwater. 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.

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

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.

4.2 AXIAL FLOW TURBINES

Axial flow turbines are those in which flow through the runner is aligned with the axis of rotation. Axial flow hydraulic turbines have been used for net heads up to 60 meters with power output up to 25 MW. However, they are generally used in head applications below 35 meters Tubular turbine (S-type). S-turbines are used below 30 meters head and 8 MW capacity. Bulb units can be used for low head 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 propeller turbine is one having a runner with 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.

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.

In general, peak efficiencies are approximately the same as for Francis turbines.

Propeller turbines may be operated at power outputs with flow from 40-120% 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 is 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.

The conventional propeller or 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 co-ordinated 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. Variable pitch propeller turbines without wicket gates are called semi Kaplan turbine.

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

4.2.1 TUBULAR TURBINES (S- Type)

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 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.

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. typical Tube turbines of Bharat Heavy Electricals based on runner diameter is shown in Figure 4.2.1.

4.2.2 BULB TURBINES

Bulb Turbines are horizontal, which have 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 4.2.2 shows transverse section of bulb turbine installation proposed for Mukerain SHP 2 x 9 MW rated and design head 8.23 m.

4.2.3 Vertical Semi-Kaplan Turbine With Syphon Intake

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 operation 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 energise 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 requested.

This type of turbine has been found to be most economical for canal drop falls (upto 3-4 m head). The turbine is set above maximum tailwater level and hence lower specific speed. A typical installation is shown in fig. 4.2.3.

4.2.4 PIT TYPE BULB TURBINE

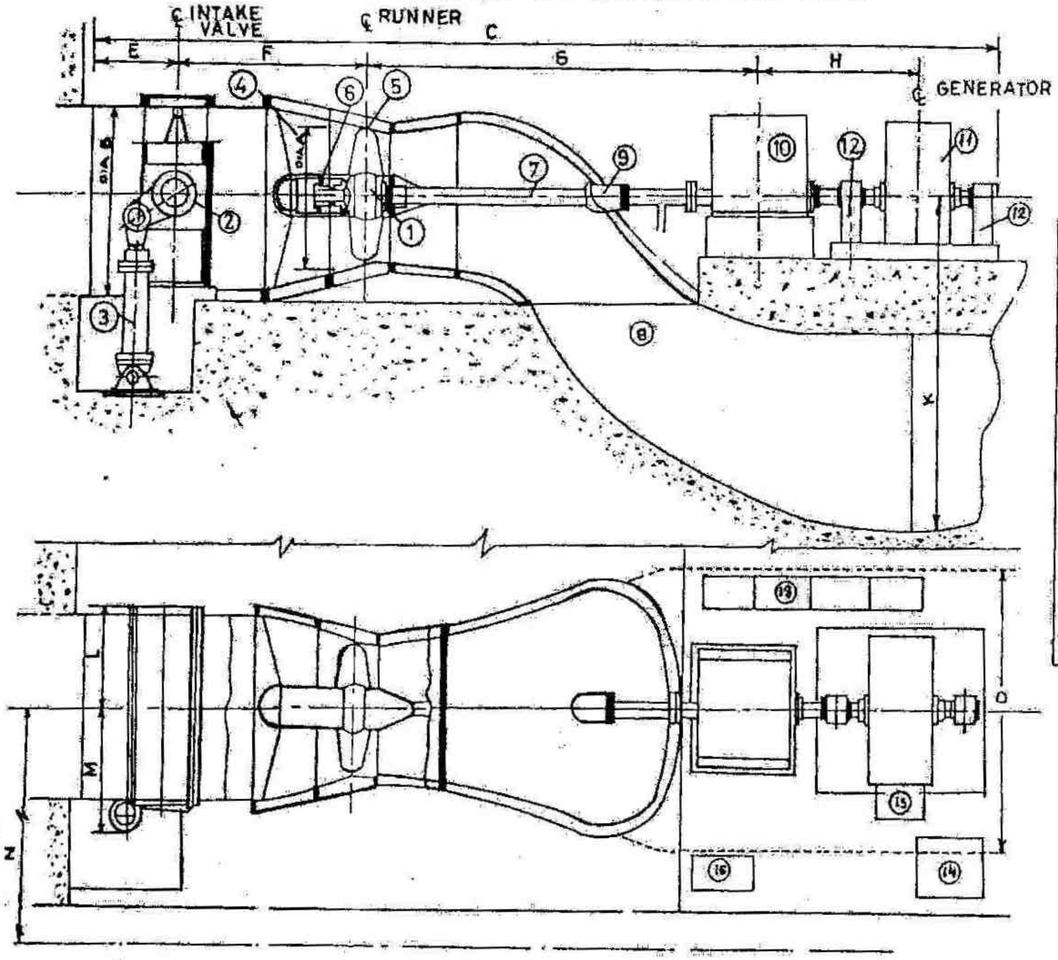
Pit type turbine is a variation of S-type arrangements. Typical pit Turbines coupled to standard high speeds generator through step up bevel/helical gears are generally used. Overall efficiency is lower because of gear box. Maximum size depends upon gear box and is generally limited to 5 MW. Higher sized units upto 10 MW have been recently installed. Performance data of these units is not available. Typical installation is shown in figure 4.2.4 (a & b).

4.3 IMPULSE 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 (Fig. 5.1). However, economic consideration (speed) or surge protection requirements may warrant investigation into the suitability of an impulse turbine in the overlapping head.

Single nozzle impulse turbine have 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 (figure 4.3.2).

ARRANGEMENT OF TUBULAR GENERATING SET



BASIC DIMENSIONS
A=RUNNER DIAMETER IN MM. ALL OTHER DIMENSIONS ARE IN PROPORTION FROM RUNNER DIAMETER

A	1200	1500	1800	2000	2200	2500
B	1700	2100	2500	2800	3000	3500
C	10000	12250	14500	16000	17750	19800
D	2500	3150	3800	4200	4650	5300
E	1200	1500	1800	2000	2200	2500
F	3000	3750	4500	5000	5500	6250
G	3200	4000	4800	5400	6000	6600
H	1450	1800	2150	2400	2650	3000
J	1200	1500	1800	2000	2200	2500
K	1950	2450	2950	3200	3550	4000
L	1000	1250	1500	1700	1900	2200
M	1250	1500	1800	2000	2300	2600
N	3700	4500	5400	6000	6500	7000

NOMENCLATURE

1. RUNNER 2. MAIN INLET VALVE
3. VALVE SERVOMOTOR
4. STAY VANE. 5. RUNNER CHAMBER
6. TURBINE BEARING. 7. SHAFT
8. DRAFT TUBE. 9. SHAFT SEAL
10. GEAR BOX. 11. GENERATOR
12. GENERATOR BEARING
13. CONTROL AND PROTECTION CUBICLE
14. NG RESISTOR
15. TERMINAL BOX 16. LAVT CUBICLE

FIG. 4.3 TYPICAL DIMENSIONS OF TUBE TURBINE

(SOURCE: B.H.E.L. INDIA)

Fig. 4.2.1 Typical Dimension of Tube Turbine (Source: BHEL India)

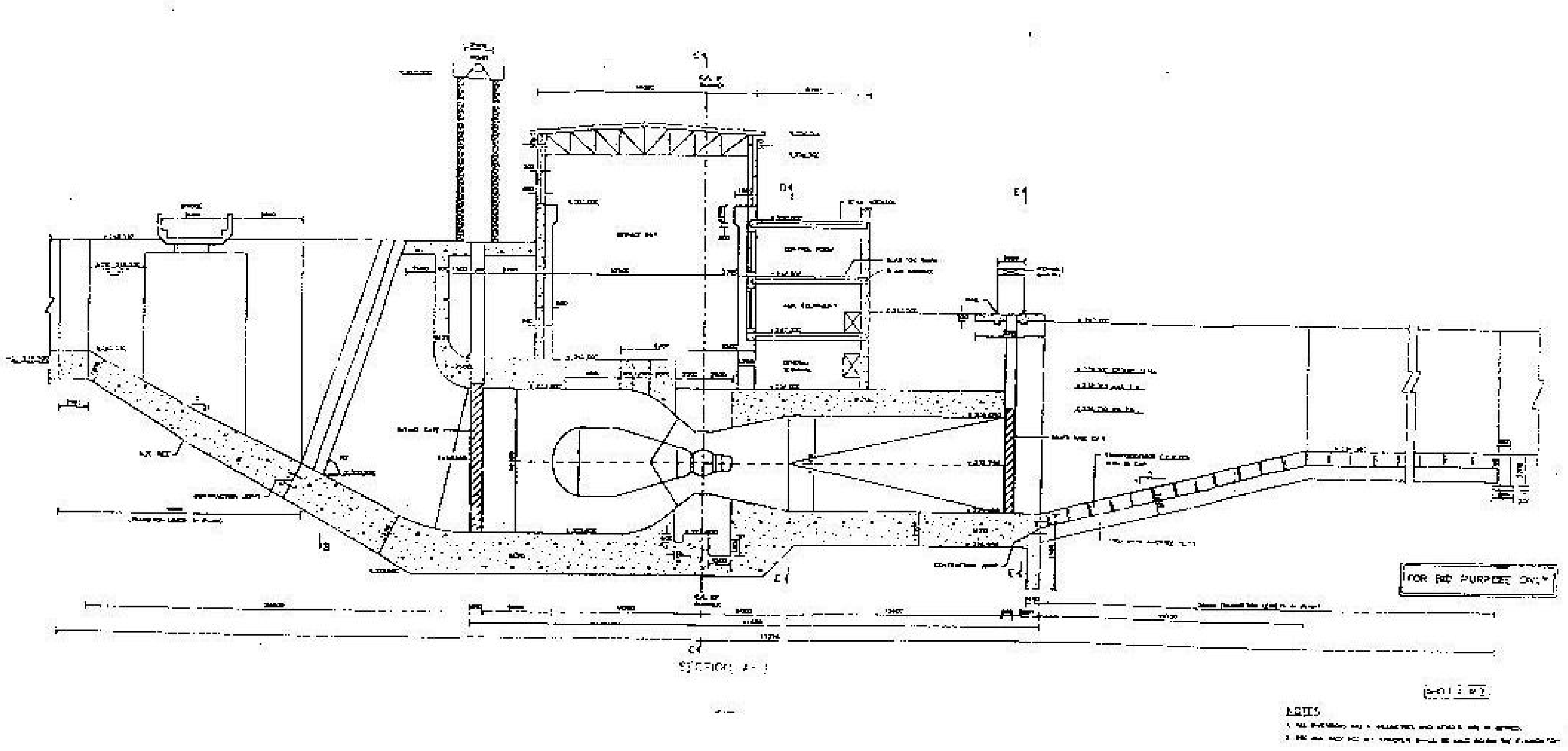


Fig. 4.2.2 Bulb Turbine for Mukerian SHP 2 x 9 MW

(Source: AHEC Specification)

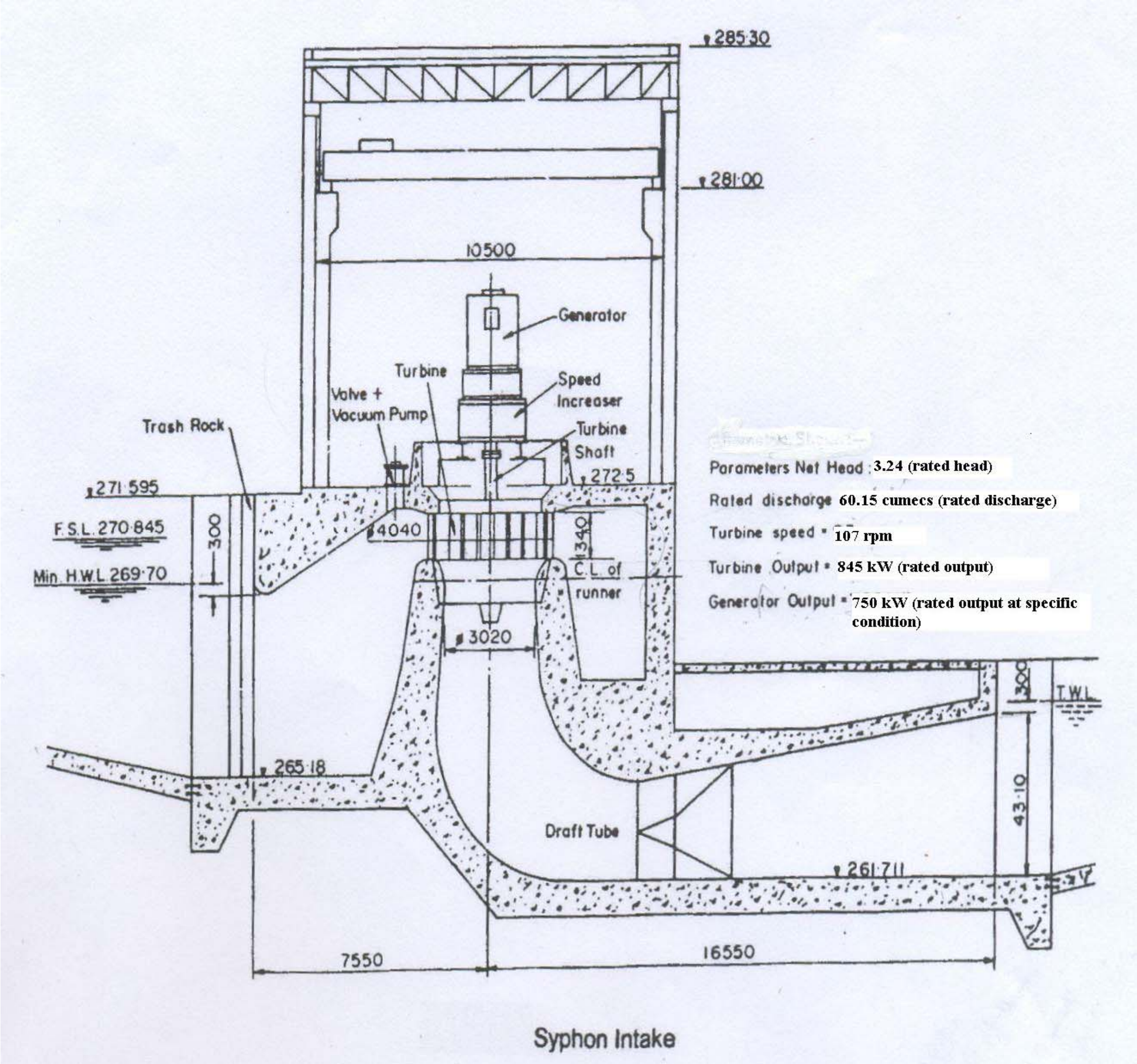
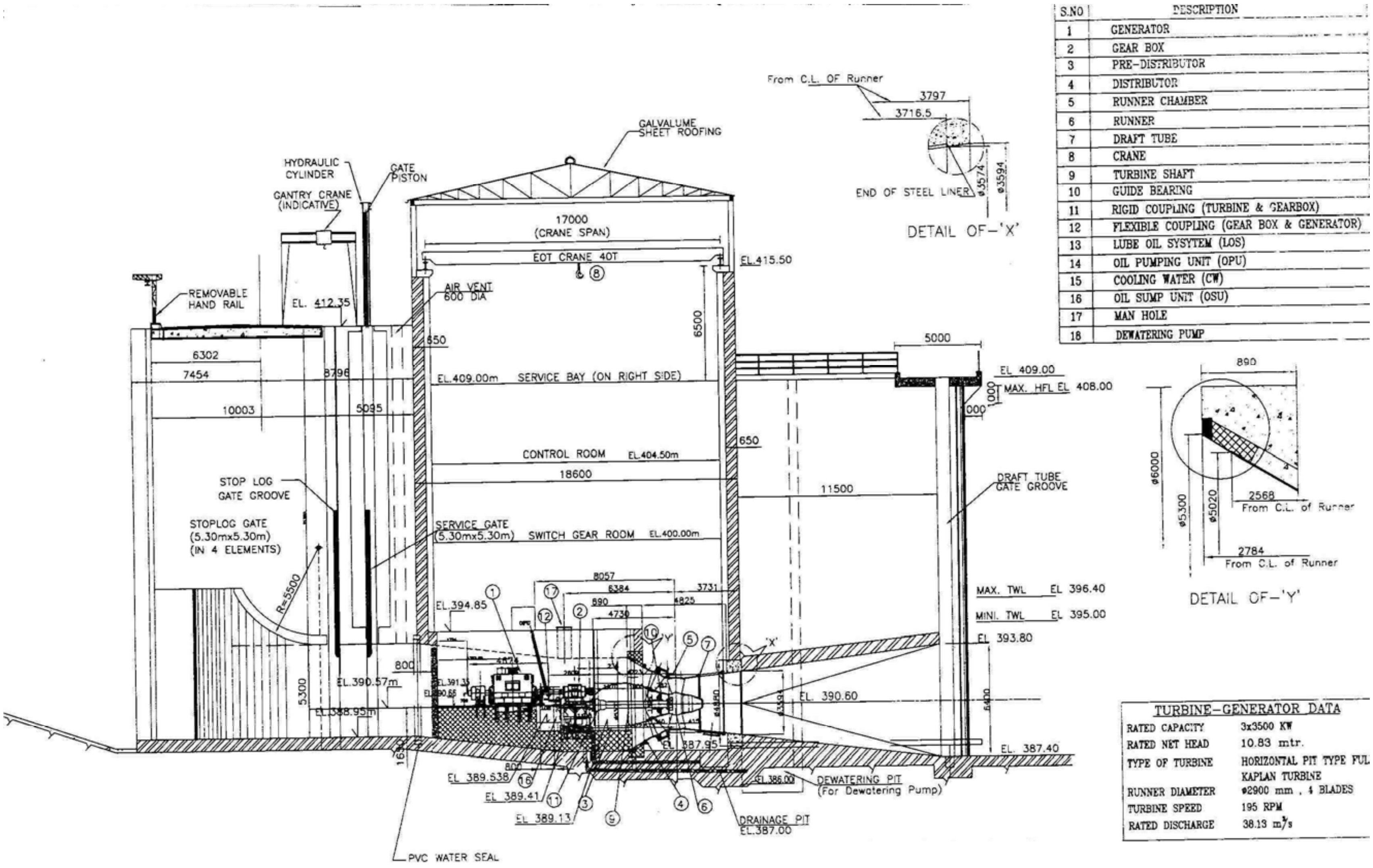


Fig. 4.2.3: Syphon Intake for Tejpura Project
(Source: AHEC Specification)



S.NO	DESCRIPTION
1	GENERATOR
2	GEAR BOX
3	PRE-DISTRIBUTOR
4	DISTRIBUTOR
5	RUNNER CHAMBER
6	RUNNER
7	DRAFT TUBE
8	CRANE
9	TURBINE SHAFT
10	GUIDE BEARING
11	RIGID COUPLING (TURBINE & GEARBOX)
12	FLEXIBLE COUPLING (GEAR BOX & GENERATOR)
13	LUBE OIL SYSYTEM (LOS)
14	OIL PUMPING UNIT (OPU)
15	COOLING WATER (CW)
16	OIL SUMP UNIT (OSU)
17	MAN HOLE
18	DEWATERING PUMP

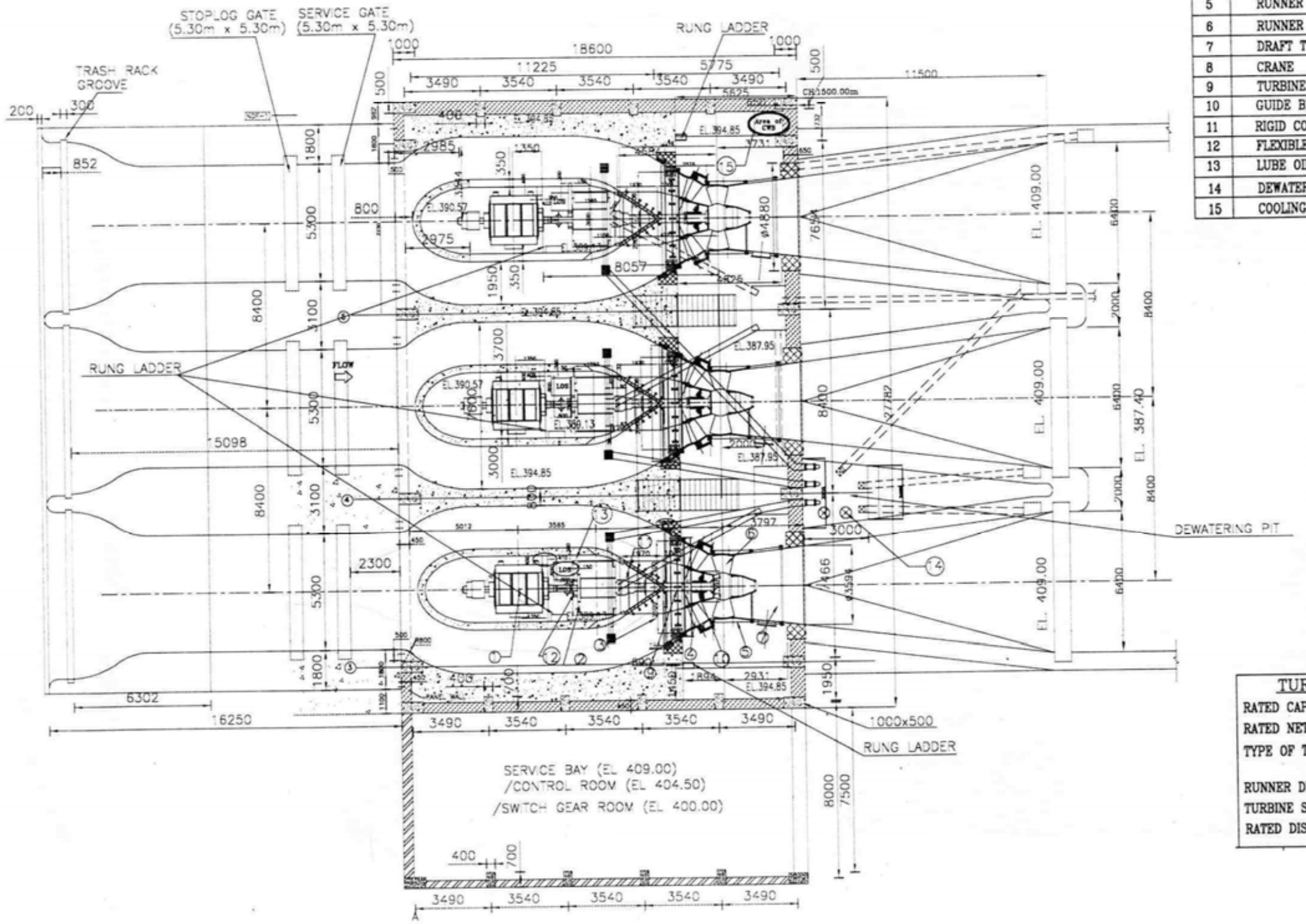
TURBINE-GENERATOR DATA

RATED CAPACITY	3x3500 KW
RATED NET HEAD	10.83 mtr.
TYPE OF TURBINE	HORIZONTAL PIT TYPE FUL KAPLAN TURBINE
RUNNER DIAMETER	ø2900 mm , 4 BLADES
TURBINE SPEED	195 RPM
RATED DISCHARGE	38.13 m³/s

SELECTION VIEW OF POWER HOUSE (2 x 3500 kW)

Fig. 4.2.4 (a)

S.NO	DESCRIPTION
1	GENERATOR
2	GEAR BOX
3	PRE-DISTRIBUTOR
4	DISTRIBUTOR
5	RUNNER CHAMBER
6	RUNNER
7	DRAFT TUBE
8	CRANE
9	TURBINE SHAFT
10	GUIDE BEARING
11	RIGID COUPLING (TURBINE & GEARBOX)
12	FLEXIBLE COUPLING (GEAR BOX & GENERATOR)
13	LUBE OIL SYSYTEM (LOS)
14	DEWATERING PUMP
15	COOLING WATER



PLAN VIEW OF POWER HOUSE AT EL. 391.35

Fig. 2.3.4

TURBINE–GENERATOR DATA	
RATED CAPACITY	3x3500 KW
RATED NET HEAD	10.83 mtr.
TYPE OF TURBINE	HORIZONTAL PIT TYPE FULL KAPLAN TURBINE
RUNNER DIAMETER	ø2900 mm , 4 BLADES
TURBINE SPEED	195 RPM
RATED DISCHARGE	38.13 m^3/s

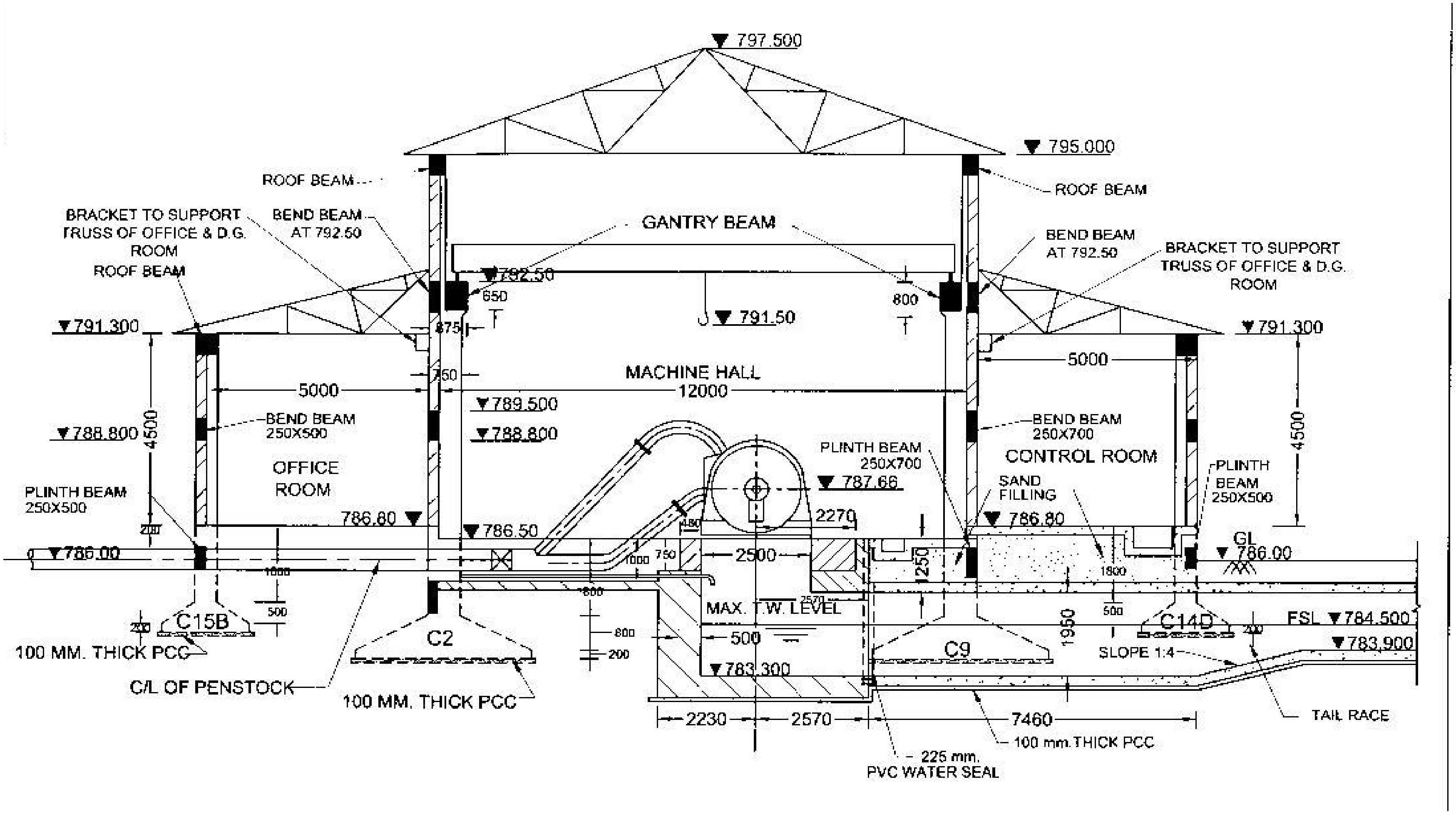
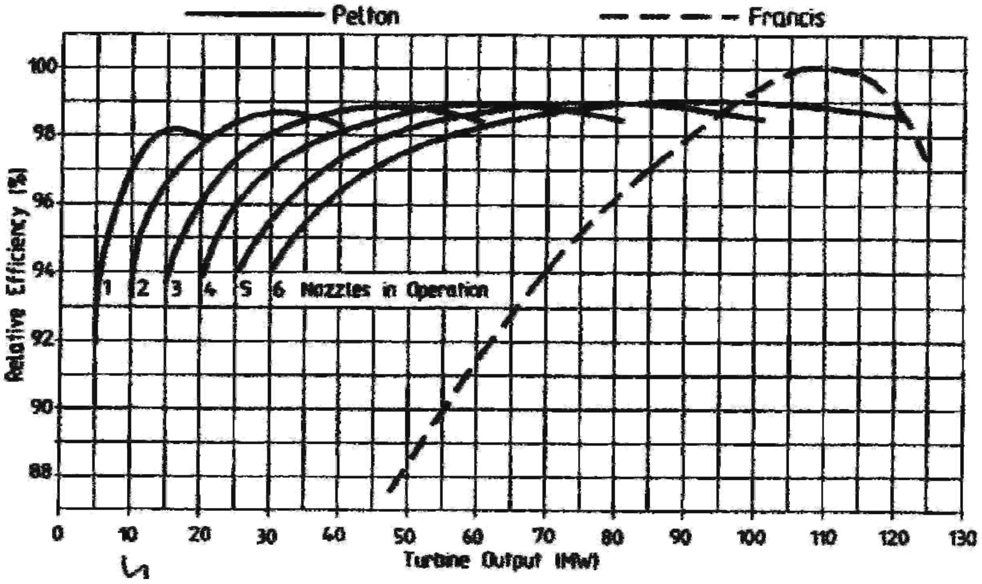


Fig. 4.3.1 Impulse Turbine for Kitpi Project (2 x 1500 KW) –AHEC Project



Typical Efficiency Versus Load Curves

Fig. 4.3.2 Francis Versus Pelton Performance. *Typical efficiency versus load characteristics for a low specific speed Francis turbine and a six-jet Pelton turbine with the optimal number of jets in service are compared*

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 features provides surge protection for the penstock without the need for a pressure 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.

The runner must be located above maximum tailwater to permit operation at atmospheric pressure. This requirement exacts an additional head loss for an impulse turbine not required by a reaction turbine.

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.

Horizontal shaft turbines are suitable for small hydro 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 justify a more conservative runner design. Abrasive martial 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.

A deflector is normally used to cut into the jet when rapid power reductions are required such as a complete loss of connected-load. The deflector is mounted close to the runner on the nozzle assembly and typically is provided with its own servomotor. Cross section of 2 jet pelton turbine of Kitpi project is at figure 4.3.1

4.3.1 TURGO IMPULSE TURBINES

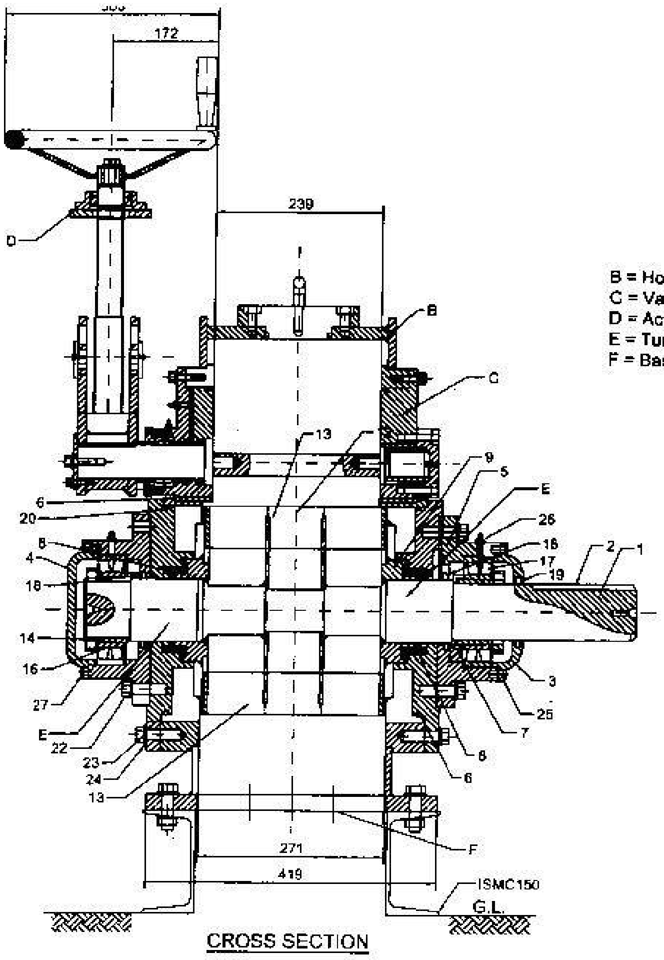
Another type of impulse turbine is the Turgo impulse. This turbine is higher in specific speed than the typical impulse turbine. The difference between a Pelton unit and a Turgo is that, on a Turgo unit, the jet enters one side of the runner and exits the other side. The Turgo unit operates at a higher 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 turgid impulse turbine is about 82 to 83 %.

4.4 CROSS FLOW TURBINES

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.

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



B = Housing
C = Valve (Guide Vane)
D = Actuator
E = Turbine Rotor
F = Base Frame

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	Adacter slev (NDE)
15	Adacter 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

Fig. 4.4 (i) Cross section view of Jagthana Cross Flow SHP (2 x 50 kW) – AHEC Project

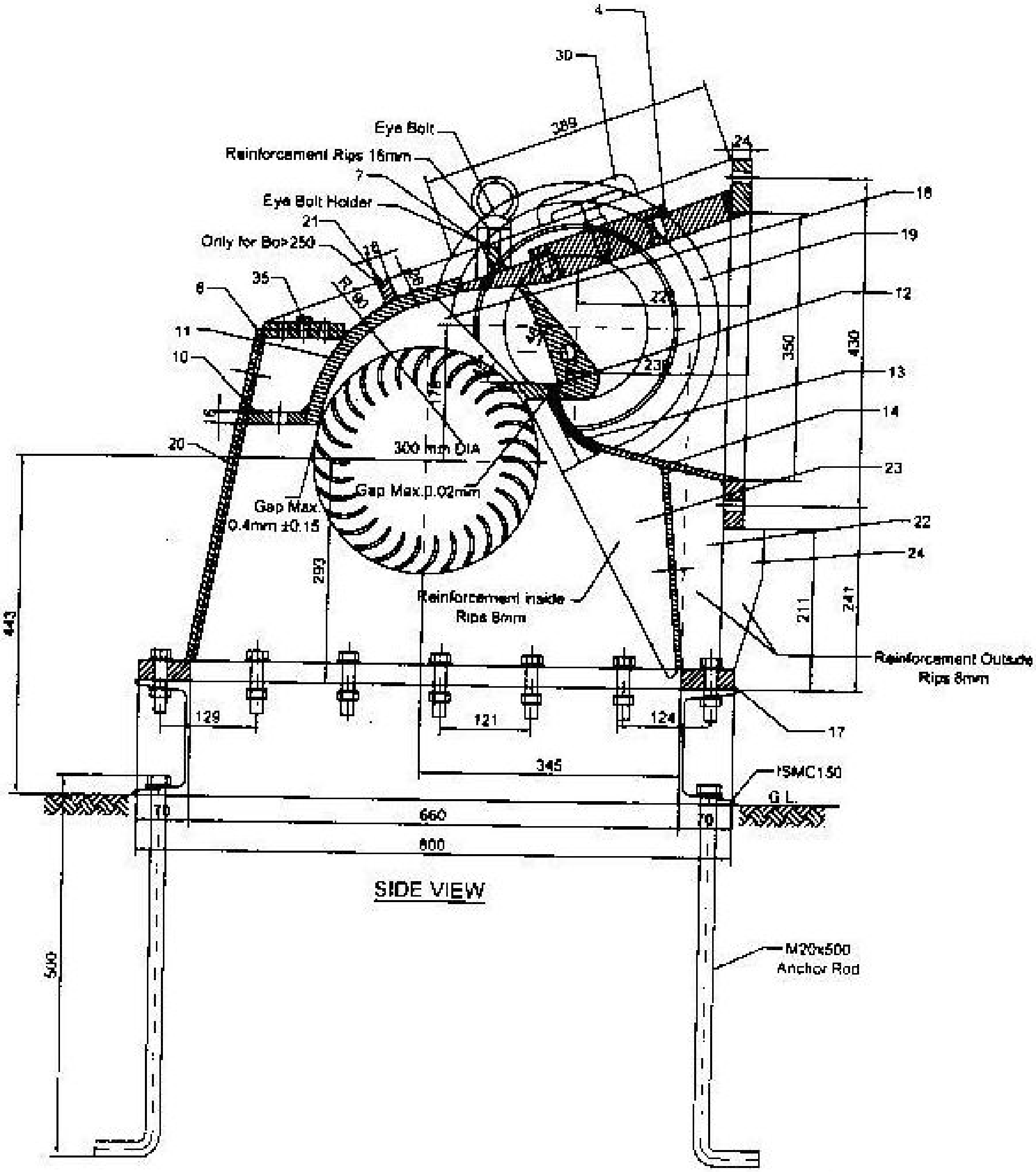


Fig. 4.4 (ii) Side view of Jagthana SHP (2 x 50 kW) with cross flow turbine (AHEC project)

Floor space requirements are more than for the other turbine types, but a less complex structure is required and a savings in cost might be realized. Efficiency of cross flow turbine of standard 300 MW dia. tested in AHEC testing labs is attached as Annexure 2 and average about 54.5%. Cross section and Side view of cross flow turbine of Jagthana SHP is at figure 4.4 (i) & (ii).

5. SELECTION OF HYDRAULIC TURBINE

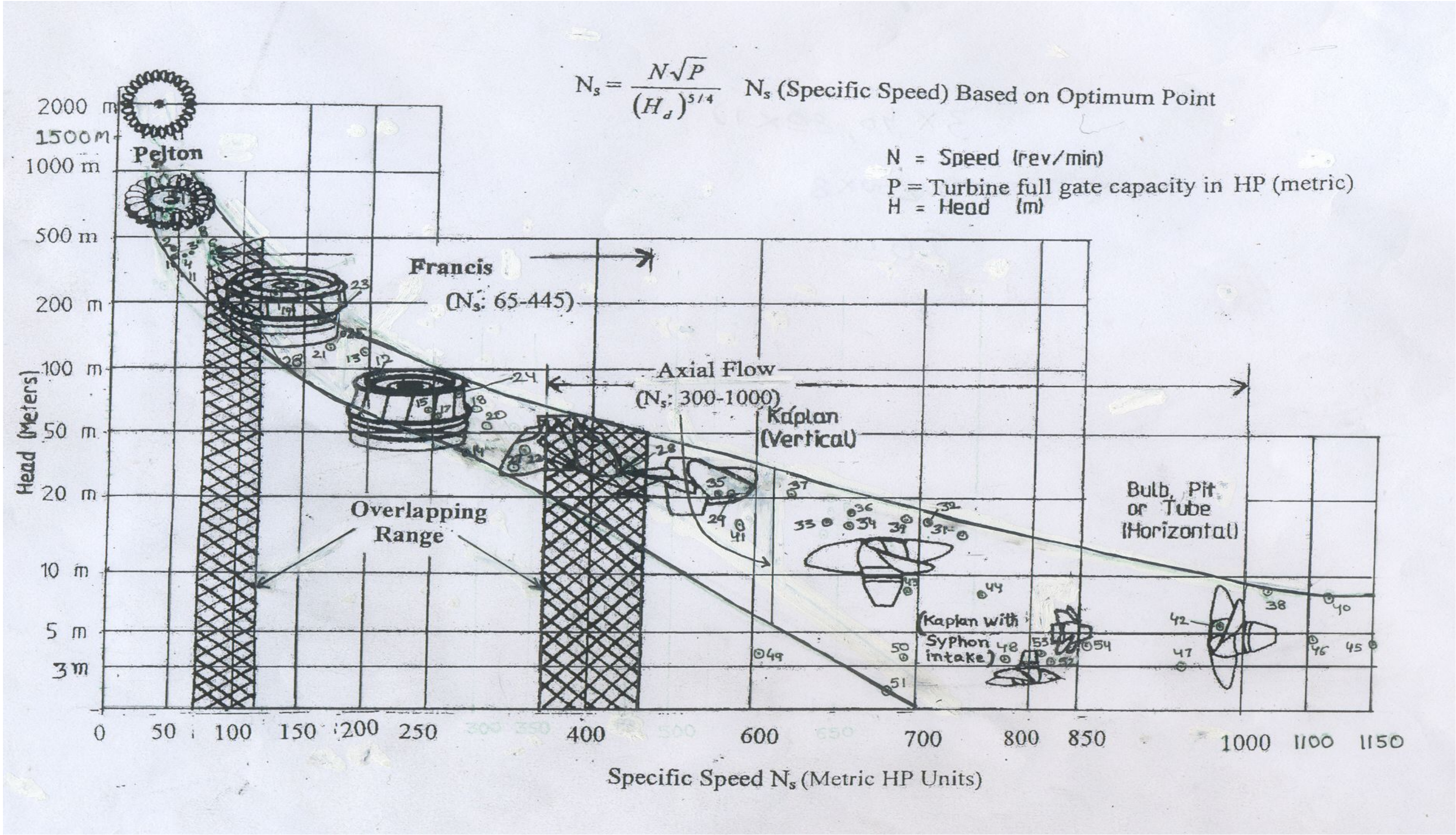
General – The net head available to the turbine dictates the selection of type of turbine suitable for use at a particular site. The rate of flow determines the capacity of the turbine. The term specific speed is generally used in classifying types of turbines and characteristics within type as shown in figure 5.1. This figure is based on ASME guide to design of hydropower mechanical design 1996 and modified by Indian Projects date attached as Annexure-1. Exact definition of specific speed is given later. Impulse turbines have application in high head hydropower installations. Application of impulse turbine in low head range is limited to very small size units.

Application range of the three types of turbine is overlapping as shown in figure 5.1. Description & Application of important turbine types is as follows:

Various types of turbines have already been explained in Para 4.0. selection criteria of hydraulic turbine upto 5 MW units size (including micro hydels) is generally based on using standard turbines. Hydraulic turbine above 5 MW unit size are generally tailor made and selection criteria is more specific.

Specification require 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. Relative efficiency of turbine types is shown in figure 4.3.2 and 5.2. The peak efficiency point of a Francis 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.



Note: *Details of SHP marked on the chart are attached as Annexure-1* (Based on ASME – Guide to Hydropower Mechanical Design (Book)

Fig. 5.1 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*

The selection of speed and setting 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.

5.1 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:

$$Ns = \frac{Nr\sqrt{Pr}}{Hr^{(5/4)}}$$

Where Nr = revolutions per Minute
Pr = power in metric horse power at full gate opening – (1 kW = 0.86 metric hp)
Hr =rated head in m.

The specific speed value defines the approximate head range application for each 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

Flow based metric system for specific speed (Nq) used in Europe is given by equitation below.

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

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

Specific speed (metric HP units) range of different types of turbines is as follows:

Fixed blade propeller turbines - 300 – 1000

Adjustable blade Kaplan turbines -	300 – 1000
Francis turbines -	65 - 445
Impulse turbines –	
i) Pelton Turbine per jet	16-20 per jet For multiple jets the power is proportionally increased
ii) Cross flow turbine	12-80

Following standards and monographs are good guides for selection of hydraulic Turbines.

i) IEC 1116- 1992-10 – Electro-mechanical equipment Guide for small hydro electric installation

ii) IS 12837 – 1989 – Hydraulic Turbines for Medium and Large Power Houses – Guidelines for Selection

iii) IS 12800 (Part 3) 1991 – Guide lines for selection of hydraulic turbines, preliminary dimensioning and Layout of surface Hydro-Part 3 Small Mini and Micro Hydroelectric Power Houses

Engineering Monograph No. 20 entitled 'Selection of Hydraulic Reaction turbines' issued by the US Bureau of Reclamation (USBR) is given below.

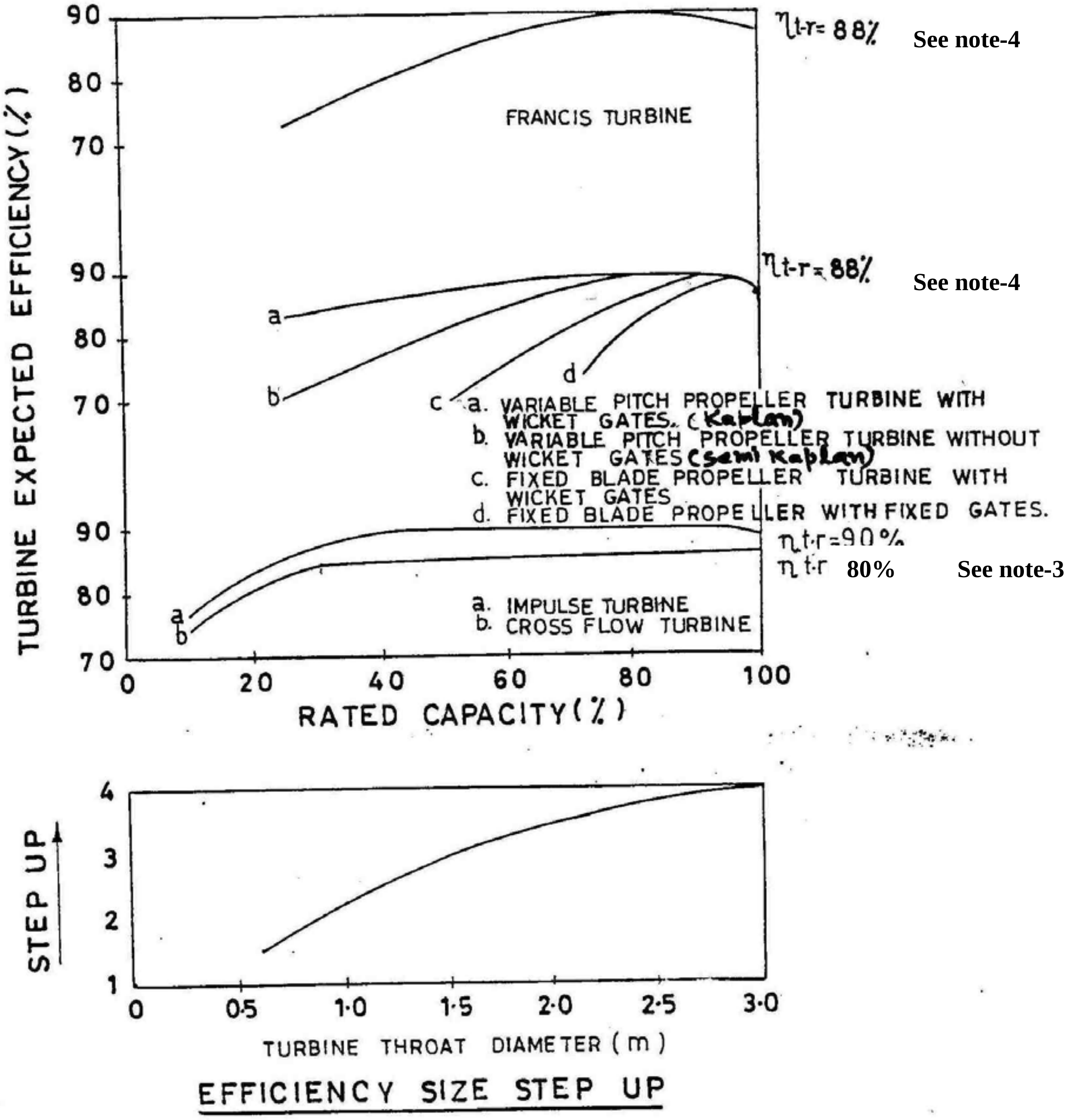
5.2 Selection Procedure for small hydro upto 3 MW unit size

5.2.1 General: Selection procedure for small hydro (SHP) including micro hydel unit size is determined from techno-economic consideration as per Para 1.6.

Preliminary selection for type of small hydro turbine can be made from figure 5.2 which is based on IEC –1116 – 1992 as modified by actual data (Annexure-3) of large no. of small hydros installed in the country. Kind (within type) and configuration (horizontal or vertical) may be based on economic consideration including cost of civil works, efficiency etc. Standard turbines available for discharge and head in the country as per data given by some manufacturers (table 5.1) and attached in CBI & P publication No. 175 – 1983 entitled "Small Hydro power Stations standardization are attached as annexure 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 pre IS 12800 part (3) for economic evaluation. Relative efficiency of type and configuration is given in Para 2.



NOTES:

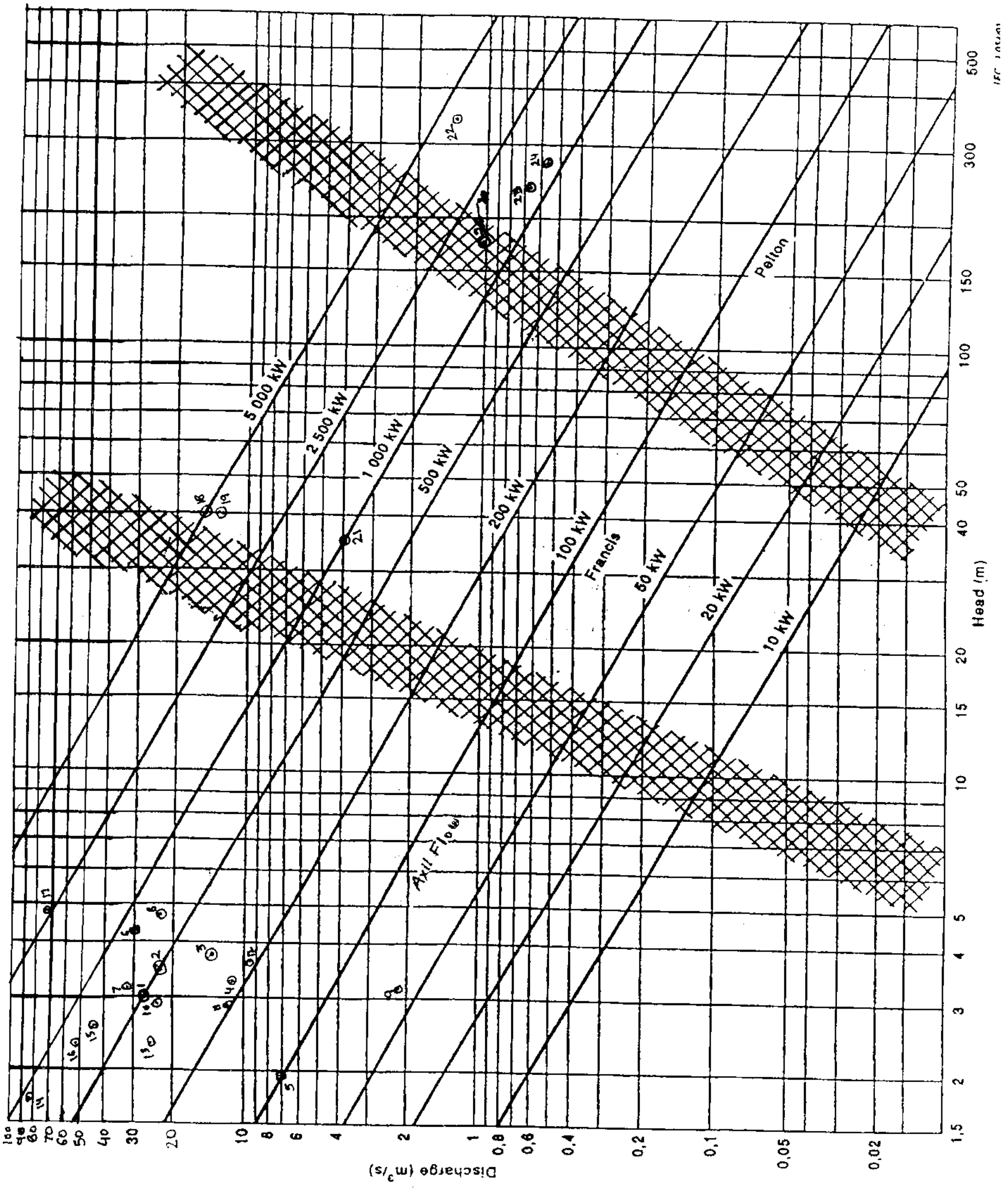
1 ηt.r =Turbine Efficiency at rated output (Pr) and head (hr)

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 - 65%.

4. Peak efficiency at design head and rated output is about 2-5% higher.

Fig. 5.2 Turbine Efficiency Curves
(Source IS: 12800)



Note: *Details of SHP marked on the chart are attached as Annexure-2*

Fig. 5.3.1 Turbine Operating Regimes (Based on IEC:1116)

Table 5.1
Standard Turbine data by some of the manufacturers in India

Annexure – 4.1	BHEL – Standard Tubular Turbines
Annexure – 4.2	BHEL – Standard Kaplan Turbine
Annexure – 4.3	BHEL – Standard Francis Turbine (Horizontal Shaft)
Annexure – 4.4	BHEL – Standard Pelton Turbine (Single Jet – Horizontal Shaft)
Annexure – 4.5	Flovel – Standard Tubular Turbines – Semi Kaplan
Annexure – 4.6	Flovel – Standard Tubular Turbines – Full Kaplan
Annexure – 4.7	Flovel – Standard Pit Type Francis Turbine
Annexure – 4.8	Flovel – Standard Francis Turbine (Spiral Casing Type)
Annexure – 4.9	Jyoti – Standard Tubular Turbines
Annexure – 4.10	Jyoti – Standard Francis Turbines
Annexure – 4.11	Jyoti – Standard Pelton Turbines
Annexure – 4.12	Jyoti – Standard Turgo Impulse Turbine
Annexure – 4.13	HPP – Standard Vertical Kaplan Turbine

5.2.2 Turbine Efficiency

Typical efficiency curves of the various types of turbines are shown for comparison in Fig 5.2. These curves are shown to illustrate the variation in efficiency of the turbine through the load range of the design head. Performances of the various types of turbines when operated at heads above and below design head are discussed. Approximate efficiency at rated capacity for the reaction turbines are shown for a turbine with a throat diameter of 300 mm. Rated efficiency will increase as the size of the turbine increases. The bottom curve shows the relationship of efficiency to throat diameter. The rated efficiency for turbines with throat diameters larger than one foot may be calculated in accordance with this curve. This curve was developed from model test comparison to apply the step-up value throughout the operating range.

The efficiency curves shown are typical expected efficiencies. Actual efficiencies vary with manufacturer and design.

To find the approximate efficiency for a turbine refer Figure 5.2 determine the approximate throat diameter from 6.2 or 6.3 and find the size step up factor in the bottom curve. Add this value to the rated efficiency values given for the approximate turbine type. 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 hydel range turbine efficiencies are lower.

5.2.3 Turbine Performance Curves – Figures 5.2.3.1 and 5.2.3.2 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 were 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.

Following determination of the selected turbine capacity the power output at heads and flows above and below rated head (hr) and flow (Qr) may be determined from the curves as follows:

Calculate the rated discharge Qr using the efficiency values-

Qr = Pr / (rv x hr x nt.r x ng), (m^3/s)

Where,

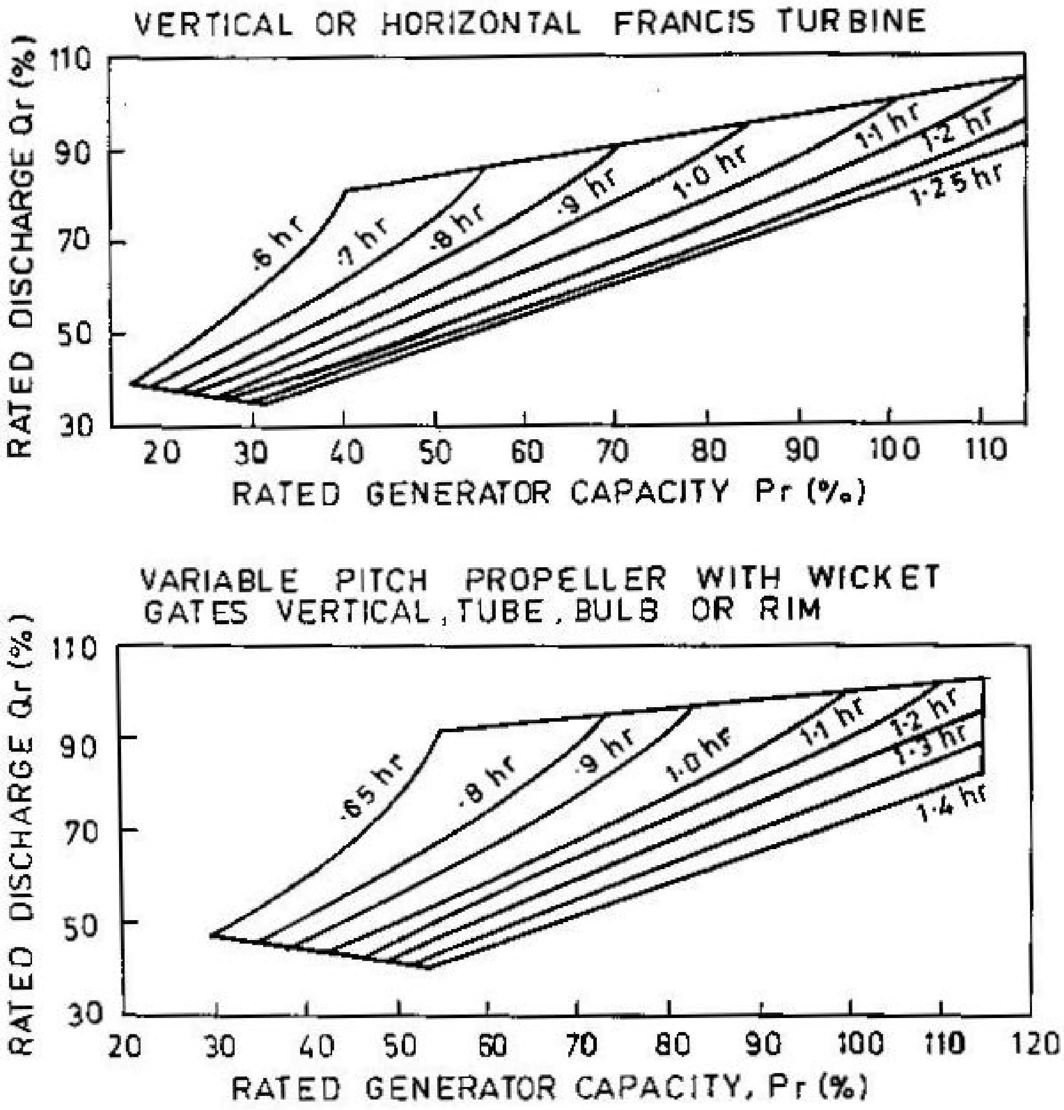
rv = specific density of water in N/m^3
nt.r = Turbine efficiency at rated load (%)

Compute the % discharge, % or and find the % Pr on the approximate hr line. Calculate the power output.

P = % Pr x Pr (kW)

The thick lines at the boarder of the curves represent limits of satisfactory operation within normal industry guarantee standards. The top boundary line represents maximum recommended capacity at rated capacity.

The turbine can be operated beyond these gate openings; however, cavitation guarantee generally do not apply these points. The bottom boundary line represents the limit of stable operation. The bottom limits vary with manufacturer. Reaction turbines experience a rough operation somewhere between 20 to 40% of rated discharge with the vibration and/or power surge. It is difficult to predict the magnitude and range of the rough operation as the water passageway configuration of the powerhouse effects this condition. Where operation is required at lower output, strengthening vanes can be placed in the draft tube below the discharge of the runner to minimize the magnitude of the disturbance. These modifications reduce the efficiency at higher loads. The right hand boundary I established from generator guarantees of 115% of rated capacity. The head operation boundaries are typical, however, they do vary with manufacturer. It is seemed that these typical performance curves are satisfactory for preliminary feasibility assessments.

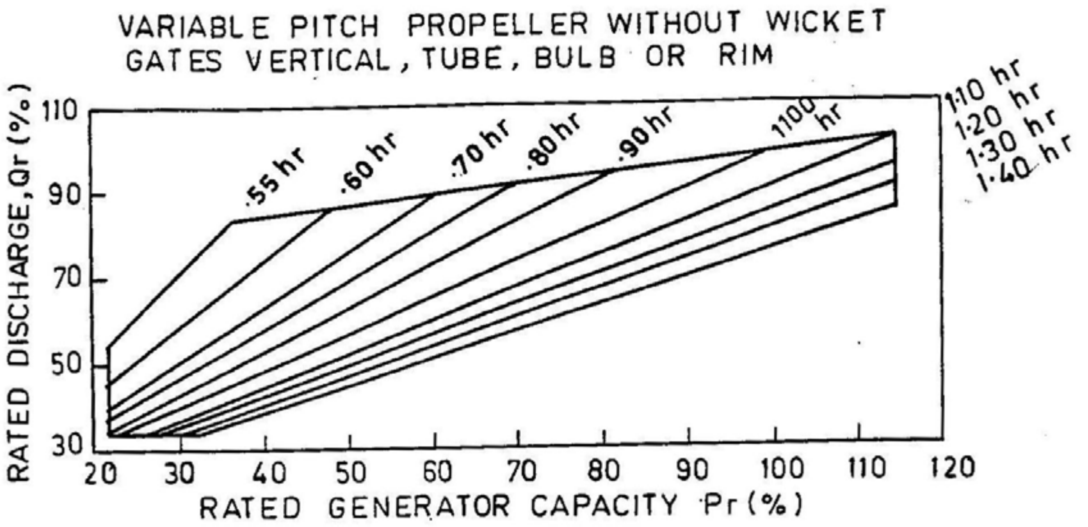


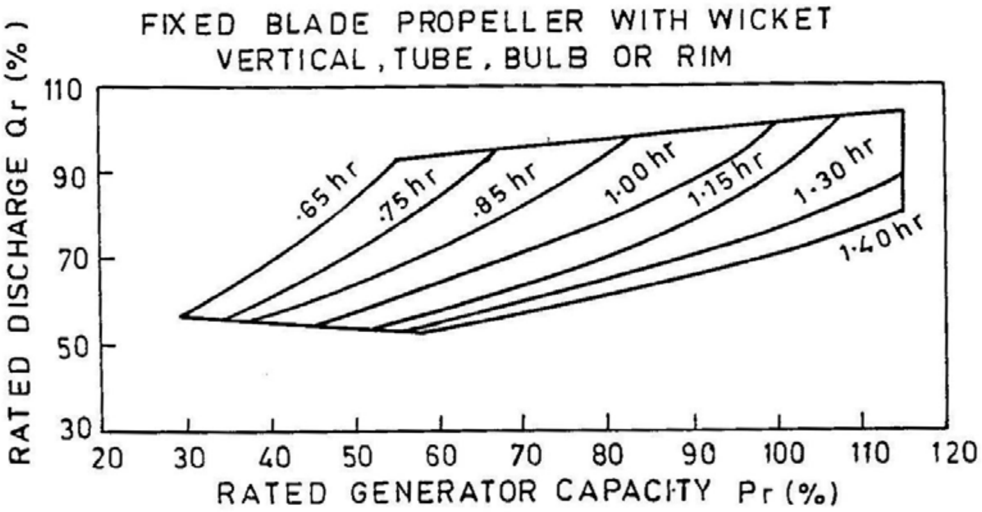
$P_r = \gamma_w,\ h_r,\ Q_r,\ \eta_{t.r}\ \ \eta_g$ (kW)

Where:

P_r = Rated capacity at hr
Hr = Selected Design Head
Q_r = Turbine Discharge at $h_r\ \ \varepsilon\ \ P_r$
$\eta_{t.r}$ = Turbine efficiency at $h_r\ \ \varepsilon\ \ P_r$
η_g = Generator efficiency , (%)

Figure 5.2.3.1 Francis and Kaplan performance curves





$Pr = \gamma$ w, hr , Q r , η t. r η 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 5.2.3.2 Propeller turbine performance curves

When the % P_r for a particular selection is beyond the curve boundaries, generation is limited to the maximum % pr for the hr. The excess water must be bypassed. When the % P_r is below the boundaries, no power can be generated. When the hr is above or below the boundaries, no power can be generated.

The optimum number of turbines may be determined by use of these curves for annual power consumption. If power is being lost because the % P_r is consistently below the lower boundaries, the annual produced by lowering the kW rating of each unit and adding a unit should be computed. If the total construction cost of the powerhouse is assumed to roughly equal the cost of the turbine and generator, the cost per kWh derived above can be doubled and compared with the financial value of the energy. If the selection of more turbines seems favorable from this calculation, it should be pursued in further detail with more accurate studies. Conversely, the first selection of the number of turbines may be compared with a lesser number of units and compared on a cost per kWh basis as described above.

Following the establishment of the numbers of units, the rating point of the turbines can be optimized. This generally is done after an estimate of the total project cost have been made. Annual power production of turbines having a higher rating and a lower rating should be calculated and compared to the annual power production of the turbine selected. With the annual estimate, cost per kWh may be calculated for the selected. With the annual estimate, cost per kWh may be calculated for the selected turbine. Total project cost for the lower and higher capacity ratings may be estimated by connecting the turbine/generator costs from the cost chart and correcting the remaining costs on a basis of constant cost per kW capacity. Rates of incremental cost divided by incremental energy generation indicate economic feasibility.

The rated head of the turbine can be further refined by optimization in a similar manner. The annual power production is computed for higher and lower heads with the same capacity rating. The rated head yielding the highest annual output should be used. The boundaries established on these curves are typical. Should energy output of a particular site curtailed, it is suggested that turbine manufacturers be consulted as these boundaries can be expanded under certain conditions.

5.2.4 Micro Hydel Range (upto 100 kW): A large number of micro hydel in remote hilly areas are being installed to supply power to remote villages.

- 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.

These are generally high head schemes. A typical micro hydel scheme is shown in figure 5.2.4.

Selected turbine efficiency and speed is of paramount importance for cost effective installation as illustrated below:

5.2.5 Cost Elements in small and micro hydel power projects as per National Consultants recommendations UNDP – GEF Hilly Projects is shown in figure 5.2.4.

These cost elements are for type of micro hydel in remote hilly area. Efficiency of indigenous turbines in the microhydel range is approx. as follows:

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

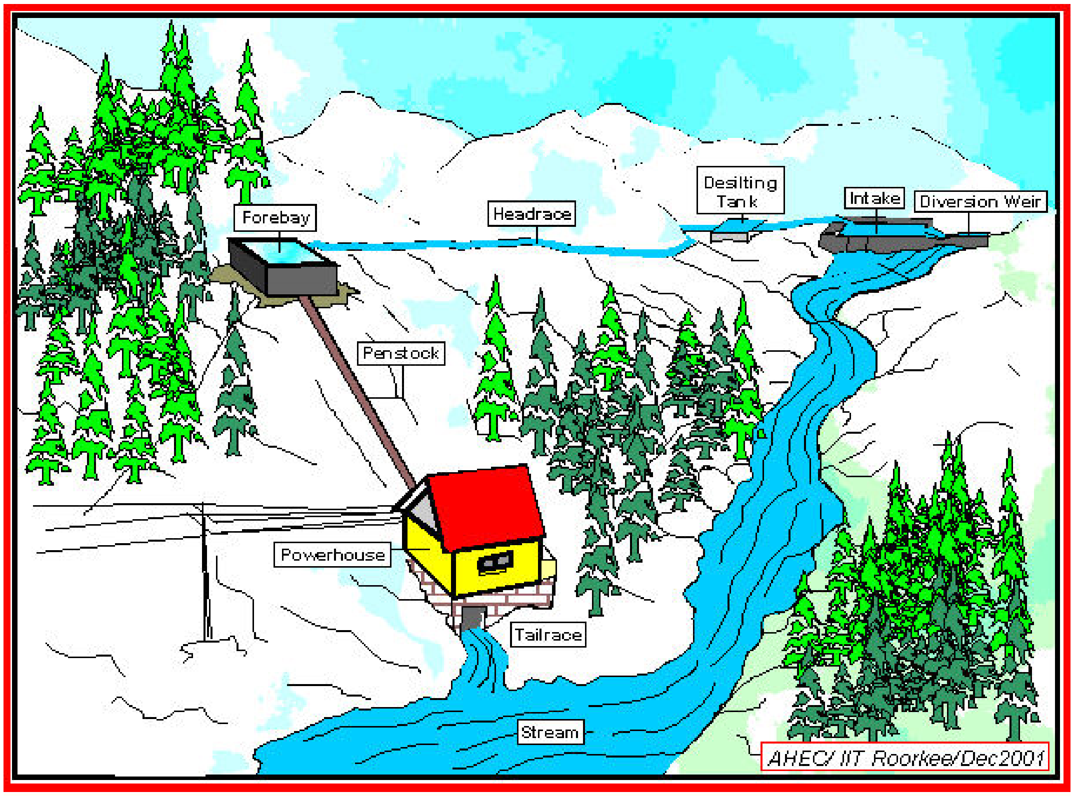


Fig. 5.4 Typical Arrangement of Small Hydro Power Station

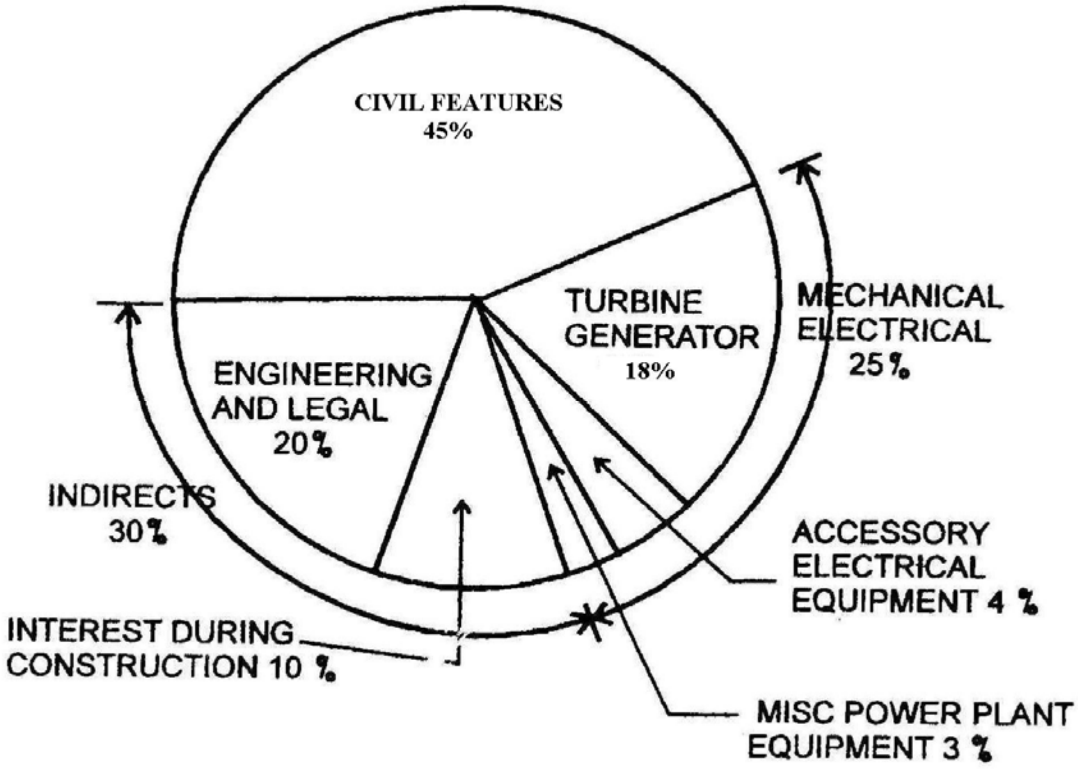


Fig. 5.2.5 Maximum Civil Features Cost (High Head Scheme)

Minimum weighted average efficiency of turbine and generator set (η Tv) $0.50x\ \eta T_{100} + 0.5\ \eta\ T_{50}$ specified in micro hydel standard issued by AHEC (extracts at Annexure 5). Accordingly weighted average efficiency of different category (size) of micro hydel is as follows:-

Category A	Category B	Category C
Upto 10 –45 kW	Upto 50 kW	Upto 100 kW
45%	50%	60%

5.3 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

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

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 5.3.
5) In case of turbine in overlapping range determine speed and specific speed relation and determine synchronous speed based on applicable range of specific as per Para 5.1. Higher speed machine is cost effective.
6) Review turbine limitation (Para 4) and fix turbine type as per micro hydel standard (Annexure-5)

5.4 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 5.2.2 is given in table 5.3. The civil works i.e. intake weir, settling tank, canal, penstock and power house costs is dependant 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 5.3

Item	Cross flow	Turgo Impulse	Francis	Remarks
Civil works 45% (For Francis turbine)	35100	29700	27000	
Electro-mechanical				1000/1500 rpm generator for francis and turgo impulse and 750 rpm gen. For cross flow
i) Turbine	3940	4320	4800	
ii) Generator iii)Equipment	11220	10200	10200	
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%.

5.5 Examples of Turbine Selection (micro hydel range)

5.5.1 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

<u>Turbine selection</u> (with following particulars)

Power (P) = 100 kW
Head = 62 m

i) As per IEC 1116- (Fig. 5.3.1), Francis turbine requiring a discharge of 0.2 cumec per turbine is feasible. Peak efficiency of Francis turbine as per figure 5.2 is 90% (at 90% gate).

ii) Available standard turbine (CBI & P Annexure- 1.1 to 1.12)

	Type	**Runner dia.**	**Speed**	**Peak Approved Efficiency**
Flovel	Francis	450	1000 to 1500 rpm	90%
Jyoti	Turgo Impulse	425	1000 rpm	85%

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.

5.5.2 Rong Kong MHP (Uttarakhand)

Site Data Q = 0.441
H = 51.0
Power required = 1 x 50 kW

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

Installation Proposed - 1 x 50 kW

<u>Turbine Selection</u> (with following particulars)

Power (P) = 50 kW
Head = 51 m

i) As per IEC 1116- (Fig. 5.3.1), Francis Turbine requiring a discharge of 0.1 cumec per turbine is feasible. Peak efficiency of Francis turbine as per figure 5.2 is 90% (at 90% gate).

ii) Available standard turbine (CBI & P- Annexure 4.1 to 4.12)

	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 cumecs per turbine. Civil work may be designed for 0.25 cumecs (10% + 5% margin) for two turbine (one for future). Check for part load efficiency.

5.6 Mini Hydro in the Range 0.1 MW to 5 MW

Selection Procedure

1) Field Data Required

   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)** available from site

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

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 5.3.
5) In case of turbine in overlapping range determine speed and specific speed relation and determine synchronous speed based on applicable range of specific as per Para 5.1. Higher speed machine is cost effective.
6) Select standard available turbine with highest synchronous speed and best efficiency range (Annexure 1.1 to 1.12).

5.7 Example of turbine selection (mini hydro range)

5.7.1 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.

Details 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 5.7.1 A. 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 in flows and loading of turbine as percentage of installed capacity is shown in Table-5.7.1 B. 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 is proposed to be interconnected by a 33 kV lines to Kanchauti and Dharchulla in a ring main for interconnection with U.K. Grid sub-station at Dharchulla.

Table –5.7.1 A
SOBLA SMALL HYDEL 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 –5.7.1 B

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 is also proposed.

Accordingly, it is considered essential to design the turbines for stand alone isolated operation as well as for parallel operation with grid.

Turbine Selection

Rated Head (H) = 185 m

Rated Power (P) per unit = 3000 kW

As per IEC 1116- (Fig. 5.2.1) it is seen that either an impulse or Francis Turbine may be suitable.

Specific speed (n_s) is related to rotational speed (n) by specific speed $n_s = n\sqrt{P}/H^{5/4}$

$$n_s = n\sqrt{P}/H^{5/4}$$

$$= n\sqrt{3000}/(185)^{5/4}$$

$$n = 12.45\, n_s$$

Runner diameter (D) and speed for various possible values of n_s are computed and compared in Table 5.7.1 C.

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 are used.

Table 5.7.1 C

S. No.	**Type of Turbine**	**N_s (metric)**	**n(r.p.m.) =12.4 n_s**	**Runner dia (m)**	**Setting of runner above tailrace**	**Remarks**
A.	Single Jet Pelton	10	125	4.11	Above maximum T.W. level	Speed nearest Synchronous
		15	187.5	2.74		
		20	250	2.06		
B.	Double Jet Pelton	15	187.5	2.74		
		20	250	2.06		
		30	375	1.30		
C.	Francis	60	750	0.675	+5.0 m	-do-
		80	1000	0.54	+0.7 m	-do-
		100	1250			Synchronous Speed Not Possible
		120	1500	0.4	-1.1	Speed nearest Synchronous

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 tailwater 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.

5.7.2 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 tailwater 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 Rancis 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 (H0 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.

5.7.3 Conclusion & Recommendations

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

5.8 Low Head Range – Canal power Houses

Cost element in a low head project such as in canal fall projects is shown in figure 5.8. Accordingly equipment cost predominate. Cost of generators is reduced by providing speed increasing gears and accordingly selection of turbine in 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. Low Head canal fall Schemes. 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.

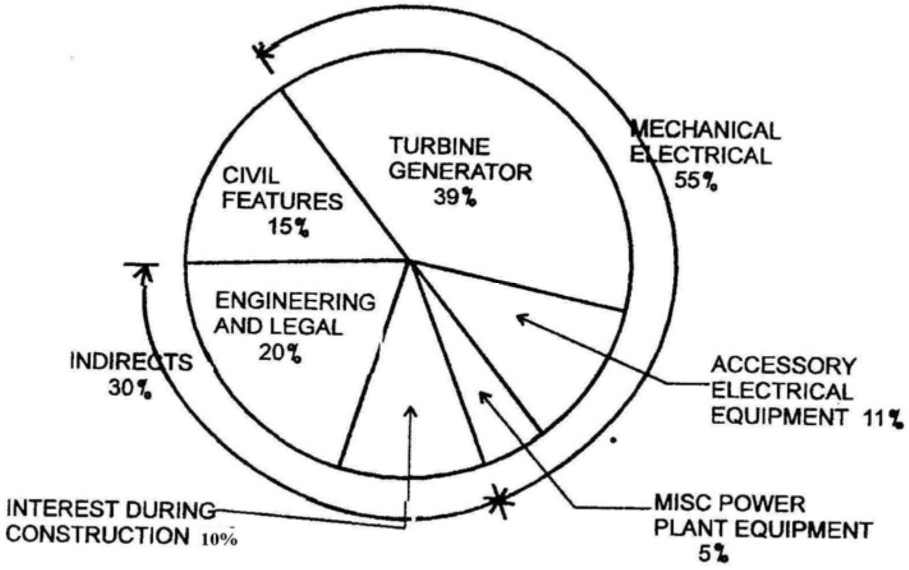


Fig. 5.8 – Minimum Civil Feature (Low Head Scheme)

5.8.1 Example of Turbine Selection

a) Tejpura SHP (Bihar)

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 IEC 1116 (Fig. 5.3) only Kaplan Axial flow turbine is feasible.

Available standard turbine CBI & P Publication (Annexure 4.1 to 4.12) is Tubular turbine S type (Full Kaplan) or Semi Kaplan turbine with runners dia. About 2200 meter is feasible (Fig. 4.2.1). 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 fig. 4.2.3 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 5.8.1.

Table 5.8.1

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 pum	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		

5.8.2 Guaranteed technical Particulars of the Tejpura Mini HP

Turbines ordered is as follows:

Type of turbine – vertical semi Kaplan with siphon intake

Rated Head (H) = 3.24 m
Rated discharge (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 %

5.9 Selection procedure for Turbines above 5 MW Unit Size

For a small/medium low head power units reaction turbine are used. For high head multiple jet Pelton turbine are used selection of turbine type is essential based on specific speed criteria.

Selection of Reaction Turbines as per USBR Monograph No. 20 Criteria

1. Trial Specific speed, n_s'

Select trial specific speed from figure 5.1 or from economic analysis. Except for unusual circumstances, the selecting specific speeds is near $\left(2334/\sqrt{h_d}\, metric\right)$.

2. Trial Speed, n':

$$n' = \frac{n_s'(h_d)^{5/4}}{(P_d)^{1/2}} \text{ or } \frac{n_s' h_d}{\left(\dfrac{P_d}{h_d^{1/2}}\right)^{1/2}}$$

where

n' = trial rotational speed,
n_s' = trial specific speed,
h_d = design head, and
P_d = turbine full gate capacity at h_d

3. Rotational speed or design speed, n:

The rotational 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 suggests the next lower speed.

Rotational speed, n $= \dfrac{120.\, frequency}{number\, of\;\; poles}$

$$n = \frac{6000}{number\, of\;\; pole} at\, 50\, Hz$$

4. Design specific speed, n_s:

$$n_s = \frac{n(P_d)^{1/2}}{(h_d)^{5/4}} \; or \; \frac{n\left(\dfrac{P_d}{h_d^{\;1/2}}\right)^{1/2}}{h_d}$$

The design specific speed is the basic parameter to which most other factors of the selection are made.

5.9.1 Example of Turbine Selection above 5 MW Unit Size (Matnar Project, Chhatisgarh)

1.Turbine Basic Data

II. Rated design head : 57.75 m
III. Rated Turbine Discharge : 41.57 cumecs
IV. Total discharge : 124.72 cumecs
V. Maximum tailrace level : 468.25 m
VI. Rated output at rated head and rated discharge : 20 MW (at generator terminals)

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 o/p = 20,000 kW

(10% overload capacity) = 22,000 kW

Turbine rated o/p required = $\frac{20000 \times 1.10 \times 1.05}{0.96 \times 0.86}$ = 27980 MHP

Trial Specific Speed (n_s') = $\frac{2334}{\sqrt{h_d}}$ (meteric)

= $\frac{2334}{\sqrt{57.75}}$ = 307 (Graph 5.1 shows $n_s = 250$)

Trail Rotational Speed (n') = $\frac{n'_s \times (h_d)^{5/4}}{\sqrt{P_d}}$

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

Design Speed

Head is expected to vary less than 10% from design head and h 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_3)

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

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

$$D_3 = \frac{84.47 \times \Phi \times \sqrt{h_d}}{n}$$

$$= \frac{84.47 \times 0.9768 \times \sqrt{81.37}}{300}$$

= 2.09 m

Manufacturer

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
With 10% overload speed = 272.7 rpm

6. Setting and Cavitation of Reaction Turbine

Highest sped 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 tailwater 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 water column at plant elevation
H_v = Vapour pressure in metres at plant location temperature
H = head on turbine, meters
σ = Plant sigma or cavitation coefficient for the turbine specific speed

The value for σ may be found from the expression which is as follows:

$$\sigma = \frac{(n_s)^{1.64}}{50.327}$$

The value of σ can also be taken from the curves relating n_s and σ shown in fig. 6.1.

The value of σ for Francis turbines are lower than those for Propeller of 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 tailwater level.

Lower setting (below tailwater) results in higher speed and hence smaller runner diameter fig. 6.2 & 6.3 shows correlation runner diameter and settling for Francis and propeller turbines.

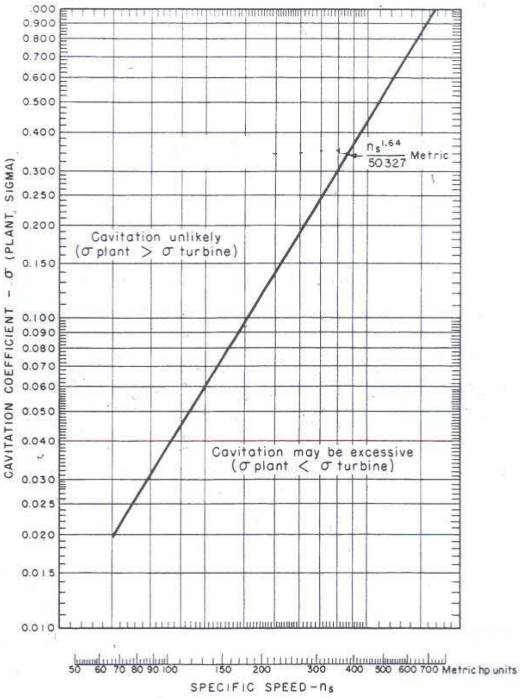
ATMOSPHERIC PRESSURE		
ALTITUDE METRES	H_a mm of Hg	H_a M of H_2O
0	760.00	10.351
500	715.99	9.751
1 000	674.07	9.180
1 500	634.16	8.637
2 000	596.18	8.120
2 500	560.07	7.628
3 000	525.75	7.160
3 500	493.15	6.716
4 000	462.21	6.295

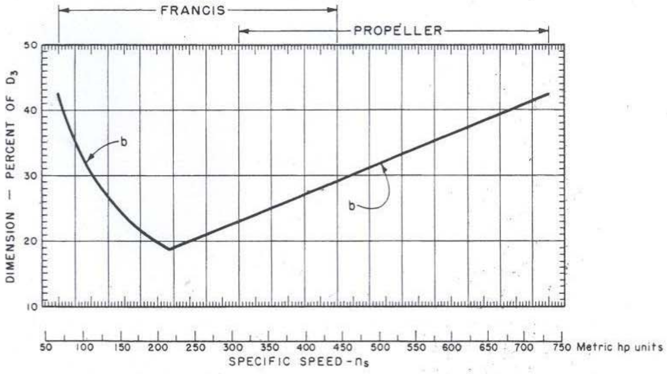
WATER PROPERTIES			
TEMP	H_v	TEMP	H_v
°F	FEET	°C	METRE
40	0.28	5	0.089
50	0.41	10	0.125
60	0.59	15	0.174
70	0.84	20	0.239
80	0.17	25	0.324

H_a = Atmospheric pressure for altitude, (m).

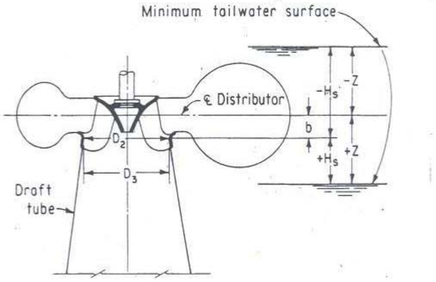
H_v = Vapor pressure of water, use highest expected temperature, (m).

$H_b = H_a - H_v$, Atmospheric pressure minus vapor pressure, (m)





D_2 at shrouding = Least diameter through shroud, (m).
D_3 = Discharge diameter of runner, (m)
b = Distance from D_2 to ℄ of distributor, (m). (estimated from curve % D_3 vs n_s).
n_s = Specific speed of turbine.

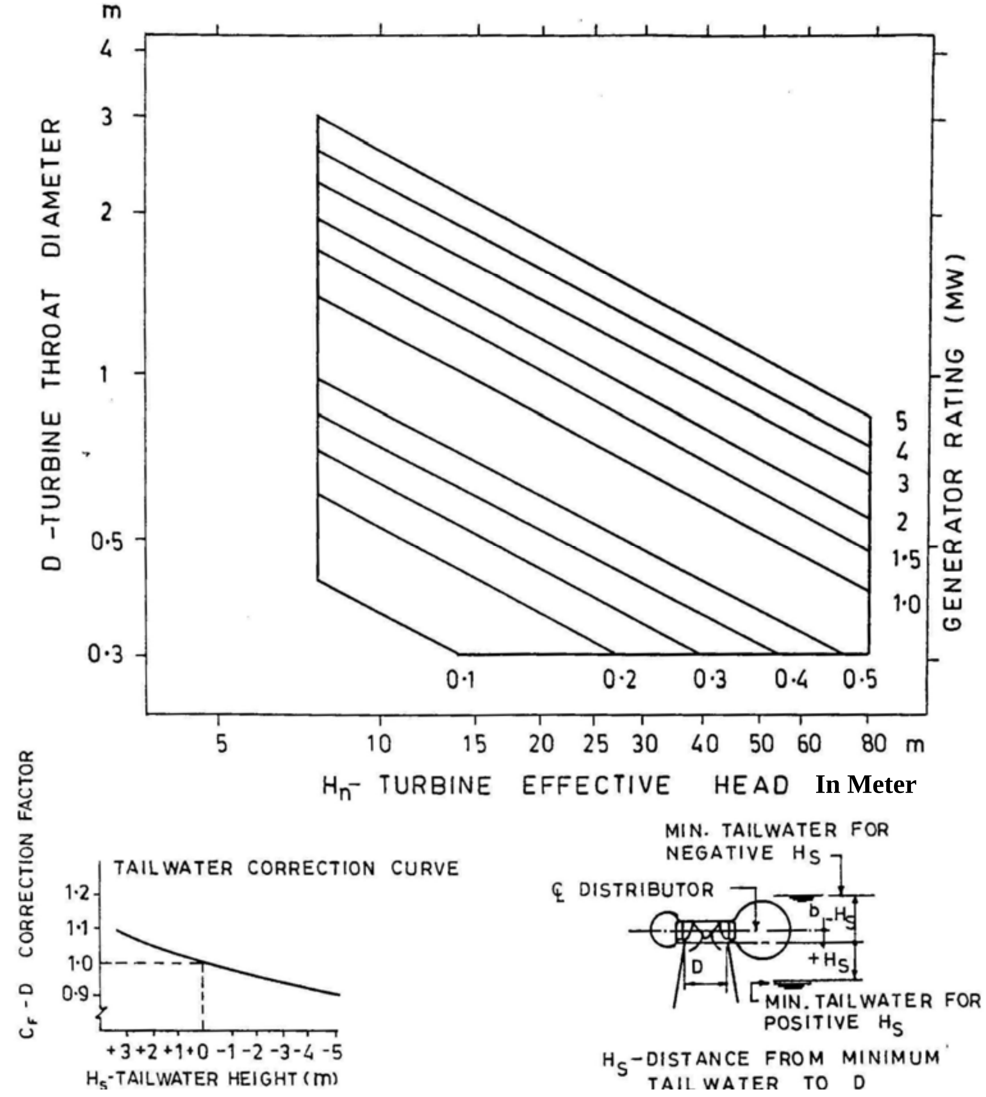


h_{cr} = Critical head, (m).
H_s = Distance from D_2 to minimum tailwater (one unit operating at full gate), (m).
$H_s = H_b - \sigma h_{cr}$ or $\sigma = (H_b - H_s) / h_{cr}$, (m).

Z = ℄ Distributor to minimum tailwater = $H_s + b$ (Total draft head), (m).

Note: Place ℄ of distributor at next lowest full foot elevation, (0.30 m).

Fig. 6.1 Reaction Turbine
(Source: USBR Engineering Monograph No. 20)



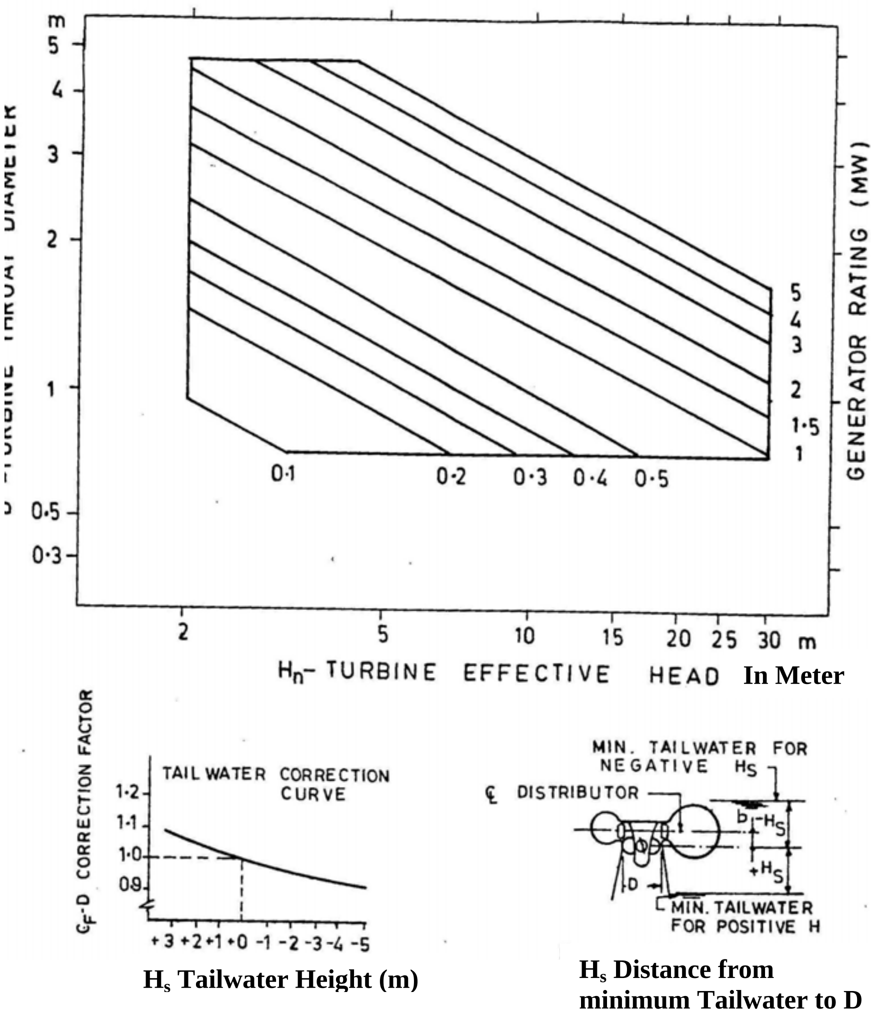
NOTES:

1 Estimated turbine runner diameters D are based upon a plant elevation of 600 m. and a tailwater 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 then 600 m add 1% to D for each 300 m. Subtract 1% from D for each 300 m. slower then the 600 m plant elevation.

Figure 6.2 Francis turbine runner diameters
(Source: Guide manual – us. Army corps of engineers)



NOTES:

1 Estimated turbine runner diameters D are based upon a plant elevation of 600 m. and a tailwater 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 then 600 m add 1% to D for each 300 m. Subtract 1% from D for each 300 m. lower then the 600 m plant elevation.

Figure 6.3: Propeller turbine runner diameters
(Source: Guide manual – US Army corps of engineers)

7. TURBINE PERFORMANCE

Turbine performance characteristics required to be provided considerably impact design ands cost of hydro stations. These characteristics depend upon design of associated water passage from forebay to tailrace and WR^2 of the rotating masses of the unit.. Head loss in penstock and pressure water system affects direct power loss and optimized by determining economic diameter of penstock and design of bends etc. Pressure and speed regulating characteristics of turbine are required to be provided according to performance requirement of the hydroelectric stations by optimizing pressure water system design and generator inertia WR^2/ GD^2.

7.1 Pressure regulation

With normal operation i.e. with load accepted or rejected either slowly as the system requires or rapidly during faults, pressure water system follow slow surge phenomena and depends upon the rate of closing the guide vanes/nozzle. The wicket gate closing time is always kept much greater than critical closure time (Tc) i.e. the time of reflection of the pressure wave, this time, $Tc = \frac{2l}{a}$ where l is the length of the pressure water system from tailrace to forebay/ surge tank and a is the velocity of the sound in water (wave velocity).

Pressure water column inertia is expressed as starting up time (Tw) of water column,

$$Tw = \frac{\sum LV}{gh}$$

Where Tw = starting up time of the water column in seconds

$$\sum LV = L_1 V_1 + L_2 V_2 + \dots\dots\dots L_n V_n + L_d V_d$$

L_n = length of penstock in whcih the velocity is uniform
V_n = velocity in section L_n at rated turbine capacity,
L_d = draft tube developed length
V_d = average velocity through the draft tube,
h = rated head of the turbine
g = gravitation constant

During preliminary stage of planning simple and short methods of calculating the pressure regulation as given in following references be adopted.

- Brown, J. Guthrie, Hydro-electric Engineering Practice, Volume 2.
- Engineering Monograph No. 20, Selecting Hydraulic Reaction Turbines, United States Department of the Interior, Bureau of Reclamation USA.

Allievies formula for pressure variation in decimals is given by

$$\frac{\Delta H}{H} = \frac{n}{2}\left\{n \pm \sqrt{n^2 \div 4}\right\}$$

Where n = $\frac{LV}{gHT}$ = $\frac{Tw}{T}$ or in case of uniform penstock dia.

L - length of penstock + ½ the length if the spiral casing

H – head in meter

T – governor closing time in seconds

V – velocity in m./sec.

This formula is sufficiently accurate only of T > $\frac{4L}{a}$ where a is the wave velocity.

Note – Use plus for pressure rise and minus for pressure drop.

Pressure rise in percentage is also given by

$$\frac{\Delta H}{H} = \frac{L \times HP \times 54}{D^2 \times H^2 \times T}$$

Where T, L & H are same as above;

D – diameter of penstock in meter

HP – rated metric Horsepower

7.2 Speed Regulation

The speed regulation or stability of a hydro-electric unit may be defined as its inherent property to ensure that changes in external conditions as well as in the turbine and governing equipment result an a periodic or rapidly damped, periodic return to the new steady state. Stability over the normal operating range with the machine connected to the system and stability after disconnection can be considered independently. Most hydro-electric stations are interconnected and as such their satiability is assisted. The more important factors upon which the stability of interconnected units depend are the flywheel effect of the unit, the hydraulic design of the water passages and speed and capacity of the unit. The GD^2 should be sufficient to insure prompt response to power demands and to restrict speed rise following loss of load. But generator GD^2 should be restricted to avoid excessive power swings. Additional GD^2 built into the generator increases the cost, size and weight of the machines and increasing GD^2 more than 50 percent above normal decreases the efficiency.

Flywheel effect is expressed as starting up time of the unit (Tm). This is the time in seconds for torque to accelerate the rotating masses from 0 to rotational speed

Tm = $\frac{GD^2 \times n^2}{3.6 \times 10^5 \times P}$ (metric units)

Where GD^2 = Product of weight of rotating parts and square of the diameter

n = rotational speed rpm
P = Turbine full gate capacity in metric horse power

Governor is the main controller and discussed in Para 8.

7.3 Speed Rise

Sudden dropping of load from a unit through opening of the main breaker will cause a unit to achieve considerable speed rise before the governor can close the gates to the speed-no-load position. The time required to attain a given over speed is a function of the flywheel effect and penstock system. The values of speed rise for full load rejection under governor control is considered an index of speed regulating capability of the unit. Normally adopted range is from 30 to 60 percent, the former applies to isolated units, where changes of frequency may be important when sections of distributed load are rejected by electrical faults. Values from 35 to 60 percent are generally adopted for grid connected hydro station. Generally units for which length of the penstock is less than five times the head can be make suitable for stable frequency regulation of the interconnected system. Also units for which $Tm \geq (Tw)^2$ can be expected to have good regulating capacity. This test should be applied over the entire head range. Plants in which more than one turbine are served from one penstock should be analyzed to determine proper governor settings and appropriate operating practices. Such plants may be unable to contribute to system transient speed regulation but adverse effects upon the system may be avoided by specifying the number of units which may be allowed to operate on free governor (unblocked) at any one time.

The turbine and generator are designed to withstand runaway speed, but at excessive speed severe vibrations sometimes develop which snap the shear pins of the gate mechanism. To minimize vibration, a speed rise not to exceed 60% can be permitted in contrast to the 35 to 45% desired for satisfactory regulation of independently operated units.

Considerations for permissible speed rise on full load rejection are as follows:

7.3.1 Small Hydro (grid connected)

Small hydro if grid connected (with no isolated and or islanding provision) cannot take part in frequency control. Accordingly these should be designed for upto 60% speed rise on full load rejection. In canal fall or similar units, speed control is required only during synchronizing. Generator loading should be controlled by level i.e. non speed control governors can be used and loading on the units is controlled by upstream canal water level. These are called non speed control governors.

7.3.2 Small Hydro (isolated grid operation)

These should be designed as frequency control units for the criteria that speed rise on full load rejection does not exceed 35%.

7.4 Pressure Rise and Speed Rise Calculation

The penstock pressure rise and unit speed rise may be calculated from the references given in Para 7.1 entitled ‘pressure regulation’. These could also be calculated as follows, which is based on USBR design monograph no. 20 referred in Para 7.1. Economic studies required to be carried out to determine whether more than normal GD^2, a larger penstock, a surge tank or a pressure regulator is required. Some examples follow:

7.5 Method for Computing Speed Rise

Notation :-

T_f = Servomotor minimum closing time, sec.
P_r = Turbine full gate capacity of hr, kW
h_r = Rated head, metre
n = Rotational speed: design, r/min.
n_s = Design specific speed, metric kW unit
GD^2 = Flywheel effect of revolving parts; kgm^2
L = Equivalent length of water conduit, m
A = Equivalent area of water conduit, m^2
g = Gravitational constant (acceleration), m/s^2
$Q_r = \dfrac{P}{h_r \text{ x } 9.804 \text{ x } 0.8}$ = Turbine full gate discharge, m^3/s
$V_r = \dfrac{Q_r}{A}$ = Conduit water velocity for full gate at hr, m/s
T_m = Mechanical startup time
T_w = Water startup time

To obtain the speed rise for full load rejection, determine the following values:-

(a) T_K = $0.25 + T_f$, full closing time of servomotor(s)

(b) $T_m = \dfrac{GD^2 \text{ x } n^2}{3.6 \text{ x } 10^5 \text{ x } P_r}$

(c) $\dfrac{T_K}{T_m}$

(d) $n_s = \dfrac{n(p_r)^{1/2}}{(h_r)^{5/4}}$ At rated cond^n, metric kW unit

(e) Determine S_R from fig. 7.5.1 using n_s & $\frac{T_K}{T_m}$

Where,

S_R is speed rise in percent of rotational speed,
n_1 for full gate load rejection to zero, excluding effect of water hammer.

(f) $T_W = \frac{\sum LV_r}{ghr}$ (water start up time)

(g) $K = \frac{T_W}{T_f}$

(h) $S^1_R = S_R\,(1 + K)$, speed rise in percent of rotational speed n_r for full gate load rejection to zero, including effect of water hammer.

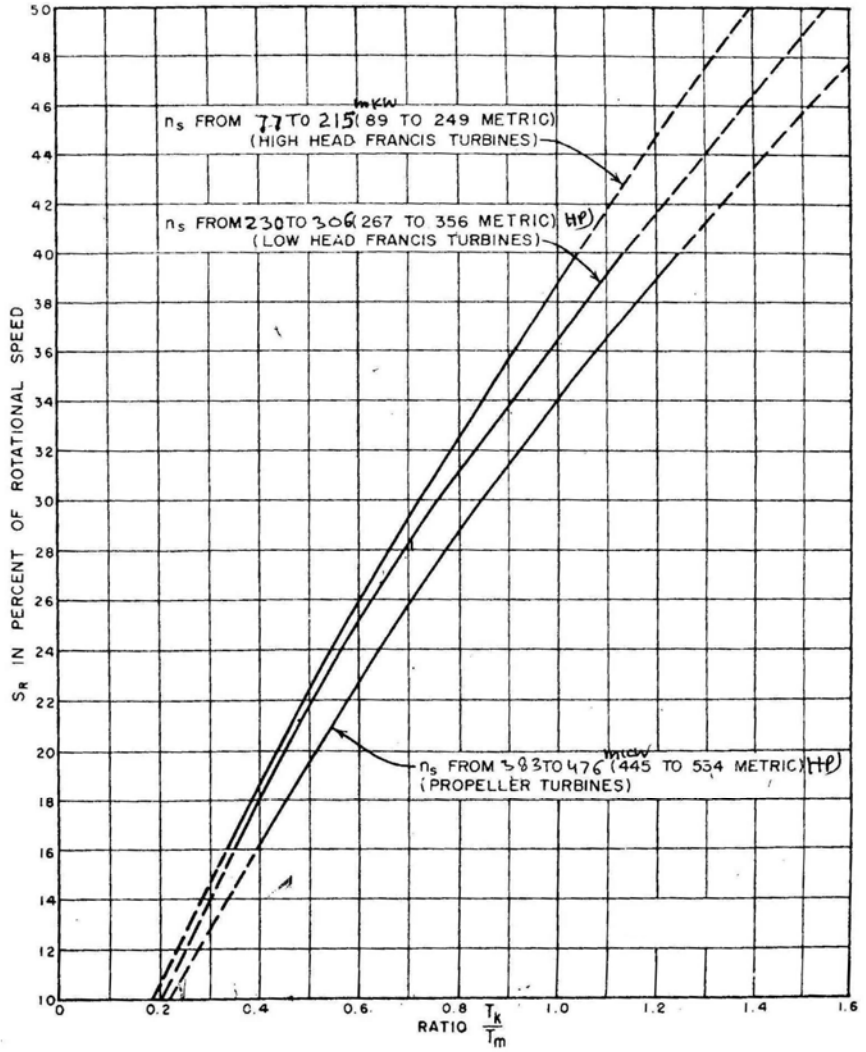


Fig. 7.5.1 – Turbine Performance
(Based on USBR Design Monograph no. 20)

Example-1

Given:-

$T_f = 5$ sec, $P_r = 29851$ kW, $h_r = 24.38$ metre

$N_{sr} = 94.7$, $GD^2 = \frac{1}{6} WR^2 = 8873333.34$ kgm^2

$V_r = 4.199 \approx 4.2$ metre/sec

L = 103.63 metre

(a) T_K = 0.25 + 5 sec (0.25 in dead time
= 5.25 sec

(b) $$T_m = \frac{GD^2 \text{ x } n^2}{3.6 \text{ x } 10^5 \text{ x } P_r} = \frac{8873333.34 \text{ x } (94.7)^2}{3.6 \text{ x } 10^5 \text{ x } 29851} = \frac{7.957685199 \text{ x } 10^{10}}{1.074636 \text{ x } 10^{10}}$$

= 7.40

(c) $$\frac{T_K}{T_m} = \frac{5.25}{7.40} = 0.709$$

(d) $$n_{sr} = \frac{n\sqrt{P_r}}{(n_r)^{5/4}} = \frac{(94.7)\sqrt{29851 \text{ kW}}}{(24.38)^{5/4}} = 302.02$$

= 302 MkW

(e) S_R = 28.1% from Chart A (Figure 7.5.1)

(f) $$T_w = \frac{103.63 \text{ x } (4.2)}{9.81 \text{ x } 24.38} = 1.8198$$

Tw = 1.82

(g) $$K = \frac{T_w}{T_f} = \frac{1.82}{5} = 0.364$$

(h) $S^1{}_R$ = (28.1) (1 + 0.364) = 38.32

Example -2

Data

Length of Penstock (L) = 153.5 m
Penstock Dia (D) = 1.289 m

Penstock thickness = 0.00889 m = 8.89 mm

Rated unit output = 1750 kW (including 10% over load capacity)
(full gate) (1750 x 1.34 = 2345 HP units)

Rated Head (h) = 46.634 m
(Full gate)

Maximum pressure rise = 30%
in penstock

First Step:- Fix closing time for 30% speed rise

Assuming governor closing time of 4 seconds

Rated Discharge (Q_r) $= \dfrac{P}{h_r \times 9.804 \times 0.8}$

$$= \frac{1750}{46.63 \times 9.804 \times 0.8}$$

= 4.78 cusecs

Velocity of water (V_r) = Q/A (A – cross sectional area of penstock)

$$= \frac{4.78}{\pi / 4 \times (1.289)^2} = \frac{4.78}{0.7854 \times 1.661521}$$

= 3.662 m/sec.

Governor closing time (assumed) = 4 second

Guide vane closing time assuming (t_0) = 4 + 0.25 = 4.25 second
(0.25 sec. as dead time)

Gravitational Constant (g) = 9.81 m/sec^2

Water starting up time (Tw) $= \dfrac{LV}{gH}$

$$= \frac{153.5 \times 3.66}{9.81 \times 46.63}$$

= 1.228 second

Pressure rise on full load rejection using Alliivies formula

$$\frac{\Delta H}{H} = \frac{T_w}{2}\left\{T_w + \sqrt{T_w{}^2 + 4}\right\}$$

Where T_w = $\frac{LV}{gHT} = \frac{1.2287}{4.25} = 0.2894 = 0.29$

L = Length of penstock + Length of Spiral Casing = 153.5

H = Head in meter = 46.63

T = Governor closing time 4 seconds

V = Velocity in meter/second = 3.66 m/s
g = 9.81 m/s^2

$$\frac{\Delta H}{H} = \frac{0.29}{2}\left\{0.29 + \sqrt{0.29^2 + 4}\right\}$$

= 33.50%

Speed Rise and WR^2

Normal WR^2 of Gen. & Turbine 42000 lb/ft^2 (GD^2 = 7 Tm^2)

Mechanical starting up time Tm = $\frac{GD^2 \times n^2}{3.6 \times 10^2 \times P_r} = \frac{7 \times 10^3 \times 750^2}{3.6 \times 10^5 \times 1750}$ = 6.25 seconds

Closing time of servo motor T_k = 4 seconds (full closing time of servomotor)

$$\frac{T_k}{T_m} = \frac{4}{6.2} = 0.645$$

Specific speed $n_{sr} = \frac{n\sqrt{P}}{h^{5/4}} = \frac{750\sqrt{1750}}{46.63^{5/4}} = \frac{31374.751}{121.48}$ = 257.48 = 258 (m units)

Speed rise S_r = 26.5% (from figure 7.5.1)

T_w = 1.23

$$k = \frac{T_w}{T_f} = \frac{1.23}{4} = 0.3075$$

$$\begin{aligned} S'_R &= (26.6)\,(1 + 0.3075) \\ &= 34.779 = 34.78\% \end{aligned}$$

8. HYDRO-TURBINE GOVERNING SYSTEM

8.1 Introduction

Governor control system for Hydro Turbines is basically a feed back control system which senses the speed and power of the generating unit or the water level of the forebay of the hydroelectric installation etc. and takes control action for operating the discharge/load controlling devices in accordance with the deviation of actual set point from the reference point.

Governor control system of all units suitable for isolated operation are a feed back control system that controls the speed and power output of the hydroelectric turbine. Water level controllers can be used for grid connected units. Governing system comprises of following sections.

a) Control section
b) Mechanical hydraulic Actuation section

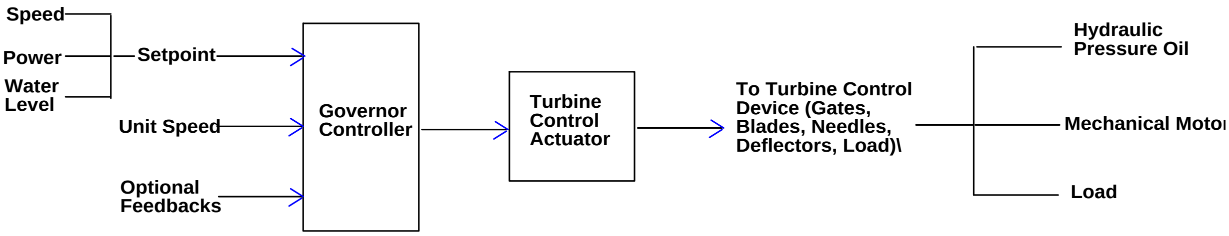


Fig. 8.1 – Basic Governor Control System

The control section may be mechanical; analogue electronic or digital. Actuator can be hydraulic controlled, mechanical (motor) or load actuator. Load actuator are used in micro hydel range; mechanical (motor operated) may be used say upto 1000 kW unit size. Hydro actuator are mostly used.

8.2 Type of Governor Control Section

8.2.1 Mechanical Controller

By the middle of 20th century, mechanical governors directly driven by prime movers through belt were used for small machines. The speed of rotation was sensed by fly-ball type pendulum. In second-generation mechanical governors, permanent magnet generator and pendulum motor were utilized for sensing the speed of the machine. The isodrome settings were achieved through mechanical dashpot and droop setting by link mechanism. These mechanical governors were fully capable of controlling the speed and output of the generating unit in stable manner. In case of faulty pendulum, manual control of the units was possible with handles and knobs. This was PI type controller.

8.2.2 Electro-Hydraulic Governor – Analogue Electronics

Next came the third generation Electro-Hydraulic Governors where speed sensing, speed/output setting and stabilizing parameters were controlled electrically and the use of mechanical components was reduced considerably. They increased the reliability, stability and life of the equipment and facilitated more functional requirements. The design of electrical part of the governors kept changing based on the advancement in electronics and development work by individual manufacturers. In this type of gov3ernor analogue circuitry is used to develop set point signal that is used to position the control actuators of hydroelectric units. An electro hydraulic interface is used to connect the electronic set point signal into a hydraulic oil flow from a hydraulic servo valve system which determine the position of the turbine control actuators. This sis a PID controller.

8.2.3 Electro Hydraulic Governor – Digital Governors

In digital governor, digital controller is used in turbine governing system. This is also PID controller. Digital control hardware running an application programme accomplishes the required control function with this system. Digital controller used for turbine governing system are very flexible and can be used for functions not directly related to the turbine governing control function.

Present day trend is to use digital governing control system in hydroelectric units. The major advantages of microprocessor based system over the earlier analogue governors (based on solid state electronic circuitry) are higher reliability, self diagnostic feature, modular design, flexibility of changing control functions via software, stability of set parameters, reduced wiring and easy remote control through optical fibre cables. Microprocessor based governor control system are capable of carrying out the following control functions in addition to speed control during idle run , operating in isolated grid; interconnected operation and islanding operation.

- Control the power output depending on variation in grid frequency i.e. load frequency control
- Joint power control of a number of generating units in a power station
- Power control as per water levels in Fore-bay and/or Tail-race
- Automatic Starting / Stopping by single command
- Fast response to transient conditions
- Control from remote place Supervisory Control And Data Acquisition (SCADA)

8.3 Turbine Control Actuator System

Actuator system compares the desired turbine actuator position command with the actual actuator position. In most of the hydroelectric units it requires positioning of wicket gates in reaction turbines, spear in pelton turbines and turbine blades in Kaplan turbines. In load actuators it shunt load bank is adjusted. Pressure oil system with oil servomotor is most commonly used actuator.

8.3.1 Governor Capacity (oil servomotor)

The size, type, and cost of governors vary with their capacity to perform work which is measured in (meter-kilograms). Mechanical governor having a capacity of more that 8300 m kg. Are of cabinet actuator type. These having a capacity less than 7000 m kg. Are gate shaft type.

The capacity is the product of the following factors: turbine gates servomotor area, governor minimum rated oil pressure, and turbine gates servomotor stroke. For gate shaft governors, the turbine gates servomotor area is the net area obtained by subtracting the piston rod area from the gross piston area. For governors controlling two servomotors mounted directly on the turbine, the effective area is the sum of the net area of the two servomotors.

Servomotor capacity can be estimated by the formulas:

1. Wicket gates servomotor capacity.

$$FY_M = 34\,(h_{wh}\,D_g.M)^{1.14}(\text{metric})$$

Where

M = wicket gate height

h_{wh} = maximum head, including water hammer, and

D_g = wicket gate circle diameter

2. Blade servomotor capacity (adjustable blade propeller turbine). - The blade servomotor capacity also varies among manufacturers. This can be roughly estimated by the formula:

$$FY_b = \frac{6.17\,P_{\max}\left(n_s\right)^{1/4}}{\left(H_{\max}\right)^{1/2}}\ \text{metrics}$$

Where

H_{max} = maximum head,

n_s = design specific speed, and

P_{max} = turbine full-gate capacity at $H_{max.}$

8.4 Small Hydro Governor Selection Consideration

Actuator and Control systems for small hydro units especially in developing countries have to be selected keeping in view the following:

(a) Traditional flow control governor with mechanical hydraulic actuator is complex demanding maintenance and high first cost. Further performance requirements of stability and sensitivity i.e. dead band, dead time and dashpot time especially for interconnected units may not be met by mechanical governors.

(b) Electronic and Digital flow control governors can be take up plant control functions.

(c) Cost of speed control and automation with currently installed analog flow governors, unit control and protection systems is high. These systems require attended operation and are mostly based on large capacity hydro units. This is making most of the units very costly and uneconomical to operate.

(d) The manpower as available is unskilled and further adequate supervision is not feasible.

(e) Load factors for stand-alone micro hydels are usually low affecting economic viability.

(f) Flow Control Turbine Governors are expensive and not recommended for small hydro units in micro hydel range. Electronic load control governing system with water cooled hot water tanks as ballast loads for unit size upto 100 kW are cost effective. This will make a saving of about 40% on capital cost. The generator flywheel is not required. If the thyristor control (ELC) is used then the alternator needs to be oversized upto 2%% on kVA to cope with the higher circulating current induced. Accordingly, in case of small units upto 100-150 kW size elimination of flow control governors using load actuator with digital speed controller make these units economically viable and properly designed will eliminate continuous attendance requirement.

(g) Data storage function can be added to the Digital Governors control system with hard disk (i.e. PC).

(h) The dummy loads in the Shunt Load Governors (ELC) can be useful load system or can be used for supplying domestic energy needs.

(i) Digital generation controllers were evolved to take care of speed control, unit control and automation, unit protection and every generation scheduling and have been successfully in operation for over ten years.

(j) Programmable logic control (PLC) based systems are with aotmation by personal computers are reliable and have been in operation in India.

(k) As dedicated PC based systems for complete generation control can be easily adopted for data acquisition and storage at a nominal cost and can also be adopted to SCADA system.

(l) Manual back up and or redundant control system are provided.

8.4.1 Application of Governor Control System to SHP

Selection of the type of controller to be used in SHP may be based on the recommendations of the American, European and Indian consultants for the UNDP-GEF project for Himalayan range. These recommendations are given in table 8.1 with following aspects.

(a) Ease of adoption
(b) Sustainability
(c) Cost saving potential
(d) Over all rating

8.5 Personnel Computers (PC) /Programmable Logic Controller (PLC) based Digital Governors

Modern control schemes also utilise personal computers (PCs) in conjunction with PLC control systems. The PCs are utilized with man-machine interface (MMI) software for control display graphics, historical data and trend displays, computerized maintenance management systems (CMMS), and remote communication and control. In addition, the PLC programming software is usually resident on the PC, eliminating the need for a separate programming terminal implement or change the PLC software coding.

A PC also can be used for graphical displays of plant data, greatly enchancing operational control. Standard Microsoft-based graphical display software packages are available for installation on a standard PC. The software package can be utilized on the PC to create specific powerhouse graphical displays based upon real-time PLC inputs. These displays typically include control displays with select-before-execute logical, informational displays for plant RTD temperatures, or historical trending plots of headwater, tailwater, and flow data.

Modems with both dial-out and dial-in capabilities can be located in either the PC, the PLC, or both to provide off-site access to plant information. These modems may also be utilised to control the plant operation from a remote location.

Programmable Logic Controller (PLC) type plant controllers with a manually operated back up system combined with PC based SCADA system are used as Governors and for Plant control and data acquisition. This makes the system costly but reliability is stated to be good and can be used for small hydro generation control. It is considered that dedicated digital control systems which is digital P.C. based can perform all functions of governing, unit control and protection as well as for data storage and can be more economical, dependable and are being manufactured in U.S.A., Europe, India and other countries. These dedicated systems with back up manual control facility of speed control in emergency by dedicated semi automatic digital controllers can be an option and is also recommended for UNDP-GEF projects in India.

Table 8.1: GOVERNORS, CONTROLS AND MONITORING SYSTEMS, TECHNOLOGY

Rating by MHPG (European Consultant)					Comments		
Concept	**Ease of adoption**	**Sustainability**	**Cost saving potential**	**Overall rating**	**MHPG**	**Mead & Hunt**	**AHEC**
Load Control	3	2	3	2.7	Most useful on non-grid connect sites, upto 500 kW. Could save more than 20% due to spin effects.	Not considered	Most useful on unit size upto 200 kW on both grid & non grid connected.
Analogue integrated governor and plant control.	3	2	2	2.3	Low cost solution for upto 500 kW grid connect.	Not considered	Not recommended cost high.
Digital integrated governor and plant controller	3	2	2	2.3	Preferred solution for large grid connect schemes. Savings where optimisation or complex operation needed.	Not considered	Preferred solution for schemes with unit size above 250 kW.
PLC controller	3	2	1	2	Useful for larger schemes with separate governors.	Recommended	Recommended
Data Logger	3	3	2	2.7	Available in India, suitable for isolated schemes using analogue or flow control governing.	Data storage and retrieval recommended by P.C.	Data storage and retrieval as part of Digital Gov. system.

Monitoring and control and data acquisition system (SCADA system) can be a part of the P.C. based digital governor and generation control equipment. Provision of data storage of one month with 16 MB of Ram memory and a 540 to 850 MB Hard Drive as part of the PC based governing and control system should be provided. This data could be retrieved on a floppy drive after one month for examination. As the communication links develop the data can also be transmitted via a Modem to a remote point for examination and supervisory control.

Auxiliary control normally forms a part of digital governor. It is further recommended that water jet diverters of emergency closure of inlet valves be provided to avoid overspeeding to runaway in case of governor failure emergency.

8.6 Governing System used in India

Basically there is no difference in governors used for large generating units and small units except for sizes, operating pressure and control features as per requirement of individual project. Also for smaller units, hydro-mechanical part of governor is built on the sump of oil pressure plant for compactness. Higher operating pressure is used to reduce sizes of control elements and pipelines. Nitrogen cylinders are used in place of pressure air to avoid use of high-pressure air compressors. Oil pipelines of sizes upto 50 mm are used in stainless steel with ermeto (dismantlable) couplings to reduce welding and maintain cleanliness.

Following types of governing system are used:

Micro Hydel - (upto 100 kW)	Digital speed control system will load actuator is used.
Small Hydros - Upto 3 MW	Flow control governing system with hydraulic actuator and digital PID speed and power control system. Mechanical motor type actuator have also been, used upto 1000 kW unit size with microprocessor based level control PI Controller
Small Hydro - Above 3 MW	Flow control PID governor with hydraulic actuator

Governing system including controller and actuator used for different capacity powerhouses designed by AHEC and consultants is given in Table 8.2.

Table – 8.2

Sl. No.	Project Name	Controller	Actuator	Remarks
Arunachal Pradesh Energy Development Agency				
1.	Pein Small Hydro Power Project (Phase I) (2 x 1500 kW), District Lower Subansiri	Digital governor PLC based alongwith plant control capability with PC (SCADA)	Oil pressure servomotor	
2.	Pareng Small Hydro Power Project (2 x 3000 kW), District Papumpare	Digital governor PLC based alongwith plant control capability with PC (SCADA)	Oil pressure servomotor	
3.	Sie Small Hydro Power Project (2 x 2800 kW), District West Siang	Digital governor PLC based alongwith plant control capability with PC (SCADA)	Oil pressure servomotor	
Uttarakhand Renewable Energy Development Agency				
1.	Nagling Micro Hydro Power Project (2 x 25 kW), District Pithoragarh	Digital controller (Electronic Load Controller)	Load Actuator	
2.	Dugtu Micro Hydro Power Project (1 x 25 kW), District Pithoragarh	Digital controller (Electronic Load Controller)	Load Actuator	
3.	Kuti Micro Hydro Power Project (1 x 50 kW Phase I), District Pithoragarh	Digital controller (Electronic Load Controller)	Load Actuator	
4.	Rong Kong Micro Hydro Power Project (1 x 50 kW Phase I), District Pithoragarh	Digital controller (Electronic Load Controller)	Load Actuator	
5.	Sela Micro Hydro Power Project (2 x 25 kW), District Pithoragarh	Digital controller (Electronic Load Controller)	Load Actuator	
6.	Borbadala Micro Hydro Power Project (1 x 25 kW), District Bageshwar	Digital controller (Electronic Load Controller)	Load Actuator	
7.	Chillud Gad Micro Hydro Power Project (2 x 50 kW), Uttarkashi	Digital controller (Electronic Load Controller)	Load Actuator	
8.	Nepalchyo Mini Hydro Power Project (2 x 100 kW), District Pithoragarh	Digital controller (Electronic Load Controller)	Load Actuator	
Bihar State Hydro Electric Power Corporation Ltd.				

1.	Rajapur Small Hydro Power Project (2 x 350 kW), District Supaul	PLC based digital electronic governor	Oil pressure servomotor	
2.	Natwar SHP Project (2 x 250 kW), District Rohtas	Digital Controller	Oil pressure servomotor	
3.	Jainagara SHP Project (2 x 500 kW), District Rohtas	Digital Controller	Oil pressure servomotor	
4.	Belsar SHP Project (2 x 500 kW), District Jehanabad	Digital Controller	Oil pressure servomotor	
5.	Rajapur Small Hydro Power Project (1 x 700 kW), District Supaul	Digital Controller	Oil pressure servomotor	
6.	Shirkhinda SHP Project (2 x 550 kW)	Digital Controller	Oil pressure servomotor	
7.	Walidad SHP Project (1 x 700 kW), District Jehanabad	Digital Controller	Oil pressure servomotor	
8.	Arwal SHP Project (1 x 500 kW), District Jehanabad	Digital Controller	Oil pressure servomotor	
NTPC Ltd., Singrauli (U.P.)				
	Singrauli SHP Project (2 x 4000 kW), District Sonebhadra	Digital Governor with integrated plant control with PC (SCADA)	Oil pressure servomotor	

8.7 U.S. PRACTICE REGARDING GOVERNOR AND CONTROL

Type of Scheme

Two basic control schemes utilized for small and medium hydro stations are (1) a single PLC with a manually operated back-up system, and (2) a redundant.

PLC system. There are various modifications of these two basic schemes, which depend upon the individual plant requirements and owner preference. The single PLC offers the advantages of low cost and simplicity, and is typically based up by a hardwired system. With a redundant PLC system, backup control and memory are provided by a second PLC. Advantages and disadvantages of the two schemes are summarized in Table 8.3 and 8.4.

Table 8.3 : Advantages and Disadvantages of the Redundant PLC Control Scheme

Advantages	Disadvantages
• 100 percent backup for the central processing unit (CPU). The CPU includes the processor, system memory, and system power supply.	• Cost. The cost of a second PLC exceeds the cost of a manual backup system.

Continued automatic control of the nit under headwater level or discharge control with one PLC out of service. This ability allows continued maximizing unit revenue when a PLC fails.	Complexity. Most small hydro plant operators are not technically trained for troubleshooting PLCs (some of this complexity is offset by the PLC and I/O card self-diagnostics now available.
Uniform spare parts. Only one set of I/O cards needs to be maintained. Items such as spare relays and control switches associated with a hard-wired system are not required.	Failure of both systems simultaneously. Although redundant PLCs do enhance system reliability, they can be prone to simultaneous failure caused by surge. Owners should insist on good surge protection engineering. Software problems. If software is non-standard, software problems will be common to both PLCs.

Table 8.4: Advantages and Disadvantages of a Single PLC with Manually Operated Backup System

Advantages	Disadvantages
Less expensive than a redundant PLC system.	Headwater level or discharge control (if performed by the PLC) is disabled whenever the PLC is disabled. When utilizing the manually.
Less chance of a common mode failure because the hardwired system is less prone to surge-induced failures and more tolerant of inadequate grounds.	Operated backup system for control, the unit's output is set a the operator's discretion. An operator will usually allow a safety margin of approximately 10 percent in headwater or discharge level to avoid problems such as drawing air into the penstock. As a result, maximum possible revenue for the unit is usually not realized during manual operation.
Operator familiarity with trouble shooting hardwired relay systems.	Nonuniform spare parts. Spare parts would have to provided for both the PLC system and the manually operated backup system. However, it should be

noted that relatively few spare parts would be needed for the manual backup system, due to its simplicity.

In either unit control scheme, all unit protective relays should be independent from the programmable controllers. This independence will allow the protective relays to function even if the PLC fails, ensuring the safety of unit equipment and personnel. For the single PLC scheme with a manually operated back-up system, it is usually best to have an independent resistance temperature detector (RTD) monitor and annunicator panel functionally operative during manual operation of the unit. These additional panels will provide the operator vital information which will facilitate operation of the plant in the manual mode.

8.8 Examples of Typical Governing Systems

i) 2 x 30 kW Microhydel with Synchronizing, Assam Project (isolated operation) – Fig. 8.2 & 8.3

Digital controller and load actuator (Electronic Load Controller) – Project by
Prof. O. D. THAPAR Consultant, AHEC

ii) 2 x 500 kW – Satpura SHP project - (Fig. 8.4)

Electronic Digital Level Controller with induction generator – grid connected – Project by Prof. O. D. THAPAR Consultant, AHEC

iii) 2 x 1000 kW –SHP project Newzeland -(Fig. 8.4)

Electronic Digital Level Controller with synchronous generator – grid connected with motor operated mechanical actuator, for peak load operation with a limited storage pool Project by Prof. O. D. THAPAR Consultant, AHEC for M/s Jyoti Ltd.

iv) 2 x 3000 kW – Sobla SHP project (Fig. 8.5)

PC based a digital PID controller with oil pressure servomotor actuator with synchronous generator suitable for isolated/grid connected operation with back up manual control and integrated plant control and off site control facility - Project by Prof. O. D. THAPAR Consultant, AHEC for M/s Jal Viduyat Nigam Ltd. UP..

v) 2 x 9 MW – Mukerain Stage –II canal fall SHP project (Fig. 8.6)

PLC Digital PID Controller with oil pressure servomotor actuator with Synchronous Bulb generator – grid connected with redundancy and redundant PC based automation (AHEC Project)

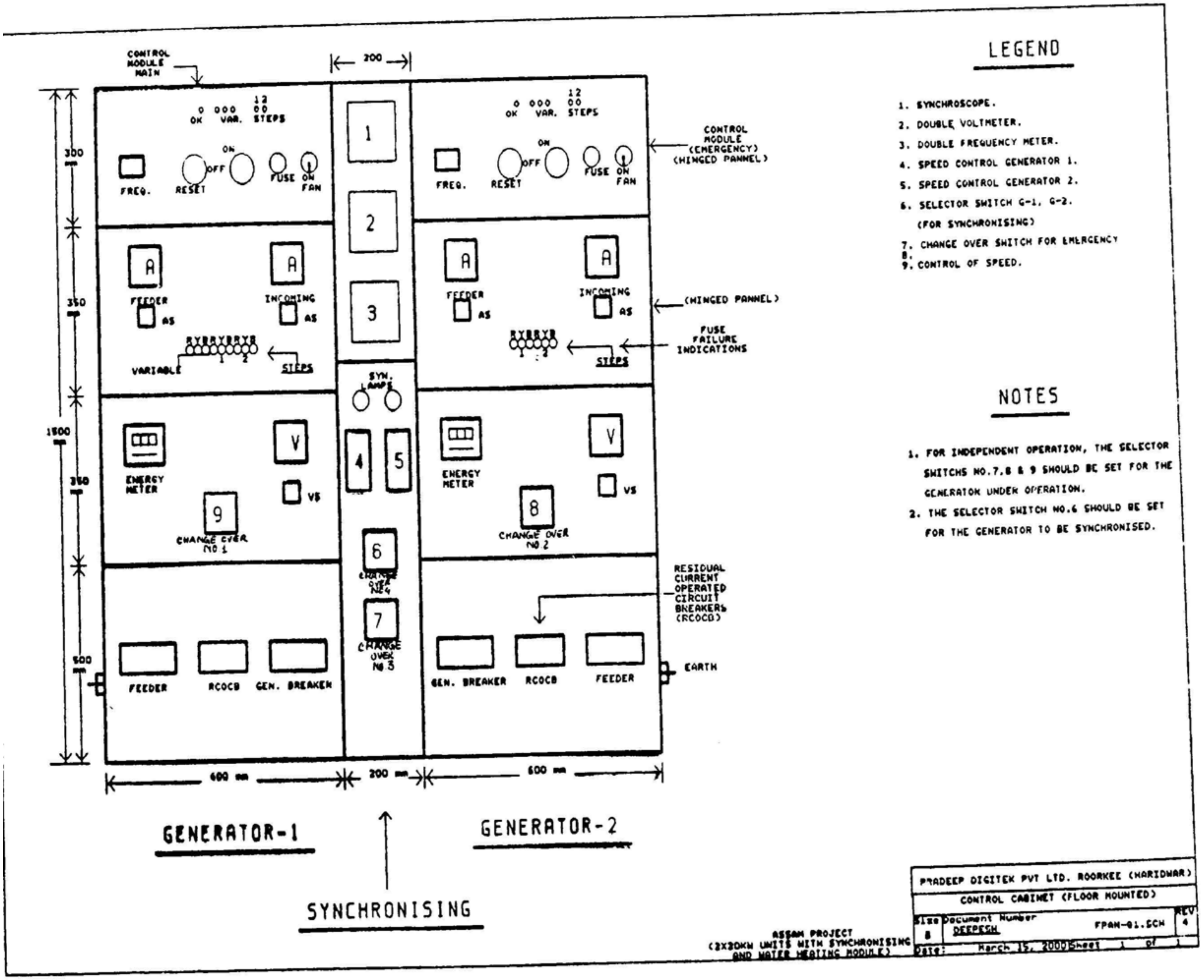

CONTROL MODULE MAIN
0 OK
000 VAR.
12 00 STEPS
ON
OFF
RESET
FREQ.
FUSE
ON FAN
200
1
2
3
CONTROL MODULE (EMERGENCY) (HINGED PANNEL)
A
FEEDER
AS
INCOMING
RYBRYBRYB
1 2
VARIABLE
STEPS
(HINGED PANNEL)
FUSE FAILURE INDICATIONS
SYN. LAMPS
4
5
ENERGY METER
V
VS
9
CHANGE OVER NO 1
8
CHANGE OVER NO 2
6
CHANGE OVER NO 4
7
CHANGE OVER NO 3
RESIDUAL CURRENT OPERATED CIRCUIT BREAKERS (RCOCB)
FEEDER
RCOCB
GEN. BREAKER
EARTH
300
350
350
500
1500
600 mm
200 mm
600 mm
GENERATOR-1
GENERATOR-2
SYNCHRONISING
LEGEND
1. SYNCHROSCOPE.
2. DOUBLE VOLTMETER.
3. DOUBLE FREQUENCY METER.
4. SPEED CONTROL GENERATOR 1.
5. SPEED CONTROL GENERATOR 2.
6. SELECTOR SWITCH G-1, G-2. (FOR SYNCHRONISING)
7. CHANGE OVER SWITCH FOR EMERGENCY
8.
9. CONTROL OF SPEED.
NOTES
1. FOR INDEPENDENT OPERATION, THE SELECTOR SWITCHS NO.7,8 & 9 SHOULD BE SET FOR THE GENERATOR UNDER OPERATION.
2. THE SELECTOR SWITCH NO.6 SHOULD BE SET FOR THE GENERATOR TO BE SYNCHRONISED.
ASSAM PROJECT (2X30KW UNITS WITH SYNCHRONISING AND WATER HEATING MODULE)
PRADEEP DIGITEK PVT LTD. ROORKEE (HARIDWAR)
CONTROL CABINET (FLOOR MOUNTED)
Size B
Document Number DEEPESH FPAN-01.SCH
REV 4
Date: March 15, 2000 Sheet 1 of 1

Fig. 8.2

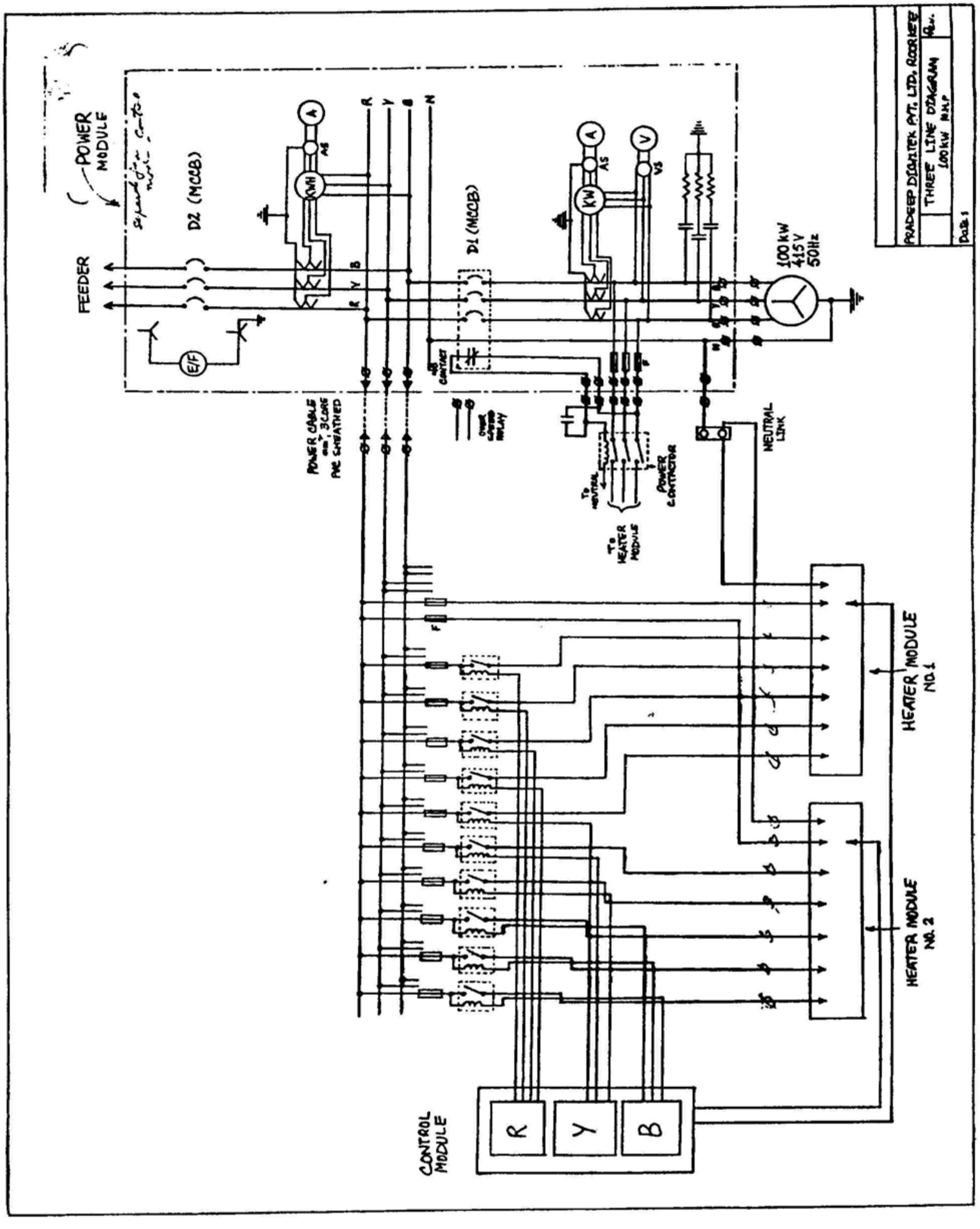

FEEDER
POWER MODULE
D2 (MCCB)
D1 (MCCB)
E/F
KWH
A
AS
KW
V
VS
R
Y
B
N
100 KW
415V
50Hz
POWER CABLE
PVC SHEATHED
NEUTRAL LINK
POWER CONTACTOR
TO HEATER MODULE
TO NEUTRAL
HEATER MODULE NO.1
HEATER MODULE NO.2
CONTROL MODULE
PRADEEP DIGMATEK PVT. LTD. ROORKEE
THREE LINE DIAGRAM
100KW M.H.P.

Fig. 8.3

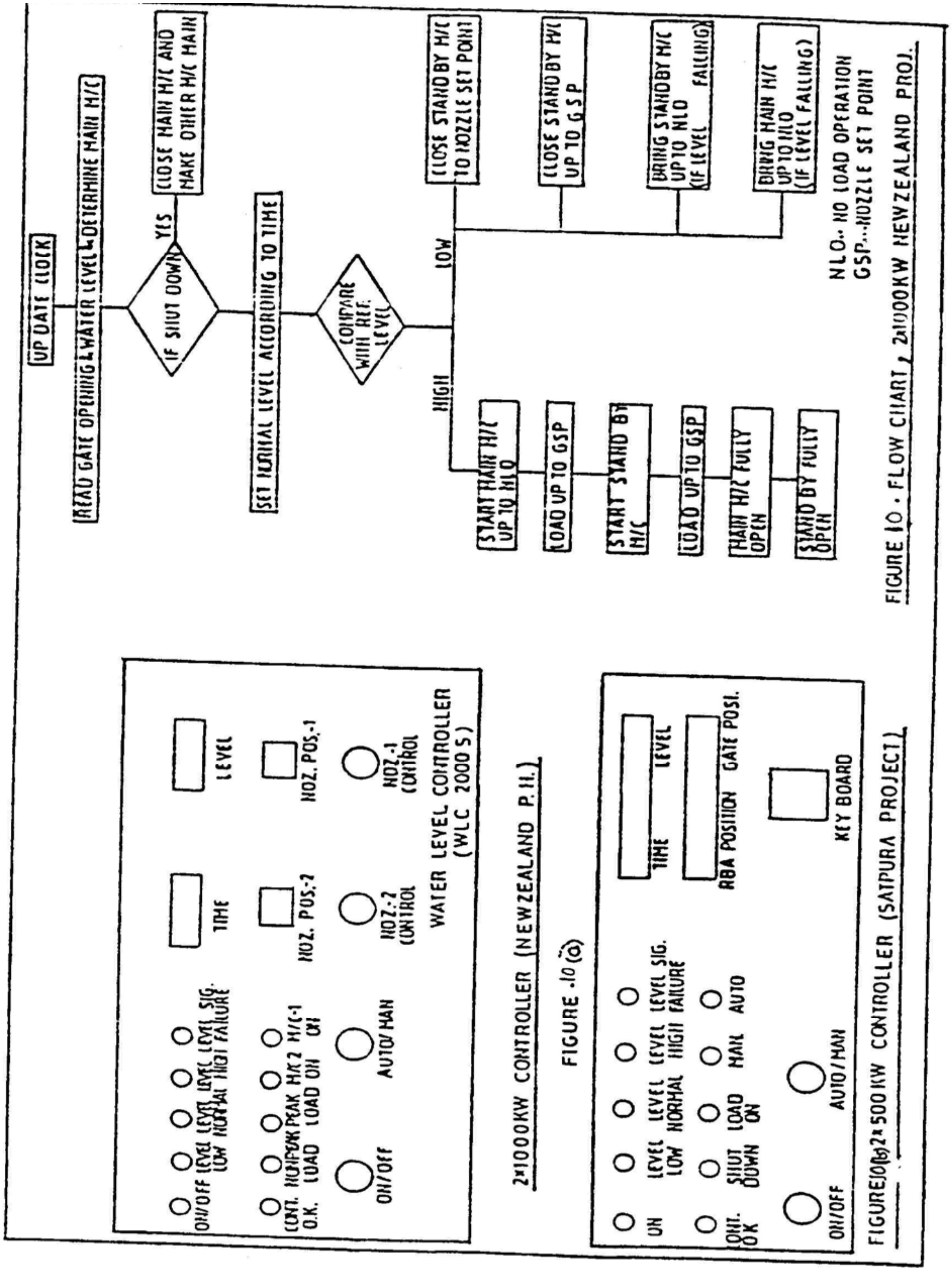


Fig. 8.4- Water Level Controllers

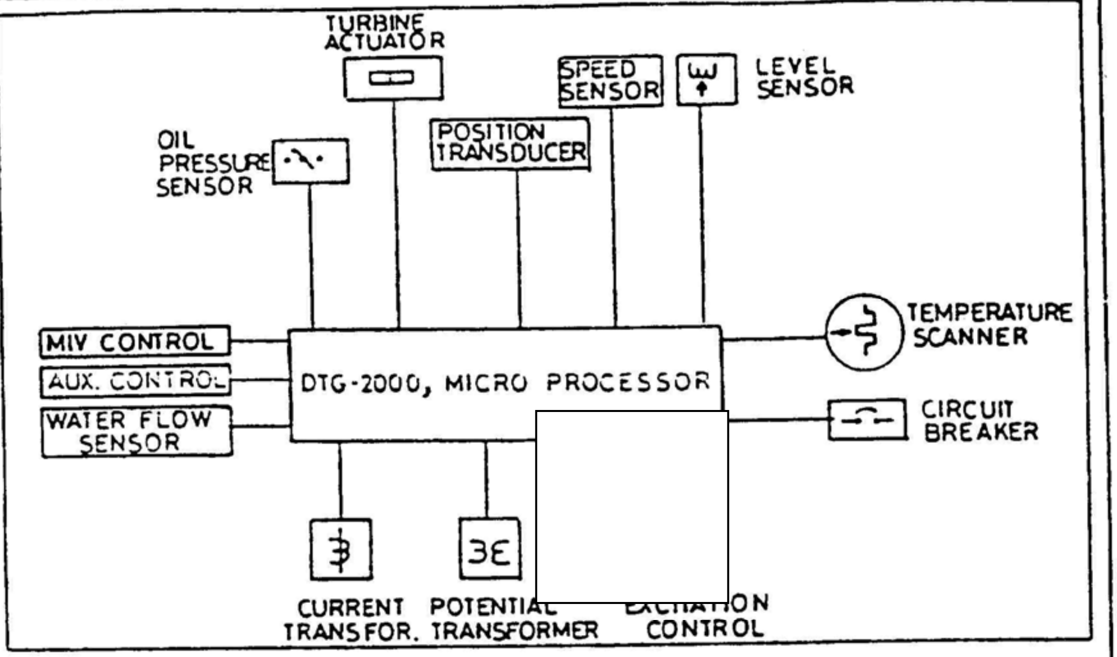
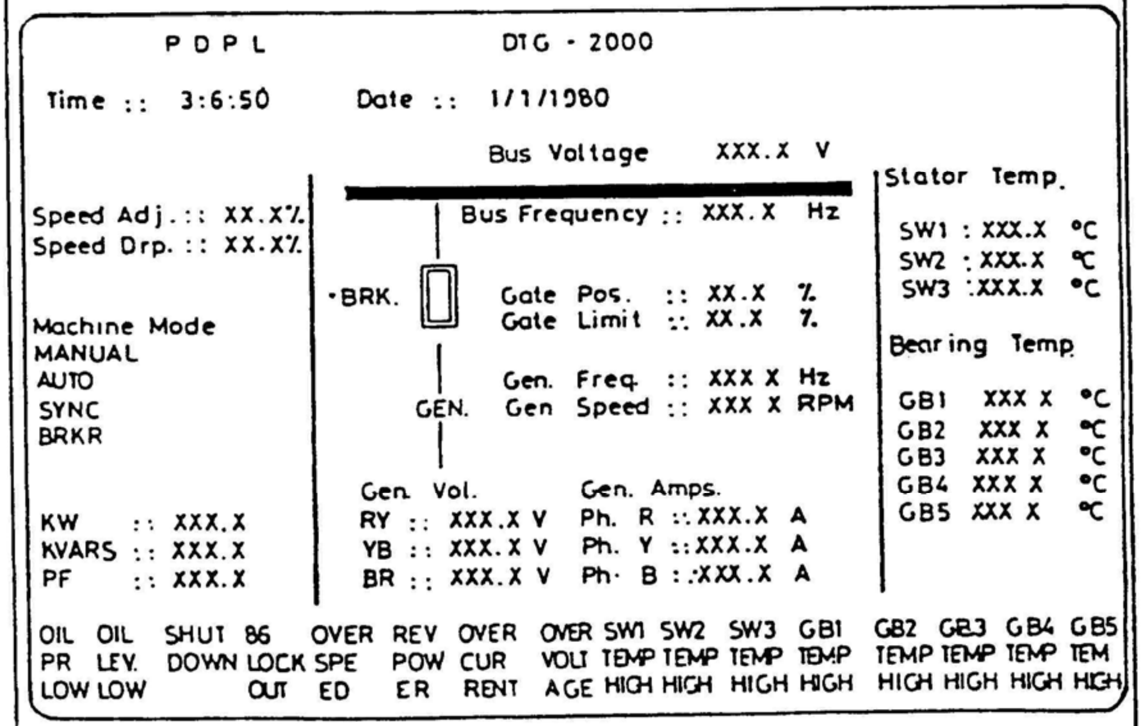


FIGURE 11



P D P L

DTG - 2000

Time :: 3:6:50

Date :: 1/1/1980

Bus Voltage XXX.X V

Stator Temp.

SW1 : XXX.X °C
SW2 : XXX.X °C
SW3 : XXX.X °C

Bearing Temp.

GB1 XXX X °C
GB2 XXX X °C
GB3 XXX X °C
GB4 XXX X °C
GB5 XXX X °C

Speed Adj. :: XX.X%
Speed Drp. :: XX.X%

Bus Frequency :: XXX.X Hz

Gate Pos. :: XX.X %
Gate Limit :: XX.X %

Gen. Freq. :: XXX X Hz
Gen Speed :: XXX X RPM

Machine Mode
MANUAL
AUTO
SYNC
BRKR

KW :: XXX.X
KVARS :: XXX.X
PF :: XXX.X

Gen. Vol.
RY :: XXX.X V
YB :: XXX.X V
BR :: XXX.X V

Gen. Amps.
Ph. R :: XXX.X A
Ph. Y :: XXX.X A
Ph. B :: XXX.X A

OIL PR LOW	OIL LEV. LOW	SHUT DOWN	86 LOCK OUT	OVER SPE ED	REV POW ER	OVER CUR RENT	OVER VOLT AGE	SW1 TEMP HIGH	SW2 TEMP HIGH	SW3 TEMP HIGH	GB1 TEMP HIGH	GB2 TEMP HIGH	GB3 TEMP HIGH	GB4 TEMP HIGH	GB5 TEM HIGH

JRE 12

Fig. 8.5 (a) PC Base Sobla Projects Governing System with Plant Control

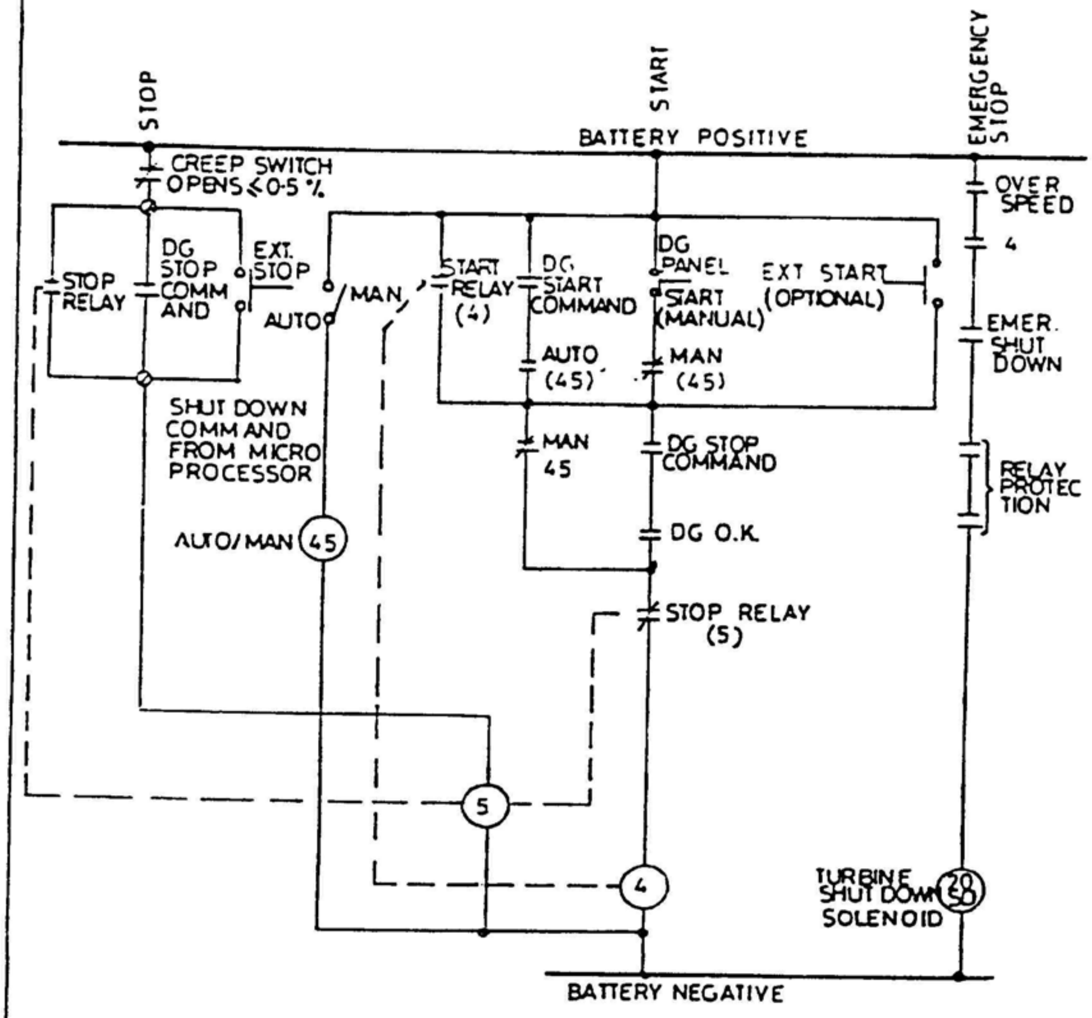
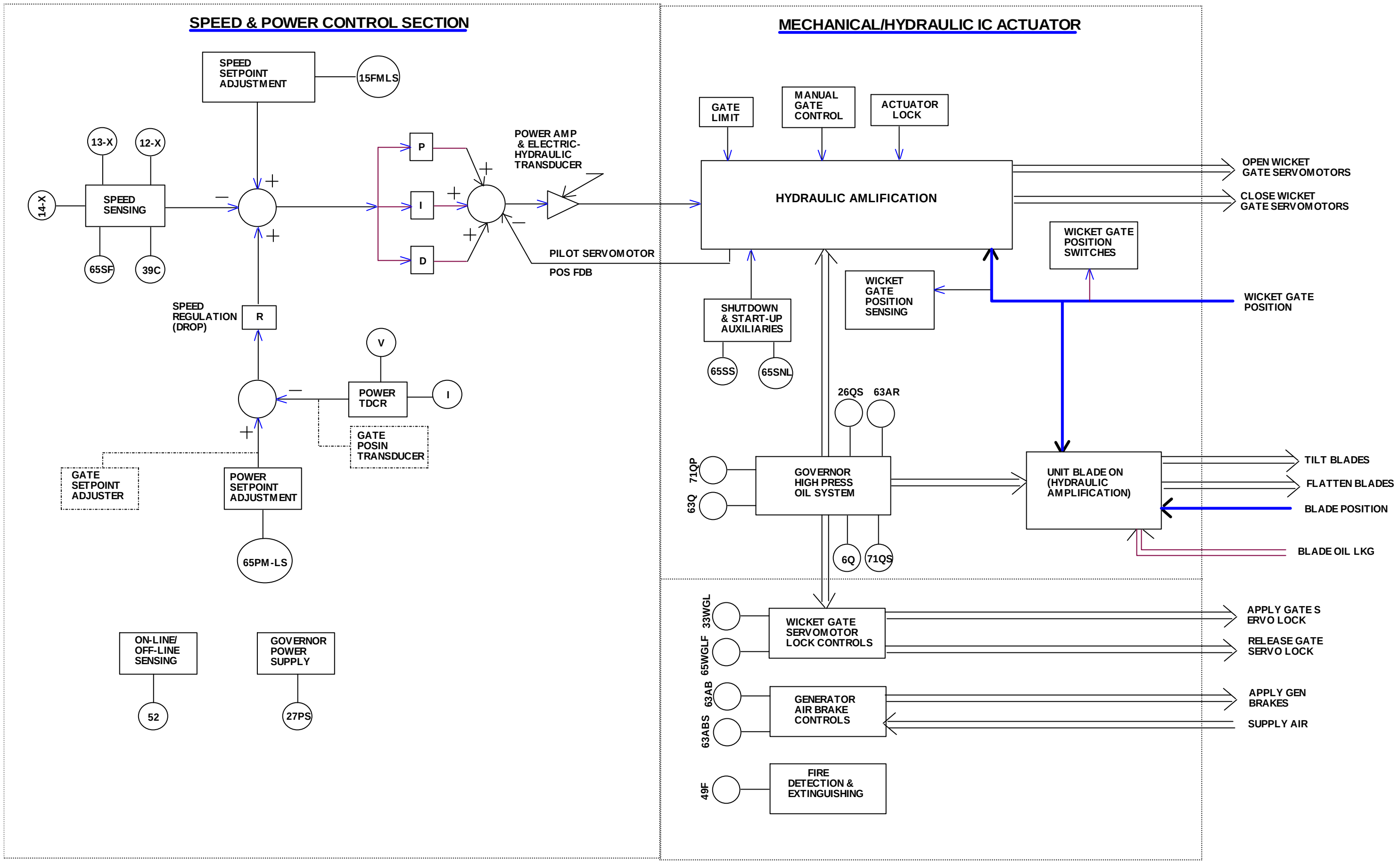


FIG. 13- START STOP SIMPLIFIED SCHEMATIC

Fig. 8.5 (b)



LEGEND

12-X 13-X 14-X	OVERSPEED,SYNCHRONOUS SPEED, AND UNDERSPEED SWITCHES
65SF	SPEED SIGNAL FAILURE
39C	CREEP DETECTOR OPERATION
15FM-LS	SPEED REFERENCE MOTOR DRIVE LIMIT SWITCHES
65PM-LS	POWER REFERENCE INDICATION
52	UNIT ON-LINE
27PS	GOVERNOR POWER SUPPLY FAILURE
65SS	START-STOP SOLEMOID AUXILIARY CONTACTS COMPLETE SHUTDOWN
65SNL	PARTIAL SHUTDOWN (SPEED-NO-LOAD) SOLENOID AUXILIARY CONTACTS
26QS	GOVERNOR HYDRAULIC SYSTEM SUMP TANK FLUID TEMPERATURE HIGH
63Q	GOVERNOR HYDRAULIC SYSTEM PRESSURE SWITCHES
71QP	GOVERNOR HYDRAULIC SYSTEM PRESSURE TANK LEVEL SWITCHES
71QS	GOVERNOR HYDRAULIC SYSTEM SUMP TANK LEVEL SWITCHES
63AR	GOVERNOR HYDRAULIC SYSTEM AIR RELIEF VALVE OPERATION
33WGL	WICKET GATE AUTOMATIC LOCK APPLIED/RELEASED
65WGLF	WICKET GATE AUTOMATIC LOCK FAILURE
63AB	GENERATOR AIR BRAKES APPLIED
63ABS	GENERATOR AIR BRAKE SUPPLY PRESSURE LOW
49F	FIRE DETECTION SYSTEM OPERATION/TROUBLE

Fig. 8.6 Electric Hydraulic Turbine Governor Control & Monitoring System (Mukerian Stage-II canal fall project 2 x 9 MW Bulb turbine)

Annexure-1

Indian Project Data

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

Sl. No.	POWER STATION	CUSTOMER	NO. OF UNITS× SIZE(MW)	HEAD (M)	SPEED (RPM)	YEAR OF COMM'ING	SPECIFIC SPEED (Ns)	TYPE OF TURBINE	REMARK
1.	Parbati Stage-II	NHPC	4×200	789.0	375.0	2006	48.57	Generating Sets with Pelton Turbine	
2.	Varahi	KPCL	2×115	460.0	250.0	1989	48.20		
3.	Sharavathy	KPCL	2×89.1	439.5	300.0	1976	56.55		
4.	Chukha	Chukha project Authority, Bhutan	4×84	435.0	300.0	1986	53.00		
5.	Tillari	GOM	1×60	628.8	500.0	1986	47.11		
6.	Bihai	Taiwan Power Co. Taiwan	1×62.5	416.8	495.0	2005	79.58		
7.	Kuttiyadi AES	KSEB	2×50	625.0	500.0	2005	43.33		
8.	Pykara Ultimate	TNEB	3×50	1027.0	600.0	2005	27.95		
9.	Malana	MPCL	2×43	480.0	500.0	2001	55.89		
10.	Lower Sungai piah	National Electricity Board, Malaysia	2×27.68	400.0	428.6	1993	48.28		
11.	Bassi	HPSEB	4×15	335.7	500.0	1970	51.61		
12.	Khandong	NEEPCO	2×25	99.0	333.3	1984	204.37	Generating Sets with Francis Turbine	
13.	Kakkad	KSEB	2×25	123.5	428.6	1999	199.34		
14.	Mahi Stage-I	RSEB	2×25	40.0	150.0	1986	285.53		
15.	Doyang	NEEPCO	3×25	67.0	250.0	2000	249.74		
16.	Khara	UPSEB	3×24	42.6	187.0	1992	322.37		
17.	Pattani	EGA Thailand	3×24	58.0	214.3	1981	251.19		Turbine only
18.	Tenom Pangi	SEB Malaysia	3×22	66.6	300.0	1983	283.24		
19.	Kundah-V	TNEB	1×21.6	259.1	750.0	1988	128.42		
20.	Madhikheda	MPEB	3×20	52.75	250.0	2005	301.19		
21.	Rangit	NHPC	3×20	129.67	428.6	2000	167.76		
22.	Birsinghpur	MPEB	1×20	40.0	200.0	1991	340.51		
23.	Poringal Kuthu	KSEB	1×16	165.3	600.0	1999	155.07		
24.	Bhatsa	GOM	1×15	70.0	375.0	1991	274.71		
25.	Sumbal Sindh	Govt. of J&K	2×11.3	149.0	500.0	1973	123.65		
26.	Gumma	HPSEB	2×1.5	176.75	1500.0	2000	109.17		
27.	Karnah	Govt. of J&K	2×1.0	36.0	750.0	1991	325.72		
28.	Balimela Dam	APSEB	2×30	35.8	187.5	2008	449.13	Generating sets with Kaplan Turbine	
29.	Donkarai	APSEB	1×25	21.0	136.4	1983	580.99		
30.	Mukerian Phase-III & IV	PSEB	6×19.5	22.0	166.7	1989	591.68		
31.	SYL Phase-I	PSEB	2×18	15.3	136.4	2010	732.41		Likely Year of Comm'ing
32.	UBDC Stage-II	PSEB	3×15	17.1	166.7	1989	711.05		
33.	UBDC	PSEB	3×15	17.1	150.0	1971	639.82		
34.	Mukerian Phase-I & II	PSEB	6×15	16.8	150.0	1983	654.13		

35.	Bansagar Phase-II	MPEB	2×15	21.0	166.7	2002	550.01		
36.	Kabini	SP&ML	2×10	18.0	200.0	2003	653.29		
37.	Pochampad	APSEB	3×9	21.4	250.0	1987	624.04	Generating sets with Kaplan Turbine	
38.	Mukerian Stage-II	PSEB	2×9	8.23	125.0	2006	1030.26		
39.	Singur	APSEB	2×7.5	18.29	250.0	1999	693.22		
40.	Teesta Canal	WBSEB	4×7.5	8.0	142.9	1999	1113.95		
41.	Bhadra R.B.	KPCL	1×6	17.0	214.0	1998	581.56		
42.	Narayanpur	MPCL	2×5.8	6.5	111.1	1999	987.31		
43.	Suratgarh	RSEB	2×2	8.66	187.5	1992	683.57		
44.	Mangrol	RSEB	3×2	7.27	166.7	1992	756.31		
45.	Sone Western Canal	BSHPC	4×1.65	3.7	120.0	1993	1150.37		
46.	Dhupdal	FORBES Gokak Mills	2×1.4	4.8	158.0	1997	1107.71		
47.	Nidampur	PSEB	2×0.5	3.0	136.4	1985	935.54		
48.	Dauhar	PSEB	3×0.5	3.5	136.4	1987	771.58		
49.	Ganekal	KPCL	1×0.35	3.69	136.4	1994	604.27		
50.	Kakatiya (19th Mile)	APSEB	3×0.23	3.3	166.7	1987	688.37		
51.	Kakroi	University of Roorkee	1×0.1	1.9	125.0	1988	678.63		

Source: Project Design by Alternate Hydro Energy Centre (AHEC), I.I.T. Roorkee

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.	Triveni SHP	Jyoti Ltd.	2x1.500	4.94	155		1056.76	Horizontal Kaplan	Synchronous Generator Vertical
2.	Nasarganj SHP	VA Tech.	2x0.500	3.99	166.66	28.06.2007	759.25	Vertical Semi Kaplan	Synchronous Generator Vertical
3.	Jainagra SHP	VA Tech.	2x0.500	4.18	187.5		783.78	Vertical Semi Kaplan	Synchronous Generator Vertical
4.	Sebari SHP	HPP Energy (India) Pvt. Ltd.	2x0.500	3.66	150		745.96	Vertical Semi Kaplan	Synchronous Generator Vertical
5.	Shirkhinda SHP	HPP Energy (India) Pvt. Ltd.	2x0.350	3.186	135		744.89	Vertical Semi Kaplan with Syphon Intake	Synchronous Generator Vertical
6.	Belsar SHP	HPP Energy (India) Pvt. Ltd.	2x0.500	3.22	129		763.22	Vertical Semi Kaplan with Syphon Intake	Synchronous Generator Vertical
7.	Tejpura SHP	HPP Energy (India) Pvt. Ltd.	2x0.750	3.46	107		770.77	Vertical Semi Kaplan with Syphon	Synchronous Generator Vertical

								Intake	
8.	Rajapur SHP	HPP Energy (India) Pvt. Ltd.	2x0.350	4.78	190		798.55	Vertical Semi Kaplan with Intake Gate	Synchronous Generator Vertical
9.	Amethi SHP	HPP Energy (India) Pvt. Ltd.	1x0.500	3.218	114		745.97	Vertical Semi Kaplan with Syphon Intake	Synchronous Generator Vertical
10.	Arwal SHP	HPP Energy (India) Pvt. Ltd.	1x0.500	2.926	103		757.83	Vertical Semi Kaplan with Syphon Intake	Synchronous Generator Vertical
11.	Walidad SHP	HPP Energy (India) Pvt. Ltd.	1x0.700	3.44	116		751.36	Vertical Semi Kaplan with Syphon Intake	Synchronous Generator Vertical
12.	Paharma SHP	City Hunan of China	2x0.500	3.36	166.7		1009.00	Fixed Blade Tubular Turbine	Synchronous Generator Horizontal
UTTARAKHAND									
13.	Dokti	Nepal Hydro & Electric Pvt. Ltd.	1x0.02	62.0	1575			Cross Flow	Synchronous Generator Horizontal, Kirloskar
14.	Kanolgod	Nepal Hydro & Electric Pvt. Ltd.	2x0.05	24.5	990			Cross Flow	Synchronous Generator Horizontal, Kirloskar
15.	Karmi-II	Nepal Hydro & Electric Pvt. Ltd.	2x0.025	70	1673			Cross Flow	Synchronous Generator Horizontal, Kirloskar
16.	Ramgarh	Jyoti Ltd.	2x0.05	50	750			Cross Flow	Horizontal Jyoti Ltd.
17.	Ratmoli	Nepal Hydro & Electric Pvt. Ltd.	2x0.025	39	1250			Cross Flow	Synchronous Generator Horizontal, Kirloskar
18.	Gangotri-I	Vodini Check Republic	2x0.050	23.6	836			Cross Flow	AVK
ARUNACHAL PRADESH									
19.	Kitpi-II	Guglor Hydro Energy gmbh	2x1.5	200	600			Pelton 2 Jet Horizontal	Synchronous Generator Horizontal

Anexure-2

List of the Cross Flow Turbines Tested at AHEC, IIT Roorkee for UREDA

S.No.	Name of Manufacturer/ Supplier	Type of water mill	Type of runner	Runner dia (mm)	Range of Testing Parameters			Maximum Efficiency	Remarks
					Head range (m)	Discharge rage (lps)	Power output (kW)		
1.	M/s Gita Flopumps India Pvt. Ltd., Saharanpur (U.P.)	Horizontal shaft	Cross flow	300	9.0-12.0	28-125	0.6-8.4	56.00	Accepted
2.	M/s Standard Electronic Instruments Corpn., Roorkee (UA)	Horizontal shaft	Cross flow (open type)	300	3.0-14.0	76-135	0.5-8.5	53.00	Accepted
3.	M/s SBA Hydro Systems (Pvt) Ltd. New Delhi	Horizontal shaft	Cross flow	300	4.0-12.0	80-132	1.1-6.6	54.00	Accepted
4.	M/s Gopal Engineering Works, Dharanaula, Almora (UA)	Horizontal shaft	Cross flow	300	3.0-8.0	75-117	2.5-9.0	55.00	Accepted

Average efficiency = 54.50

Annexure-3

List of points showing in Fig. 5.3 (Indian Projects)

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 (ThroughNHPC)	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 hoarse power units.

Annexure-4.1

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	–	–	–	–

Annexure – 4.2

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		

Annexure – 4.3

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

Annexure – 4.4

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		

Annexure–4.5

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

Annexure–4.6

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

Annexure-4.7

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

Annexure–4.8

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

Annexure – 4.9

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

Annexure-4.10

Jyoti – Standard Francis

Runner dia. (mm)	**350**	**425**	**500**	**650**	**800**	**1000**
Head (m)	**Turbine Output in Kilowatts**					
10	25	35	95	160	245	385
20	70	105	270	457	695	1085
30	130	190	495	840	1270	1990
40	200	290	560	955	1450	2265
50	270	400	640	1080	1950	2530
60	360	550	840	1415	2560	4000
70	460	675	940	1580	2400	3750
80	550	825	1150	1930	2900	4530
90	670	985	1370	2300	3485	5445
100	785	1150	1600	2700	4090	6390
110	690	1015	1410	2380	3605	-
120	-	1150	1600	2710	4105	-
130	-	1300	1810	3060	4635	-
140	-	1455	2025	3465	5245	-
150	-	1615	2250	3800	5760	-
160	-	1780	2475	4180	6335	-
170	-	1950	2700	4565	-	-

Annexure-4.11

Jyoti – Standard Pelton Turbines

Runner dia. (mm)	300	425	600	750	900	1100
Head (m)	**Turbine Output in Kilowatts**					
100	20	40	90	120	190	275
110	25	50	105	140	215	320
120	30	55	120	160	250	366
130	32	60	130	180	285	410
140	35	70	150	205	320	465
150	40	80	165	225	355	515
160	45	85	180	245	390	570
170	50	95	200	270	435	625
180	55	100	215	295	460	675
190	60	110	235	325	510	740
200	-	120	255	345	550	790
225	-	140	300	415	645	940
250	-	165	355	485	760	1100
275	-	190	410	560	880	1275
300	-	215	465	635	1005	1450
325	-	245	525	715	1125	1635
350	-	275	585	800	1255	1825
375	-	305	650	890	1395	2030
400	-	-	-	975	1535	2235
425	-	-	-	1080	1695	2465
450	-	-	-	1165	1830	2660

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

Annexure–4.12

Jyoti – Standard Turgo Impulse Turbine

Runner dia. (mm)	**225**	**275**	**350**	**425**	**450**	**525**	**600**	**675**	**750**
Head (m)	**Turbine Output in Kilowatt**								
40	17	26	41	61	68	100	131	168	207
50	23	35	57	86	96	140	184	233	290
60	31	48	75	113	126	185	241	308	382
70	40	62	94	141	158	232	304	388	481
80	47	73	115	174	195	284	373	473	587
90	56	87	137	207	232	338	444	564	702
100	-	109	161	242	271	397	521	622	822
110	-	126	186	279	312	458	601	764	948
120	-	144	212	319	357	521	684	868	1078
130	-	161	239	359	402	589	772	982	1217
140	-	180	267	404	450	658	862	1097	1360
150	-	-	295	446	500	727	956	1212	1509
160	-	-	325	491	549	801	1053	1336	1636
170	-	-	356	537	602	878	1152	1465	1822
180	-	-	388	585	655	957	1255	1596	1986
190	-	-	421	635	711	1038	1367	1731	2153
200	-	-	455	687	770	1126	1475	1879	2327

Annexure-4.13

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

Annexure-5

Power Generation Equipment Special Requirement

	Description	**Category (Installed Capacity in kW)**		
		Category A (Upto 10 kW)	**Category B (Above10kW and upto 50 kW)**	**Category C (Above 50 kW and upto 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)	Upto 10 kW	(Above10kw and upto 50 kW**) as specified**	**(**Above 50 kW **and upto 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		
Overall Efficiency	Minimum required Weighted Average Efficiency of the turbine Generator set $(\eta T\ Av)$ $0.50 \times \eta T_{100}+0.50\ \eta T_{50}$	45%	50%	60%