13.1 Introduction

Large potential of energy remains untapped in our flowing streams, river slopes, canal falls in the vast canal irrigation system and small irrigation and water supply dams. This energy available near rural consumption centre can meet significant energy needs of the country. Injected in existing grids these plants tend to stabilize local distribution grids and reduce energy losses. Isolated systems in far-flung inaccessible areas, are the cheapest alternative source of energy. Bulk of this power is in low and ultra low head (below 3 meter range). Major constraints in exploiting this energy as small hydro-electric power is high capital costs, equipment availability; high cost of controls and management and low load factor.

Technology development is required for exploiting low head energy available in these canals falls, velocity head etc. Non conventional low head hydraulic equipment available or under development throughout the world for economic development of technically feasible and economically viable low and ultra low head system were examined for installation at Kakrooi projects under Indo-US collaborative small hydro research project and Ralla canal SHP and velocity head project sponsored by Punjab Government in Alternate Hydro Energy Centre. Equipment and system options available were studied. Installation at Kakrooi fall ultra low head scheme is discussed. A large number of economically viable canal fall projects were subsequently taken in hand. Type of equipment installed is summarized. Velocity head energy has so far not been utilized.

Cost reduction by standardization was adopted for successful installation of mini hydro schemes under UNDP World Bank project entitled ESMAP Energy sector management assistance programme on canal drops and irrigation dams. A large number of mini hydro schemes were installed and are in successful operation. Standardization for selection of turbine and generators adopted in these schemes is outlined.

13.2 Technology for Utilizing Low Head Hydropower

Technology requires cost reduction especially in civil works, reduction in construction time and possible increased efficiency of equipment and innovation in hydro turbines.

The cost of installation of hydro turbine especially in low range can be reduced to make it economically viable by adopting following methods:

i) Use of standard turbine generator.
ii) Use of pre-packaged turbine generator to reduce erection time
iii) Use of machines designed to withstand full runaway speed continuously to reduce the cost of safety devices.
iv) Decreased civil works cost by adopting the following methods:
   a) Adoption of low specific speed machine to enable higher setting above the tailrace thus reducing excavation, civil cost and erection time.
   b) Reduction in spillway capacity by using turbine in sluicing mode.
   c) Use siphon intake to eliminate intake gates and draft tube gates

Some of the hydro turbine packages which were considered for application in low head range fulfilling the condition stated above are discussed in Para 13.3.

**Speed Increaser:** The turbine can be connected through speed increaser gear box to lower generator costs. Speed increaser lowers overall plant efficiency by about one percent for a single gear increase and almost two percent for double gear increaser. Belt drive as speed increaser is cheaper than gear box. Upper limit for such an application is about 200 kW generator power.

**Regulation and Control:** Water flow control to regulate output power as per demand is not possible in schemes on irrigation works as such the schemes are grid connected and the entire power is injected the
into the grid. In case of standalone schemes synchronous generator fitted with electronic load controllers are used.

13.3 Hydro Turbine for Low Head

Hydro Turbine for ultra low head: Available operating head has a significant effect on the physical size and cost of hydraulic turbines. This is due to the fact that the volume of water needed to produce a specified amount of power varies inversely with the head. Following turbine options in ultra low head range as commercially available or under development in USA and other countries at the time (1982-88) were examined for feasible installation at Kakroi Fall National Demonstration Project (1.9 m head) and other projects under reference.

i) Axial Flow Propeller Turbine
ii) Cross flow turbine
iii) Schneider engine
iv) Marine thruster turbine
v) Pump Used As Turbine (PAT)
vi) AUR and STO

13.3.1 Axial Flow Turbines (Propeller Turbines)

These high efficiency turbines are generally discussed in chapter 3 (Para 3.3.2). Applications of these turbines for very low head installations are governed by following considerations.

For a low head machine, it is a general practice in India to use Horizontal `S’ Tubular Turbine due to easy maintenance and better efficiency for low head installation. This choice is limited for runner dia. up to 3 meters. For a runner dia. above 3 meters Bulb type offers the most economic solution.

The tubular turbine is a slow speed machine and requires a gear box for speed increase in order to use a standard generator. Generally there is efficiency drop (1 to 2%) in the gearbox. For tubular turbine there are four options i.e. Kaplan, Semi-Kaplan. Propeller with adjustable guide vanes and Propeller fixed guide vanes type machine. In case of Propeller Type Turbine, the efficiency range of operation is limited to 80% to 120% variation in head and 75% to 115% variation in discharge. Kaplan Turbine has adjustable runner blades and guide vanes. In order to accommodate the runner blade adjustable mechanism in the runner hub, the size of runner should be large enough. The turbine is best suited where there is wide variation in head and/or discharge and its efficiency over a wide range of partial load is very good. Butterfly valve (BFV) for shut off purpose is not required in this type of turbine, as the guide vanes themselves will close the turbine. The cost of this type of turbine is high. Semi-Kaplan turbine has fixed guide vanes and adjustable runner blades. The necessity of large dia runner to accommodate mechanism for adjustable runner blade remains the same as for Kaplan turbine. Butterfly valve is required for shut off purposes. This type of turbine is less complicated than full Kaplan turbine. The efficiency range of operation is limited compared to the full Kaplan turbine. The cost of butterfly valve is however, considerable with the result that the overall cost of the machine sometimes becomes as high as that of Kaplan turbine which is more efficient over a wide range of operation than Semi-Kaplan turbine.

13.3.1.1 Standard Tubular Turbines

Standardization of turbines is the major effort towards cost reduction. Standard Tubular Turbines are available equipped with fixed or variable pitch runner blades and with or without wicket gate assemblies. A fixed blade runner without wicket gate assemblies properly chosen for performance is likely to give economic installation. Such an installation may not regulate turbine discharge and power output. This results in a lower cost of both the turbine and governing system. To estimate 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. All tube turbines are equipped with inlet valves/drop gates for shut off and start up functions. Generator and turbine moving parts should be designed for runaway speed. The required civil features are different for horizontal units than for vertical mounted open flume units. Standard tubular turbines made by M/s BHEL of India for low head installations are shown in figure 3.5 Standard tube turbines by other Indian manufacturers is also discussed in chapter 3 Para 3.7.2.
Various type of low head axial flow turbines by M/s Voest Alpine of Austria one of the premier manufacturer in Europe is given below.

### Various Arrangements of Axial flow Type units (Voest Alpine)

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Type of unit</th>
<th>Output (kW)</th>
<th>Head (m)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Splitter semi-split</td>
<td>50-200</td>
<td>1 – 8</td>
<td>Installed in Kakroi demonstration project Figure 13.1</td>
</tr>
<tr>
<td>2.</td>
<td>Open or closed flume</td>
<td>150 – 1000</td>
<td>2 – 10</td>
<td>Figure 13.2</td>
</tr>
<tr>
<td>3.</td>
<td>Horizontal tubular type</td>
<td>150 – 1000</td>
<td>2 – 25</td>
<td>Standard configuration</td>
</tr>
<tr>
<td>4.</td>
<td>Inclined type</td>
<td>150 – 1000</td>
<td>3 - 25</td>
<td>Fig. 13.3</td>
</tr>
</tbody>
</table>

Outputs for the types listed under 1 thru 4 are stated according to requirement. Actually the outputs under 3 to 4 could be increased up to 10000 kW.

Besides the above listed basic arrangement other features like, directly coupled vs speed increaser vs belt drive (split-type only), 3-4-5 or 6 blade runner, double regulated, single regulated (runner blades or wicket gates) play an important role in the general technical concept.

Which one of the possible basic arrangements is to be employed in the overlapping head ranges) depends largely on the operation and maintenance requirements, topography of the construction site, fluctuation in head water level and /or tail water level.

![Figure 13.1: Splitter Semi Split](image)

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Figure 13.2: Open or Close Flume

Figure 13.3: Inclined
Figure 13.4: Vertical Semi Kaplan with Syphon Intake
Vertical Semi Kaplan Turbine with Siphon Intake

Vertical semi-Kaplan turbine with Siphon intake with adjustable runner blade and fixed guide vane is being very frequently used. Moveable runner blade is controlled by a hydraulic servomotor. The runner blades are adjusted to accommodate the variation in flow of water through the turbine and consequent control of load on the machine. This is achieved by movement of piston of runner servomotor. This also eliminates provision of intake/draft tube gates. By adopting proper control of opening of runner blades the load on the machine will be adjusted such that the level of water in the upstream of the fall will remain undisturbed. In this case also a gearbox is used between the turbine and generator for using standard generator and in this case also the efficiency comes down by 1 to 2% due to gearbox. In this case the investment cost is also less as the cost of machine as well as the cost of civil works in construction of power station is less. As the name suggests, the Vertical Turbine with Siphon Intake operation on the Siphon Principle i.e. the intake flume chamber valve is closed and made water tight and vacuum is created by a pump which enables water to enter flume chamber and energise the runner. When the machine reaches synchronous speed this is synchronised with the grid like any conventional turbine. Shut down is brought about by following the reverse procedure i.e. by breaking vacuum. Since turbine operates on a Siphon Principle, it is not necessary to have Intake and Draft gates thereby reducing the cost. The drawing shown in Figure 13.4 fully explain how the machine operation is started by creating Siphon Intake and figure 3.7 shown a typical installation.

1. The Siphon Intake semi Kaplan Vertical Turbine runs at 30% minimum load without the problem of cavitation. Its efficiency at this minimum load goes down to about 76% only.

2. This type of turbine is suitable for variable head also. This type of turbine was not considered for Kakroi project as it was under development by M/s HPP France.

ESSEX Bulb Turbine

Essex bulb turbine package unit was developed by M/s ESSEX turbine USA. The standard power module consists of an axial flow turbine, planetary speed increaser, and generator in a short cast-iron pipe section. The unit can be mounted fully submerged and without the need for a conventional powerhouse. The turbine parameters are given below. This was not considered being still in experimental stage.

\[\begin{align*}
Q &= 4.44 \text{ m}^3/\text{s} \\
H &= 2.16 \text{ m} \\
n &= 144 \text{ rpm} \\
\text{Efficiency} &= 88.5\%
\end{align*}\]

Cross Flow Turbine

Cross flow turbines are free from cavitation but are susceptible to wear when excessive silt or sand particles are in the water. Runners are self cleaning and in general maintenance is less complex than for the other types of turbines. Floor space requirements are more than for the other types of turbines but a less complex structure is required and hence less costly.

Peak efficiency of the cross flow (Osberger) turbine is 85%. At the present time, the largest size runner produced by cross flow is 600 mm in diameter. This limits the unit capacity but multi unit installation can be used. Allowable head range is from 1 to 200 m. osberger turbine Fabris Co. Germany offers this type of turbine under the name ‘Osberger Turbine’. Maximum unit capacity at 2 m head is about 50 kW and this limits its use in ultra low head range. Efficiency of indigenous (figure 3.10 (a) & (b) turbines is about 60 – 65% and hence was not recommended.

Schneider Engine: The Schneider engine is a new turbine type utilizing translating hydro foils attached to flexible link chains which transform the motion of the foils across the flow passage into rotary, shaft motion. Hydro engines work at head as low s 0.5 m. with the output from a few kW to 700 kW at 3 meter head. The efficiency of these engines was reported as 86%. These were developed by Schneider Engine Company, Justin, Texas, USA and their subsidiary in South Korea. A prototype 170 kW plant was installed on canal drop in 1983-84 in USA. Initial defects noted are still to be rectified in US prototype. Rectified
unit made for Kakroi failed to deliver contracted power and efficiency on witness testing in Korea and order was cancelled.

13.3.4 Marine Thruster: Low cost ultra low head hydro plants by using ship thrusters for turbines were developed by Energy Research & Applications (ER & A) of Santa Monica, California. A prototype installation on a canal fall in California indicated turbine efficiency of 60% reportedly due to high head losses in civil works (inlet structure, draft tube etc.). Later installation claimed better efficiency. The packages are applicable at head range from 2 meters to 5 meters approximately with a minimum flow requirement of 35 c. f. s. for smallest unit. Power output of the unit varies 25 kW to 465 kW for largest. Not recommended due to low efficiency.

13.3.6 AUR and STO Engines

These are U.K. patented devices for ultra low head power generation. In AUR energy is extracted from water by vertical displacement of floats within chambers. Unit size is about 10 – 15 kW and efficiency of about 45%.

In Salford Transverse Oscillator (STO) oscillatory motion of rod is produced by water thrust in a number of cells. The movement is converted to usable power by means of hydraulic system. STO works equally well when direction of water flow is reversed and hence suitable for tidal applications. Efficiency of an STO engine was reported as 35%. Installation costs are low. Not recommended due to low efficiency.

13.4 Velocity Head Turbines

Large kinetic energy is available in our flowing rivers and lined canals. Kinetic energy of these flowing streams can be tapped and converted into electricity by suitably designed turbines. It is considered that 10% of this kinetics energy in a river/canal can be extracted and at good sites arrays of such system may be generate about 1 – 2 MW of power per km. In lined canal we may extract about 600 to 1000 kW per km of canal. This power available near rural consumption centres can thus contribute in a substantial fashion to solve our rural energy problems.

These non-conventional water turbines, which convert kinetic energy of the flowing stream into mechanical energy and subsequently into electrical energy can be named as ‘velocity turbines’ or ‘No Head Turbines’. These run-of-the river turbine units will generally operate on the equipment of less than 0.12 m of head, and in a river or canal with a reasonable current resource the units are estimated to produce cost effective electricity as per system concepts developed by Aero Vironment, Inc. of Pasadena, CA USA.

Two systems concepts developed in USA were considered for adoption in India.

i) Ducted turbine system (figure 13.5): The ducted turbine system consists of an augmenter duct, a rotor with two cantilevered blades, a nacelle containing gear box and electrical generating equipment, a rigid mooring system and an electrical transmission system. The augmenter duct increases the volume through the turbine rotor thus enhancing cost effectiveness and minimizing the runner rotor diameter required for a given resource and rated power.

ii) Free rotor system (Figure 13.6): The free rotor turbine has no augmenter duct and the rotor blades are larger than those for ducted system. Internal features are similar to those of ducted rotor system. The free rotor system is essentially an underwater wind mill and offers the potential for simplicity and lower system costs.

Both ducted and free rotor turbine systems may produce cost effective electricity. The 3 m ducted unit may produce 20 kW for a current speed of 2.2 meter/sec. with an installed system cost of approximately Rs. 3.00 Lacs. The 3 m free rotor turbine may be rated 15 kW for a current speed of approximately 4 m/sec. A proto type of free rotor system for installation on a lined canal in Punjab was made but not installed.
13.5 Kakroi Canal Fall Project

A 1.6 m to 2.5 m fall on a canal branch at kakroi near Sonepat about 50 km from Delhi was developed as National Demonstration Project under Indo-US Collaboration Research Programme in Small Hydro to evolve suitable technology and designs for tapping this abundant renewable energy resources. Kakroi fall is on Western Yamuna canal (Delhi Branch). The canal is to meet demand of drinking water to Delhi, Gurgaon and irrigation requirements in the downstream reaches. The canal was being remodeling to increase capacity.

Power potential of the scheme, layout of works, different governor less units available at that time installed, different type of devices for shut off, synchronizing and full load operation in grid installed to make the scheme economical viable is brought out and discussed.
13.5.1 Power Potential

The design discharge of the upstream (to include local irrigation needs) and downstream sections of the fall was to be 58.67 cumecs \( \text{m}^3/\text{s} \) (2072 cusecs) and 52.35 \( \text{m}^3/\text{s} \) (1849 cusecs) after remodeling. The discharge varies from 300 cusecs minimum for drinking water to 52.35 cub m/s (1849 cusecs). The head available during various stages of discharge is shown in figure 13.7.

It may be noted that head on the turbine is dependent on the downstream side level of the canal which increases as the discharge increases. The upstream side level can be maintained at full supply level. The power potential at the site was of the order of 200 – 470 kW. Therefore, provision was made for an ultimate installation of 400 kW capacity. In the first phase, 3 units of 100 kW capacity were installed. In the second phase, when additional discharge in the canal is available with a higher duration, the fourth unit of 100 kW capacity was proposed to be installed.

(FSL- Full Water Supply Level)

Figure 13.7: Stage Discharge Curve

13.5.2 General Arrangement

The powerhouse was constructed on bypass channel to the canal so that regular operation on the canal is not disturbed. The general arrangement of works is shown in figure 13.8 & figure 13.9.

13.5.3 Bypass Channel

The bypass channel was designed for a maximum discharge of 31.2 cumecs which is sufficient to cater to the discharge required for generation of 400 kW of electricity. Bypass channel constructed for remodeling of the main canal was used for installation of the generating units and bypass spillway.

Normally adopted radius or curvature of lined channel is 300 meters. However, to reduce the cost of channel, a radius of curvature of 60 meters was adopted. The head race channel was lined with cement concrete. The nose of the diversion channel was made of instu cement concrete to prevent damage because of sharp diversion angle adopted.
Splitter walls were provided in the expanded section of the channel to minimize flow-separation. The power station structure is located on the downstream side of the axis passing through the existing canal fall.

Figure 13.8: General Layout

Figure 13.9: General Arrangement of Powerhouse
13.5.4 Silt Remover

A single row of hoppers initially proposed in the upstream of trash racks for silt removal were subsequently removed because of expected low efficiency and high costs. Following measures for silt removal and streamline flow were installed on experimental basis.

i) Guide vanes were provided at the off-taking point for coarse silt exclusion (Figure 13.10)

ii) Iowa bed vanes were provided in the curved diversion channel to prevent the sediment deposition on the inside of bend (Figure 13.10).

iii) Splitter walls were provided in the expansion to minimize the possibility of separation of flow and thus reduce the energy loss (Figure 13.11).

Figure 13.10: Proposed Arrangement at Diversion

Figure 13.11: Splitter Walls in Expansion

13.5.5 Float Operated Byepass

Arrangement for by-passing full discharge (31.15 cumecs) in the event of emergency tripping of all four units was provided by a by-pass spillway for the stipulated discharge on the right side of the power house.
Float operated automatic radial gates were provided on the spillway to restrict upstream water level rise beyond design full supply level in such an emergency (Figure 13.12).

13.6 Electro-Mechanical Equipment

It was decided to install three different types of experimental units for low cost study and standardization. Accordingly tubular turbines without guide vanes coupled to synchronous generators and induction generators and a centrifugal axial flow pump coupled to a synchronous generator were proposed. A centrifugal axial flow pump as turbine coupled to a synchronous generator was not commercially available at that time and it was tentatively decided to install a Schneider Engine as a third unit as mentioned in Para 13.3 order was cancelled and Essex bulb turbine was ordered. Fourth unit was to be installed after increase in discharge in canal.

13.6.1 Turbine Generators

Brief technical particulars of the turbines and generators installed are given below:

<table>
<thead>
<tr>
<th>Unit No. 1</th>
<th>make</th>
<th>Voest Alpine, Austria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine type</td>
<td>Split flow with manually operated runner blade with fixed wicket gates</td>
<td></td>
</tr>
<tr>
<td>Net head</td>
<td>1.9 m</td>
<td></td>
</tr>
<tr>
<td>Turbine output</td>
<td>At net head 112 kW (100 kW after speed increaser)</td>
<td></td>
</tr>
<tr>
<td>Rated discharge</td>
<td>8.91 cumecs</td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>193</td>
<td></td>
</tr>
<tr>
<td>Runner diameter</td>
<td>1400 mm</td>
<td></td>
</tr>
<tr>
<td>Nos. of runner blades</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Nos. of fixed vanes</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Material of construction</td>
<td>Aluminum Bronze</td>
<td></td>
</tr>
<tr>
<td>Wicket gate</td>
<td>Cast cated</td>
<td></td>
</tr>
<tr>
<td>Turbine casing &amp; bearing</td>
<td>Fabricated mild steel</td>
<td></td>
</tr>
<tr>
<td>Housing</td>
<td>Cold rolled</td>
<td></td>
</tr>
<tr>
<td>Turbine shaft</td>
<td>Forged steel</td>
<td></td>
</tr>
<tr>
<td>Draft tube</td>
<td>Mild steel</td>
<td></td>
</tr>
<tr>
<td>Turbine Axis</td>
<td>10° to Horizontal</td>
<td></td>
</tr>
<tr>
<td>Generator</td>
<td>Synchronous, 140 kVA, 415 V, 3 phase, 50 Hz, 0.8 power factor</td>
<td></td>
</tr>
<tr>
<td>Generator efficiency</td>
<td>100 % full load 90.7 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>80 % full load 90.8 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60 % full load 90.6 %</td>
<td></td>
</tr>
<tr>
<td>Speed increaser</td>
<td>Belt pulley</td>
<td></td>
</tr>
</tbody>
</table>
Equipment layout is shown in drawing 13.6.1 (b) and unit at figure 13.1.

**Unit No. 2**
Make: Bharat Heavy Electricals Ltd., India
Turbine type: S-Type, Horizontal shaft
Net head: 1.9 m
Turbine output:
- At net head: 115 kW
- At 1.522 m: 82.5 kW
- At 2.50 m: 100 kW
Turbine Efficiency: At 100 % full load 87.8 %
Rated discharge: 7.03 cumecs
Speed: 125 RPM
Nos. of runner blades: 4
Runner diameter: 1500 mm
Material of construction:
- Runner blade: Cast steel bolted to cast steel hub
- Shaft: Forged steel
- Discharge ring: Carbon steel
- Draft tube: Mild steel
Generator:
- Induction, 125 kW, 425 Volts, 3 phase, 50 Hz, 0.8 pf at full load, 750 RPM, class B insulation.
- Generator Efficiency:
  - At 100 % full load: 91.6%
  - At 80 % full load: 90.5%
  - At 60 % full load: 89.0%
Speed increaser: Single stage helical

Equipment layout is shown in drawing 13.13 (a) and unit at figure 3.4.

**Unit No. 3**
Make: Essex Turbine Inc. Mangolia, Massachusatts USA
Turbine type: Axial flow – Bulb ET – 1657
Turbine output:
- At 2.5 m head: 95 kW
- At 1.9 m head: 69 kW
- At 1.52 m head: 50 kW
Turbine efficiency: At 100 % full load 88%
Discharge: 4.29 cumecs
Speed: 144 RPM
Runner diameter: 1657 mm
Nos. of runner blades: 9
Material of construction:
- Runner blade: Aluminium Bronze
- Shaft: Forged steel
- Discharge ring: Carbon steel
- Draft tube: Mild steel
Generator:
- Synchronous, 100 kW, 3 phase, 50 Hz located within the bulb
- Generator efficiency:
  - At 100% full load: 94.8 %
  - At 80% full load: 94.5 %
  - At 40% full load: 93.8 %
Speed increaser: Planetary gear
Efficiency of speed increaser: 97%

Equipment layout is shown in Drawing No. 13.14.

**13.6.2 Turbine Generating Unit – Control System**

The control philosophy is based on manual starting of the unit but stopping on emergency conditions automatically to provide fail safe operation.

The turbines were provided with conventional governing system and moveable wicket gates to effect cost reduction on equipment. Thus the units are designed to operate on constant input – constant output mode.

In view of the above approach, one intake gate was provided on each of the turbine and its operation is designed as follows.
a) **For Synchronous Generators:**

On “Start” signal being received, the gate opens to speed-no-load position. Finer control of the gate opening to achieve synchronous speed (frequency matching) can be accomplished in case of synchronous generator by inching operation of the gate or else by controlling the load on synchronous generator provided for the purpose by gate control of thyristor bridge provided. A three phase 36 kW heater is provided for the purpose. By finer adjustment of the load and gate opening, the generator is synchronized with the grid. After synchronization is done, the load switch is opened and signal is given to the intake gate to full open position. As the gate opens, the loading on the generator increases which is fed into the grid.

On ‘Stop’ signal or on faults, the master trip relay actuates the intake gate operation mechanism (dead weight) to close and also pulls out the generator from the system by tripping the generator breakers. Dead weight closing of gates is up to speed no load position as to provide Cushing effect and manual complete closing by hand.

b) **For Induction Generators:**

The induction generator unit supplied by BHEL was provided with a butterfly valve which is hydraulically operated. The butterfly valve is opened by applying oil pressure in a hydraulic servomotor. It is held in open position by oil pressure against gravity acting on the counterweight provided on the operating lever of the butterfly valve. During closing, the oil pressure is released by operation of a solenoid valve provided for the purpose into the oil sump. The closing operation is also assisted by gravitational force acting on the counterweights provided.

![Figure 13.13 (a) BHEL Turbine Unit](image)

![Figure 13.13 (b) Voest Alpine Turbine](image)
13.6.3 Intake Control Gates/valve

The intake gates used for different turbine generating units are as follows:

<table>
<thead>
<tr>
<th>Turbine – Generating Unit</th>
<th>Intake Control gate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1: Voest Alpine</td>
<td>Vertical fixed wheel gate</td>
</tr>
<tr>
<td>Unit 2: BHEL</td>
<td>Butterfly valve</td>
</tr>
<tr>
<td>Unit 3: Essex</td>
<td>Vertical fixed wheel gate</td>
</tr>
</tbody>
</table>

The butterfly valve and the vertical fixed wheel control gates are hydraulically operated for smooth operation and control.

On the unit no. 2, in addition to the control gate, another vertical fixed wheel gate was been provided as emergency gate. This gate is also a vertical fixed wheel gate. In the event of a failure of the control gate to close in case of fault/abnormal operating conditions, the emergency gate is actuated to close. The gate is electric motor operated and is held in open position by an electro-magnetic brake. In case of failure of control gate to close, an electro-magnetic clutch/electromagnetic brake will unlatch the emergency gate to close under gravity.
On the unit no. 2, a radial gate was provided at the entry into the intake tube of the turbine, upstream of the butterfly valve. The radial gate was provided to examine its suitability as a flow control device for ultra low head/low head turbines.

On bay no. 4, one vertical fixed wheel gate was provided at the upstream and was provided presently to be used as stop-log gate. No operating mechanism for this gate was been provided which could be decided when the equipment and its associated control for this bay are decided at a future date.

Generator & Feeder Protection

The following protections were provided for the turbines and generator.

- Restricted earth fault 64 REF
- Over current and earth fault 51 & 51N
- Unbalanced phase current
- Over voltage
- Under voltage
- Over speed

The speed of the generators - Voest – Alpine and BHEL units, are measured by non contact type Tachogenerator of electromagnetic probe type. An over speed relay was provided in the tachogenerator monitoring unit for causing tripping of the unit in the event of over speeding of the units.

The following protections was provided for the feeders.

Over current and earth fault 51 and 51N

13.6.4 Cost Comparison

Comparative cost of turbine generators and associated civil works at Kakroi based on quotations received and apportioning of civil works among various units according to area occupied is given in table 13.1. The cost is based on 1984 price level for 100 kW, 1.9 meter rated head turbine (1.5 meter for Essex unit). Generation cost at various plant load factors based on 10% annual interest on capital; description (straight line method) 25 years for equipment and 100 years for civil works and 1.5% for operation and maintenance annually capital is shown in figure 13.15 Assuming full load operation at maximum efficiency, the comparative plant factors for different types of units for fixed quantity of water will vary in proportion to overall plant efficiencies and is also shown in figure 13.16.

Figure 13.15: Generation Cost Vs Plant Load Factor
### Table-13.1

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Turbine Generator (100 kW)</th>
<th>Capital cost (Rs. Million) (1985 price level)</th>
<th>Annual cost (Rs. Million)</th>
<th>Total peak efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Equipment</td>
<td>Civil Engg.</td>
<td>Total</td>
</tr>
<tr>
<td>1.</td>
<td>Tube turbine S-type coupled to induction of generator</td>
<td>1.84</td>
<td>1.40</td>
<td>3.24</td>
</tr>
<tr>
<td>2.</td>
<td>Tube turbine split type coupled to synchronous generator</td>
<td>2.45</td>
<td>1.05</td>
<td>3.5</td>
</tr>
<tr>
<td>3.</td>
<td>Essex Bulb Unit</td>
<td>1.88</td>
<td>2.77</td>
<td>3.78</td>
</tr>
</tbody>
</table>

i) Rs. 0.1 million added to equalize cost with synchronous generator.

ii) Total cost apportioned between units in the ratio of area occupied.


### 13.6.7 Conclusion

i) Ultra low head hydropower generation is feasible by high plant factor operation; system cost reduction and integrated operation.

ii) Cost of inlet valve/gates is quit high.

iii) The silt remover works were not very satisfactory.

iv) By-pass arrangement should be made preferable in the main canal

### 13.7 Recent and subsequent Schemes for Ultra low head development of small hydro power

A large number of ultra low head canal fall schemes were taken up in India based on the experience of kakroi project and development of new types of generating equipment.

A typical list of such grid connected schemes in Bihar State of India (AHEC Project) are shown in table 13.2 showing head; type of turbine; type of generator etc.

### Table 13.2 Typical Canal Fall and Ultra Low Head Projects in BIHAR

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Power Station</th>
<th>Sponsorer/Manufacturer</th>
<th>No. of Units x Size (MW)</th>
<th>Head (M)</th>
<th>Speed (RPM)</th>
<th>Discharge m³/sec</th>
<th>Specific Speed (Ns)</th>
<th>Type of Turbine</th>
<th>Type of Generator</th>
<th>Year of Commissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Agnoor</td>
<td>M/s Boving Foures</td>
<td>2 x 0.500</td>
<td>2.744</td>
<td>140</td>
<td>41.90</td>
<td>750</td>
<td>Horizontal tubular full kaplan</td>
<td>Synchronous horizontal</td>
<td>Commissioned</td>
</tr>
<tr>
<td>2</td>
<td>Dhelabagh</td>
<td>HPP Energy (India) Pvt. Ltd.</td>
<td>2 x 0.500</td>
<td>2.400</td>
<td>90/750</td>
<td>51.80</td>
<td>Vertical Semi Kaplan with Syphon Intake</td>
<td>Synchronous Generator Vertical</td>
<td>Commissioned</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Triveni SHP</td>
<td>Jyoti Ltd.</td>
<td>2x1.500</td>
<td>4.94</td>
<td>155</td>
<td>72.52</td>
<td>1056 .76</td>
<td>Horizontal Kaplan</td>
<td>Synchronous Generator Vertical</td>
<td>Commissioned/ under commissioned</td>
</tr>
<tr>
<td>4</td>
<td>Nasarganj SHP</td>
<td>VA Tech.</td>
<td>2x0.500</td>
<td>3.99</td>
<td>166.66</td>
<td>34.28</td>
<td>759.25</td>
<td>Vertical Semi Kaplan</td>
<td>Synchronous Generator Vertical</td>
<td>Commissioned/ under commissioned</td>
</tr>
<tr>
<td>No.</td>
<td>Name of SHP</td>
<td>Developer</td>
<td>Installed Capacity (MW)</td>
<td>Voltage (kV)</td>
<td>MVA</td>
<td>PF</td>
<td>Rated Capacity (MW)</td>
<td>Type of Turbine</td>
<td>Type of Generator</td>
<td>Commissioned/Under Commissioned</td>
</tr>
<tr>
<td>-----</td>
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<td>----------------------------------</td>
</tr>
<tr>
<td>5.</td>
<td>Jainagra SHP</td>
<td>VA Tech. HPP Energy (India) Pvt. Ltd.</td>
<td>2x0.500</td>
<td>4.18</td>
<td>187.5</td>
<td>29.62</td>
<td>783.78</td>
<td>Vertical Semi Kaplan Generator</td>
<td>Vertical</td>
<td>Commissioned/Under Commissioned</td>
</tr>
<tr>
<td>7.</td>
<td>Sebari SHP</td>
<td>HPP Energy (India) Pvt. Ltd.</td>
<td>2x0.500</td>
<td>3.66</td>
<td>150</td>
<td>35.97</td>
<td>745.96</td>
<td>Vertical Semi Kaplan Generator</td>
<td>Vertical</td>
<td>Commissioned/Under Commissioned</td>
</tr>
<tr>
<td>8.</td>
<td>Belsar SHP</td>
<td>HPP Energy (India) Pvt. Ltd.</td>
<td>2x0.500</td>
<td>3.22</td>
<td>129</td>
<td>4.07</td>
<td>763.22</td>
<td>Vertical Semi Kaplan Generator</td>
<td>Vertical</td>
<td>Commissioned/Under Commissioned</td>
</tr>
<tr>
<td>9.</td>
<td>Tejpur SHP</td>
<td>Vepro Energy (India) Pvt. Ltd.</td>
<td>2x0.750</td>
<td>3.46</td>
<td>107</td>
<td>61.0</td>
<td>770.77</td>
<td>Vertical Semi Kaplan Generator</td>
<td>Vertical</td>
<td>Commissioned/Under Commissioned</td>
</tr>
<tr>
<td>10.</td>
<td>Rajapur SHP</td>
<td>HPP Energy (India) Pvt. Ltd.</td>
<td>2x0.350</td>
<td>4.78</td>
<td>190</td>
<td>23.0</td>
<td>798.55</td>
<td>Vertical Semi Kaplan Generator</td>
<td>Vertical</td>
<td>Commissioned/Under Commissioned</td>
</tr>
<tr>
<td>11.</td>
<td>Amethi SHP</td>
<td>HPP Energy (India) Pvt. Ltd.</td>
<td>1x0.500</td>
<td>3.218</td>
<td>114</td>
<td>2.17</td>
<td>745.97</td>
<td>Vertical Semi Kaplan Generator</td>
<td>Vertical</td>
<td>Commissioned/Under Commissioned</td>
</tr>
<tr>
<td>12.</td>
<td>Arwal SHP</td>
<td>HPP Energy (India) Pvt. Ltd.</td>
<td>1x0.500</td>
<td>2.926</td>
<td>103</td>
<td>24.4</td>
<td>757.83</td>
<td>Vertical Semi Kaplan Generator</td>
<td>Vertical</td>
<td>Commissioned/Under Commissioned</td>
</tr>
<tr>
<td>13.</td>
<td>Walidin SHP</td>
<td>HPP Energy (India) Pvt. Ltd.</td>
<td>1x0.700</td>
<td>3.44</td>
<td>116</td>
<td>26.40</td>
<td>751.36</td>
<td>Vertical Semi Kaplan Generator</td>
<td>Vertical</td>
<td>Commissioned/Under Commissioned</td>
</tr>
<tr>
<td>14.</td>
<td>Paharma SHP</td>
<td>City of Hunan of China</td>
<td>2x0.500</td>
<td>3.36</td>
<td>166.7</td>
<td>42.0</td>
<td>1009.00</td>
<td>Fixed Blade Tubular Turbine Generator</td>
<td>Horizontal</td>
<td>Commissioned/Under Commissioned</td>
</tr>
<tr>
<td>15.</td>
<td>Rampur SHP</td>
<td>HPP Energy (India) Pvt. Ltd.</td>
<td>2x0.500</td>
<td>3.36</td>
<td>152</td>
<td>42.0</td>
<td>718</td>
<td>Semi Kaplan turbine with syphon intake</td>
<td>Synchronous generator</td>
<td>Commissioned/Under Commissioned</td>
</tr>
<tr>
<td>16.</td>
<td>Natwar SHP</td>
<td>1 x 0.400</td>
<td>3.569</td>
<td>652</td>
<td>9.87</td>
<td>712.6</td>
<td>Vertical semi Kaplan siphon intake</td>
<td>Induction generator</td>
<td>Commissioned/Under Commissioned</td>
<td></td>
</tr>
<tr>
<td>17.</td>
<td>Dehra SHP</td>
<td>2 x 0.500</td>
<td>2.08</td>
<td>750</td>
<td>62.36</td>
<td>742.85</td>
<td>Vertical semi Kaplan siphon intake</td>
<td>Induction generator</td>
<td>Commissioned/Under Commissioned</td>
<td></td>
</tr>
<tr>
<td>18.</td>
<td>Sipha SHP</td>
<td>M/s Boving Foures</td>
<td>2 x 0.500</td>
<td>2.69</td>
<td>110</td>
<td>48.22</td>
<td>740.62</td>
<td>Vertical semi Kaplan siphon intake</td>
<td>Synchronous generator</td>
<td>Commissioned/Under Commissioned</td>
</tr>
<tr>
<td>19.</td>
<td>Matholi SHP</td>
<td>HPP Energy (India) Pvt. Ltd.</td>
<td>1 x 0.400</td>
<td>2.35</td>
<td>-</td>
<td>25.94</td>
<td>-</td>
<td>Vertical semi Kaplan siphon</td>
<td>Synchronous generator</td>
<td>Commissioned/Under Commissioned</td>
</tr>
</tbody>
</table>
13.8 Standardization and Cost Reduction and ESMAP

13.8.1 Techno-Economic Design Criteria for Selection

Cost Effective Mini hydro schemes on irrigation dams and canals were proposed by UNDP/World Bank under ESMAP (energy sector management assistance programme) programme highlighted as follows. A no. of scheme were installed under the programme and are running successfully. Criteria for cost reduction was standardization of turbines and using standard induction generators. Brief outline of the criteria for selection of turbine and generators is given for detailed information reference be made to ESMAP project reports.

In designing economically viable irrigation based mini-hydro schemes, the primary objective was to maximize the number of kilowatt hours produced annually per unit of investment; this techno-economic criteria is referred to as the annual energy productivity of a given scheme. It was considered that maximising annual energy productivity concept provides reliable and consistent techno-economic criteria for selecting the optimal plant size.

During preliminary design, an iterative procedure was used to select and evaluate different configurations of multi-unit turbine-generators. Each configuration was screened to ensure that energy would be produced for Rs. 0.80 /kWh. Or less (1990 price level); for design purposes, this required that each scheme would have to produce a minimum of 20.6 kWh annually per 100 Rs. invested to be competitive economically with power supply form the grid.

13.8.2 Design Criteria

To improve upon the original designs, considerable attention was given to identifying practical measures to minimize capital cost. For turbine-generator units, this was achieved by developing a set of standardized specifications according to available heads and discharges. As a result, a set of eight standardized specifications based on runner diameters were developed for the turbine requirements of all fifty-three schemes, ranging in diameter from 2800 mm. To 1000 mm (i. e, for fixed blade tubular turbines). Similarly a set of eight standardized capacities were specified for the induction (asynchronous) generators; the minimum capacity was 350 kW and the maximum was 3500kW. All redundant equipment and instruments that had previously been incorporated into the electrical protection and switching arrangements were eliminated. Standardized single line diagrams and electrical protection schemes were developed to cater to the requirements of all the fifty-three schemes. To minimize the costs of civil works, alternative layouts and designs of the main civil structures were re-defined and evaluated according to three criteria: (i) layouts of civil structures and alteration to the existing irrigation facilities were reduced to a minimum; (ii) layouts of civil structures and electrical switching systems were streamlined to facilitate construction, so that schemes would be implemented within two irrigation seasons; and (iii) layouts were specified so as not to cause any permanent loss of productive agricultural land .To the extent possible for each category of mini-hydro scheme, a set of standard designs was developed for main civil structures, particularly the power house structures, and the water intake and conveyance structures.

13.8.3 Standardization

The scale of operation of the mini-hydro projects is small relative to the size of central power stations in the respective states. Therefore, it is not cost-effective to develop one-off designs for each project. Furthermore, the type and performance of turbines for mini-hydro applications vary significantly form manufacturer to manufacturers; some degree of flexibility is required at the design stage so that eventually it would be possible to consider alternative configurations of turbines that also would satisfy minimum
performance specifications. Given the advantages of some degree of standardization, it was considered useful to develop a set of minimum performance specifications to correspond to the range of available heads and discharges for the prospects covered by the study. The procedure outlined in flowchart (table 13.3) was used, as described below:

Classifications of Schemes by Head and Discharge. First, the schemes were grouped into eight standardized head categories, second, for each category of standardized head, the schemes were allocated to sub-categories based on a set of standardized discharges per unit (Table 13.4).

**PROCEDURE FOR STANDARDIZATION OF DESIGNS FOR PROSPECTIVE MINI-HYDRO SCHEMES**

<table>
<thead>
<tr>
<th>Select optimum Configuration of scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Head Design flows</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Arrange Design Heads in Groups of Limited Range, and select Standardized Design Head</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Review Design Flows specified for Each Category of Design Head, and Select Standardized Groups of Design Discharges</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>For Each Category, Identify Technically Feasible turbine options, compute Minimum runner Diameters, and Maximum turbine speeds Taking into Account Cavitation Factors, turbine settings, etc</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Compute Generator output and select appropriate speeds to match Turbine Speed</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Specify speed increaser Requirements and Select Generator Speed</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Establish final designs for Schemes, Standardized Specifications (Design Head, flows, Unit Capacity, etc)</td>
</tr>
</tbody>
</table>

*Table 13.3*
Development of Standardized Specifications for Turbines. The runner specifications (i.e., the maximum operating speed of turbine, minimum diameter of runners) for each category of design head and discharge was computed and compared with reference monographs obtained from international engineering design firms and local manufacturers in India. A set of eight standardized runner diameters were developed for the turbine requirements of the schemes, ranging in diameter form 2800 mm to 1000 mm (Table 13.5) for fixed babled tubular turbines. For the most part, runner diameters were uniform for schemes associated with the major irrigation systems. For example, due to standardisation, all schemes on the Guntur and Adanki Branch Canals of the Nagarjuna Sagar System in Andhra Pradesh would handle 22.5 cumecs per turbine – generator unit; therefore a common runner diameter of 2000 mm was specified.

13.8.4 Development of Standardized Specifications for Induction Generators

Induction (asynchronous) generators, essentially induction motors which are driven at slightly above synchronous speed, were specified for all schemes. The analysis indicated that induction generators were required for with eight capacities in the range 350 kW to 3500 kW. The operating speed of the turbine and generator were used to establish the specification for speed increasing mechanisms. The goal was to keep the speed of the turbines as high as possible and to minimize the gearbox ratio by maintaining the lowest feasible speed for the generators.

Table 13.4 Standardized specifications for turbines

<table>
<thead>
<tr>
<th>Scheme Name</th>
<th>Standardized head (meters)</th>
<th>Standardized discharge (cumecs)</th>
<th>No. of units</th>
<th>Turbine runner dia (MM)</th>
<th>Rotating speed turbine generator (RPM)</th>
<th>Generator capacity (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.0</td>
<td>50.0</td>
<td>As Per available discharge</td>
<td>2800</td>
<td>167.5</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>30.0</td>
<td></td>
<td>2500</td>
<td></td>
<td>650</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>22.5</td>
<td></td>
<td>2000</td>
<td>187.5</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>12.0</td>
<td></td>
<td>1200</td>
<td>187.5</td>
<td>750</td>
</tr>
<tr>
<td>B</td>
<td>4.25</td>
<td>30.0</td>
<td>-do-</td>
<td>2500</td>
<td>250</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td>4.25</td>
<td>22.5</td>
<td></td>
<td></td>
<td></td>
<td>650</td>
</tr>
<tr>
<td>C</td>
<td>7.0</td>
<td>22.5</td>
<td>-do-</td>
<td>2000</td>
<td>214</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>7.0</td>
<td>12.0</td>
<td></td>
<td>1400</td>
<td>33</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>7.0</td>
<td>7.5</td>
<td></td>
<td></td>
<td></td>
<td>650</td>
</tr>
<tr>
<td>D</td>
<td>10.0</td>
<td>22.5</td>
<td>-do-</td>
<td>2000</td>
<td>187.5</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td>12.0</td>
<td></td>
<td>1400</td>
<td>333</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
<td>5.0</td>
<td></td>
<td>1000</td>
<td>333</td>
<td>600</td>
</tr>
<tr>
<td></td>
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<td></td>
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<td></td>
<td>650</td>
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<td></td>
<td></td>
<td>350</td>
</tr>
</tbody>
</table>

315
<table>
<thead>
<tr>
<th>Type of turbine</th>
<th>Rated head +Hr (m)</th>
<th>Min/Max Head (% of Hr)</th>
<th>Rated power – pr (kW)</th>
<th>Min/Max Capacity (% of Pr)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Fixed Blade propeller</td>
<td>2.20 and 55.125</td>
<td>250-15,000 and over</td>
<td>30-115</td>
<td>May be operated up to 140% of rated head depending on turbine salting</td>
<td></td>
</tr>
<tr>
<td>Vertical Semi-Kaplan with Adjustable Blades (propeller)</td>
<td>2.20 and over 45-150</td>
<td>1000-15,000</td>
<td>10-115</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical Francis</td>
<td>8-20 and over 50-125</td>
<td>250-15,000</td>
<td>35-115</td>
<td>Minimum rated head is 8 meters</td>
<td></td>
</tr>
<tr>
<td>Horizontal Francis</td>
<td>8-20 and over 50-125</td>
<td>250-2000</td>
<td>35-115</td>
<td>Minimum rated head is 8 meters; maximum capacity is 200 kW</td>
<td></td>
</tr>
<tr>
<td>Tubular (Adjustable blades/ fixed gates)</td>
<td>2-18 65-140</td>
<td>250-15,000</td>
<td>45-115</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tubular (fixed blade runner with wicker gates)</td>
<td>2-18 55-140</td>
<td>250-15,000</td>
<td>35-115</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulb</td>
<td>2-20 45-140</td>
<td>1000-15,000</td>
<td>10-115</td>
<td>Minimum capacity is 1000 kW</td>
<td></td>
</tr>
<tr>
<td>Rim</td>
<td>2.9 max 45-140</td>
<td>1000-8000</td>
<td>10-115</td>
<td>Minimum capacity is 1000 kW</td>
<td></td>
</tr>
<tr>
<td>Right angle drive propeller</td>
<td>2-18 55-140</td>
<td>250-2000</td>
<td>45-115</td>
<td>Minimum capacity is 2000 kW</td>
<td></td>
</tr>
<tr>
<td>Open flume</td>
<td>2-11 max 90-140</td>
<td>250-2000</td>
<td>30-115</td>
<td>Minimum capacity is 2000 kW</td>
<td></td>
</tr>
<tr>
<td>Closed flume</td>
<td>2-20 50-140</td>
<td>250-3000</td>
<td>35-115</td>
<td>Minimum capacity is 3000 kW</td>
<td></td>
</tr>
</tbody>
</table>

Hr. the rated head, is defined as the head at which full gate out put equals the rated output of the generator.

Table 13.5 Overview of turbine performance specifications
13.8.5 Revision of Preliminary Designs Using Standardized Specifications.

The preliminary designs for each scheme were adjusted to reflect the standardized specifications for design head, design discharge levels, and installed capacity.

13.9 Pump Used As Turbine (PAT)

Commercially available centrifugal pumps have been used in India to advantage as hydraulic turbines in micro hydro range as low initial cost is more important than high efficiency. Pumps are designed as fluid movers; they may be less efficient as hydraulic turbines than equipment expressly designed for that purpose. However, advantages of using a pump as a turbine are as follows:

- Due to the large number of standards pumps produced, standardized PAT can be significantly less expensive than a specially designed turbine.
- The delivery time is generally much less for pump than for turbines.
- Spare parts and maintenance or repair services are readily available for pumps than turbines.
- The control of PAT by load control governors.
- These factors contribute to cost saving.

The performance of a machine will have different best efficiency point (BEP) flow parameters when operating as a turbine than when operation as a pump. This is true because the energy for losses due to friction etc. must be derived from the flowing fluid in a turbine in a pump, the energy losses are included in the mechanical energy supplied to the pump drive shaft and are not transmitted to the fluid. Therefore, a machine operating at a particular speed, the flow and head will be less than pumping than when in the turbine mode.

Based on actual tests carried out in Alternate Hydro Energy centre IIT Roorkee (AHEC) the characteristics indicate the following:

* Turbine best efficiency point is at higher flow and head than pump best efficiency point.
* Turbine maximum efficiency tends to occur over a wide range of capacity.
* There is a point of zero power output corresponding to a particular head runaway speed.

The determination of turbine performance from a pump is the chief problem in matching machine performance to site characteristics. The most reliable method is to obtain turbine performance by actually testing the pump in reverse mode. This, unfortunately is usually too expensive to be paid for by the owner of a small hydro power site. A typical installation is shown in figure 13.16.

13.9.1 Selection of Pump as Turbine

The following procedure may be adopted for selection of a pump to be used as turbine for given site data (Developed by Dr. R. P. Saini, Associate Professor, AHEC)

1. Arrive at the values of turbine rated head (HT in m) and turbine rated discharge (QT in m³/s) from a given site data.
2. The above data yields the value of available hydraulic power (P = 9.841 x QT x HT x ηT x ηG) keeping. For the given QT and HT determine available pump (from pump catalogue) for QT & HT as trial speed or assume speed (750 rpm to 1500 rpm).
3. Find the value of specific speed for turbine data

\[ N_{ST} = \frac{N \sqrt{Q_T}}{(H_T^{0.75})^{1}} \]

4. Examine whether it is desirable to use double suction pump. This should be done whenever possible because shaft of double suction pump experience negligible thrust. Neglecting the effect of efficiency and assuming nT = np,

\[ N_{sp} \approx 3N_{ST} \text{ for single suction pump} \]
\[ \approx \frac{N_{ST}}{\sqrt{2}} 4 \text{ for double suction pump} \]
5. Find the value of conversion factors from test curves or theoretical curves and find the value of $H_p$ and $Q_p$.

6. Find from the pump catalogues whether pump for chosen values of $Q_p$, $H_p$ and $N_p$ is available. If not, select suitable pump speed for which a pump is available to match desired $Q_p$ and $H_p$. Find new specific speed and check the values of conversion factors for the same with little trial and error, it will be possible to select a pump.

7. In all cases recheck all the values for selection pump and find output power expected.

8. Nomogram for Selection of Head and Discharge of Pump Used in Turbine Mode developed in AHEC given in figure 13.18.

13.9.2 Types of Pumps Used As Turbine

   Radial flow pump ($Nsp = 10$ to $40$)
   Mixed flow pumps with outlet edge parallel to machine axis
   ($Nsp = 40$ to $80$)

   Mixed flow with outlet edge inclined to machine axis provided with volute chamber
   ($Nsp = 80$ to $100$)
   High specific speed axial flow pumps delivering axially, provided with vanes
   ($Nsp 100$ to $1000$)
Figure 13.17

Nomogram For Selection of Head and Discharge of Pump Used in Turbine Mode
13.9.3  Turbine Performance of a Pump

Based on actual tests carried out in Alternate Hydro Energy Centre IIT Roorkee the characteristics indicate the following; Turbine performance as pump as shown in figure 13.17.

Turbine best efficiency point is at higher flow and head than pump best efficiency point. Turbine maximum efficiency tends to occur over a wide range of capacity.

**Conversion Factors for PAT**
- Conversion factor for head, \( h = \frac{H_T}{H_p} \)
- Conversion factor for discharge, \( q = \frac{Q_T}{Q_p} \)
- Specific speed, \( N_s = N \frac{Q_T}{(H_T)^{0.75}} \)

**Installation**
When a centrifugal pump is used as a turbine it will usually be installed differently. It will require a diffuser and draft tube assembly if its maximum efficiency is to be achieved. With a draft tube assembly the total head \( H \) for the system will now become the difference in elevation between the sump level and the intake level. In most cases involving small hydro the sump level will be somewhere between three and six feet below the turbine. If this distance gets too great the turbine runner (impeller) could be damaged by the effects of cavitation. Pump as turbine for irrigation works was not considered suitable because of limitation on size and efficiency.
References


vi) THAPAR O.D., “Ultra Low Head Small Hydropower Station Tehcnology for Economic Development Water Power 85, International Conference Las Vegas USA.


viii) ESMAP (Report No. 139/91 A,B,C) - Joint UNDP/World bank Energy Sector Management Assistance Programme Report – Mini Hydro development on irrigation dams and canal drops pre-investment study volume I, II, III Technical Supplement

ix) Micro Hydro Standards issued by AHEC IIT Roorkee