CHAPTER 1

SMALL HYDRO ELECTRIC POWER DEVELOPMENT
USING BULB TURBINE

1.1 Hydro Power Potential in India

In 1897, the first hydro power plant was installed in India with an installed capacity of 130kW. Since then about 22000 mw of hydro power plant capacity have been set up consisting of 130 hydel plants with about 585 generating units. This constitutes only 25% of hydel resources as India is possessing large potential in both major / medium and small hydro resources. A systematic and comprehensive survey of the hydro electric potential of India has been carried out by Central Electricity Authority and the potential is assessed as 84044 MW at 60 Plant Load Factor (PLF). The scope of the study involves identification of sites for small hydro schemes with installed capacity of 2 to 15 MW on small rivers / streams. Small / mini hydro power schemes with 100 kW to 2000 kW capacity and micro schemes with 100 kW capacity are installed at canals.

The total small hydro power of India is been assessed as 6781.81 MW in terms of installed capacity from a total of 1512 schemes, which include schemes already in operation, under construction and identified. Out of assessed potential of 6781.81 MW for a total of 1512 identified schemes, 6153.9 MW is contributed 977 schemes on small rivers / streams heads and 564.39 MW is from 436 schemes on canal falls. Other existing schemes of 99, account for balance 63.52 MW of the assessed potential.

1.1.1 Small Hydro Power Potential in India

In line with the strategy of global hydro development, small hydro technology is making significant contribution to sustainable, clean energy policy. Small hydro is playing an increasingly important role in promoting social and economic development, taking into account the fact that electricity supply and availability is essential for developing rural areas and for industrial growth.
• Decentralized renewable energy can solve numerous local problems relating to energy supply. There are three main drivers behind the global trend towards small hydro.

• The promotion of renewable power is in full accordance with the latest national legislation (green certificates) in various countries.

• An increasing dependence on primary energy sources could lead to serious economic threats. Power supplies from alternative, decentralized sources are becoming more and more attractive.

• Small hydro has the lowest environmental impact of all energy sources, including other renewable energies. It fully corresponds to environmental commitments, including the Kyoto protocol.

Hydroelectric power plants are generally classified under the following three categories:

(i) Run of river power houses
(ii) Storage type power houses
(iii) Pumped storage power houses

Run of river power house have very limited storage capacity and uses water as is available in the river. The power generation follows the pattern on inflows available. Some of the run of river power house have diurnal storage / pondage to permit storing water during off peak hours for using peak hours of the same day. Storage type power house have reservoir of sufficient size to permit carry over storage from the rainy season to dry season. This helps developing substantially more power than that available through natural flows. Pumped storage power house have head water storage and tail water storage. During peak load, the water from head water storage is released to generate power, whereas during the off – peak period, secondary power from other power stations is utilized to pump water from tail water storage to head water storage. The pumped storage schemes provide capacity to meet peak loads.
1.1.2 Assessment of Power Potential and Optimization of Installed Capacity

1.1.2.1 Power Potential

Evaluation of power potential of the scheme forms a primary step in the planning of a hydroelectric project. It relates to the assessments to be made of probable quantum of electrical energy which can be expected to be produced at the site based on characteristic features of stream flow and head available at the site, indifferent periods of an year, and the generating capacity (kW) which is needed to be provided in the power station in order to generate the assessed quantity of energy (kWh). This considered assessment forms the basis for the planning of the layout and design of the scheme and estimation of the cost and evaluation of the financial aspect of the scheme. This step has to follow hydrological studies and field investigations.

Power potential is a function of head and discharge quantity of water at any point of time and is determined by using the following formula.

\[ P = \rho g Q H \eta_0 / 1000 \]  

Where

- \( P \) = power output in kW
- \( \rho \) = density of water kg/m\(^3\)
- \( g \) = acceleration due to gravity m/s\(^2\)
- \( Q \) = discharge in m\(^3\)/s
- \( H \) = net head in meters
- \( \eta_0 \) = overall unit efficiency in percentage

1.1.2.2 Head

The following definitions of various heads are of relevance in assessing the power potential and determining the installed capacity.

(i) Gross head is the difference in elevation between the water levels behind the fore bay / dam and the water level in tailrace. This can be assessed by simple surveying technique.

(ii) Net head is the gross head less all hydraulic losses except those chargeable to the turbine. The intake, water conductor system and penstock losses are deducted form the gross head
to arrive at the net head. The scroll case and draft tube losses are considered chargeable to the turbine and not considered for compilation of net head.

(iii) Design head is the net head at which peak efficiency is desired. This head is normally the weighted average head. This is the head, which determines the basic dimensions of the turbine.

(iv) Rated head is normally the same as design head. Some organizations however define the rated head as the net head at which the output at full gate opening of the turbine produces the rated output of the generator.

1.1.2.3 Optimization Studies for Determination of Installed Capacity

The size and features of the project is finalized after carrying out studies of cost and benefits for various alternatives. The first step in optimization is the assessments of energy generation with various installed capacities. The incremental values of energy generation with the increase of installed capacity and their relative costs provide a basis for determining the installed capacity. The installed capacity, in an isolated system, has to match with the fore bay capacity and power requirements. In a system, where the power generation from the project is proposed to be fed into the grid, the scale of incremental energy generation with increase incapacity is the first guide. For determining the optimal installed capacity, a few alternative capacities are considered with cost and benefits. The alternative which shows the least cost of energy generation is adopted.

1.1.2.4 Number of Units to be Installed

For a given total installed capacity, the plant cost generally increases with an increase in the number of units. Efficiencies of bigger machines are higher than the smaller machines (turbines and generators) of the same type. If the power demand and discharge is reasonably uniform, it would be advisable to install lesser number of units say one or two, with due consideration for meeting essential energy generation requirement when a unit is taken out for maintenance.
The efficiency of the turbine decreases at part load operation due to the decreasing flow rate. From this consideration, it is better to use smaller size machine greater numbers for facility of widely variable operating conditions. For determining the number of units, careful considerations is given to the variation in output, during various months of the year and also the shape of the load curve where the power is fed.

If the scheme is provided with a pondage where the water could be regulated over the day and the power is proposed to be fed into the grid. It is preferable to have lesser number of units is a power house.

1.2 Development of Small Hydro Power Generation

1.2.1 Economics of Small Hydro Power Generation

The development of small hydro power is being increasingly taken up all over the world especially in the developing countries because of their various merits, varied application and flexibility of utilization. In many countries, more attention is being paid to the development of small hydro power generation. Due to the crisis caused by high rise in costs of fossil fuels together with increased awareness towards environmental impact of large projects etc leads to thrust of small hydro.

In India development of small hydro is particularly much suited, since multitude of population of the country is still living in villages scattered in far flung isolated places and living below a required standard. There is a minimum need to provide them with energy which is very essential, especially for a better standard of living. Since transmission of energy to such remote areas would be cost-intensive and also to meet power requirements through diesel generation would be equally costly, energy supply through small schemes located in the vicinity of small rivers / streams would be generally most suitable.

1.2.2 Environmental Impact of Small Hydro Power Projects

Unlike thermal generation, hydro power projects produce no air or thermal pollution. In fact in comparison to other sources of energy generation, hydro plants produce power that is compatible with the environment. Actually small, mini or micro hydro power projects tend to create no or negligible environmental impacts as compared to large scale projects.
As it is observed, the main scheme features for small projects are, by and large, the same as for the medium and major projects which comprise of diversion, water conductor system, penstock, power house etc., except in the case of a storage type scheme which involves creation of a reservoir and thereby submergence of land, the other features such as water conductor system, power house etc., have hardly any environmental impact. Several prevalent environment effects are certainly associated with creation of an impoundment under a reservoir may have adverse as well as beneficial effects.

While the slack water pool formed upstream of the dam it would cause inundation of land submerged, affect aquatic and/or terrestrial organisms however, at the same time regulated water flows from an impoundment would mean sustained uniform flow in comparison to the pulsating discharges, ensuring improved quantity and quality of water for different uses including moderation of the floods etc. In the case of run-of-river projects which also incorporate small pondage, storing only one or two days of average river flows for achieving peaking benefits in power generation generally does not create any environmental impact.

It needs no emphasis that the development of small hydro is very relevant today. There is greater awareness towards harnessing of small hydro potential to achieve objectives such as providing light, increased agricultural output, improve employment conditions by making availability of energy for industrial growth, improve life styles, and bring about conditions for faster rural developments so as to arrest migration of rural population to the over crowded urban centers.

The developments can be brought about by effectively implementing exploitation of available energy source. Because of innumerable merits such as flexibility of utilization, ready availability with practically no adverse environmental impacts and inflationary tendencies on completion, the small hydro is comparatively more attractive.

Small hydro power project is the top ranker as one of the most sought renewable energy source compared with other alternative sources of energy such as windmill, solar, tidal, geo-thermal and biomass. As the small hydro is well developed and proven unlike other alternatives mentioned above which has not been fully developed for large commercial exploitation. The other advantage
of small hydro power is the existing river flows and the canal flows which are recoverable resources.

The general economic relevance of harnessing hilly streams, canal falls, run of rivers, etc for small hydro is, its comparatively shorter period of two to three years as against five to seven years for major hydro power projects. In the context of gestation period it would be relevant to mention that the technological innovations and improvement, cut down the commissioning period of this small hydro. Another important factor is the standardization of generating equipments for small hydro which cuts down the cost of equipment and also the manufacturing period. The other and more vital part of small hydro is the higher rate of return on the capital investments.

1.3 Run of River Scheme

The general tendency of reviewing the small hydro schemes as miniaturized version of major hydro projects is not acceptable as the concept of small hydro differs in planning, development, construction and utilization of valuable small resources available then and there. Basic elements of civil works such as diversion weir, water conductor system, etc., are reduced or eliminated with the innovation, simplification and standardization of small hydro equipments. As regards to the run of river schemes, very few civil structure for guiding river water into the power station and leading the discharge from power station back into the river through tailrace channel are required essentially.
1.3.1 Layout of Bulb Turbine in Run of River Scheme

Run-of-river power stations utilize the irrigation demand left out in a river with chains of barrage power stations, such a way that the water flowing in the river is temporarily stored in each barrage and utilized for electrical power generation. In each barrage the headrace water level is kept equal to the
tailrace level of the previous powerhouse to avoid stagnation of tail race water in a chain of power house.

The intake hydraulic structure consists of a barrage reservoir created by vertical lift type gates. The bulb turbine with four or five runner vanes can be beneficially utilized in a run of river scheme. The axial flow design of the bulb turbine overcomes the problem of reduction in turbine efficiency due to higher specific speeds by making smaller deflection angle of water flow into the turbine runner. Conical draft tube plays an important role in recapturing the kinetic energy of the water at the exit of runner vanes and hence the performance of the bulb turbine is much higher in a run-of-river scheme than the conventional Kaplan turbines.

The bulb turbine construction is complex with a sophisticated water tight casing for the generator immersed in the water flow in a run of river scheme. The cost of electrical and mechanical equipments for the bulb turbine unit is comparatively smaller. The bulb turbine can be used for a maximum gross head of 25m for a maximum output power of 50MW for a run of river scheme. The runner diameter for the bulb turbine may be as large as 7.5m with a maximum discharge of water as high as 500m$^3$/sec in a rotational speed of 500rpm.

1.4 Bulb Turbine
1.4.1 Development of Bulb Turbine

![Diagram of a bulb turbine](Fig 1.3 Bulb turbine)
Bulb turbine is developed for low head power generation in the small power developments. The turbines are made almost horizontal shaft machines to improve their performance. Generators are coupled in the same turbine shaft and are housed inside the water tight bulb casing. The water flows all over the unit and these types of generating units are normally utilized for exploring heads up to 25m. Conventional vertical shaft Kaplan turbine is used for heads more than 25m and up to 50m.

Bulb turbine is horizontal shaft type, with movable wicket gates and adjustable runner blades. The rotating part of generator and turbine is supported by two guide bearings. The turbine consist of fixed parts embedded in concrete, such as the outer stay cones, intake-liner, stay column and the draft tube liner. Stationary parts which can be dismantled, such as the discharge ring, outer and inner distributor cones and the rotating parts like the main shaft and the runner.

1.4.2 Turbine Runner

The turbine runner has four adjustable blades, designed to be operated by means of oil pressure from the governor system. The runner blades are made of 13% Cr – 4% Ni stainless cast steel. The profile of the runner blades are designed so as to have highest efficiency of the turbine and to prevent occurring of cavitation. The runner blades are carefully shaped and ground to conform to the contours of the homologous model turbine runner blades. The runner blades are designed and constructed to safely withstand the stresses due to operation at maximum runaway speed under conditions of maximum operating head with no load on the generator.

The runner blade is connected to the blade trunion by means of blots to facilitate to removal of the blade without disassembly of the runner control mechanism mounted in the runner hub. The runner blades are assembled with the hub, control mechanism, and the cone at the factory. They are dynamically balanced before shipment. The turbine runner is transported without the runner blades, but together with the runner hub, the runner control mechanism, and temporary blind cover on the runner hub. The runner hub is cast steel or fabricated plate steel and accurately and spherically machined in the area of the blade ends to minimize lockage from the blade-to-hub clearance at all blade
positions. A bolted, flanged connection is provided for attaching the runner hub to the main shaft and the runner cone. The coupling bolt holes in the runner hub is reamed with the runner and shaft assembled.

The runner is provided with a welded steel plate cone to direct the flow as it leaves the runner. Oil pressure inside the runner hub is always greater than the upstream pressure in the water passage.

1.4.3 Runner Control Mechanism

The runner blade servomotor operates the runner blades with levers, by means of pressure oil from the governor through an oil distributing head located at the upstream end of the generator auxiliary shaft. Pressure oil from the oil distributing head is led to the blade servomotor mounted in the runner hub via the double pressure oil pipes placed inside the main shaft. The pressure oil pipe inside of the main shaft is connected at the position of the coupling between the main shaft and the generator rotor. The blade operating mechanism will have sufficient capacity to operate the runner blades through a complete opening or closing stroke, with minimum normal governor operating oil pressure.

1.4.4 Pressure Oil Distribution Head

The distribution head is mounted on the upstream end of the generator auxiliary shaft. Pressure oil from the governor for controlling the servomotor is distributed to the double pipes, which are separate to the outer pipe and inner pipe used for leading the closing and opening directing oil respectively. The double pipes are mounted on inside of the main shaft, through main shaft. The distribution head, keeping the pressure not less than maximum upstream water pressure even when the unit is shutdown, will also supply runner hub oil.

1.4.5 Stay Cones

The stay cones are made of steel plate, and consist of outer and inner conical rings and two stay columns, which are welded with each other. The outer cone has suitable numbers of ribs and anchors to increase its rigidity in concrete structure and is capable of transferring the loads due to water thrust and maximum torque during short circuit. The stay cone is divided into suitable
number of sections which are assembled to each other at site by bolted flanges and welding.

The inner stay cone is assembled with the stay columns by welding. The inner cone is divided into the two halves with a flange connection. The inner stay cone is also flange-connected with the generator stator frame at the upstream side, and with the inner distributor cone at the downstream side. The stay columns are hollow in order to allow the passages for
a. Various piping for 1) lubrication oil, 2) evacuation of condensation water, 3) evacuation of water leaking from the shaft seal and 4) some of control cables.
b. Maintenance personnel.

1.4.6 Distributor Cones

The outer and inner distributor cones are made out of steel plates. The outer distributor cone is connected to the outer stay cone and to the discharge ring, at the upstream and downstream sides, respectively, by means of bolts. The inner distributor cone is flange-connected with the inner stay cone at upstream side, and with the inner turbine cone at downstream side. The surface of the distributor cones where the wicket gates are moved is spherically and accurately machined to keep close clearance.

1.4.7 Discharge Ring

The discharge ring is made up welded steel plate complete with steel ribbings on its outsides. A portion of the inside surface surroundings the runner is overlaid with stainless steel and spherically machined for close running clearance with the runner blades. The discharge ring is divided into two sections, upper half and lower half, for flange connection. The upper half of the discharge ring is capable of being dismantled in order to allow the assembly or dismantling of the runner blades and the runner assembly. An expansion joint at the downstream end of the ring, is provided to facilitate erection and dismantling of the discharge ring. The discharge is connected to the outer distributor cone at the upstream end by bolts and nuts with the flange.
1.4.8 Draft Tube Liner

The draft tube liner is of conical shape and made of the steel plate of 9/12 mm of thickness. This liner has sufficient ribs and suitable numbers of anchor bars and is extended downstream to a point where the mean water velocity is less than 5m/sec at the rated conditions.

1.4.9 Guide Vane (Wicket Gates) and Operating Mechanism

Sixteen wicket gates are assembled between the outer and inner distributor cones, to control the water entering into the runner with a minimum hydraulic losses. The wicket gates are made fabricated plate steel and outer stem is made of carbon steel. The wicket gates are uniform in shape. The sealing faces of each wicket gate is accurately machined and finished to minimize water leakage through the gates and all gates are inter-changeable. The outer and inner gate stems have 18-8 Cr-Ni stainless overlay and are provided with oil-less metal made spherical bearings, as a combined guide and thrust bearing, and suitable seals.

The turbine is provided with two oil pressure-operated servomotors having a sufficient capacity to supply the force necessary to operate the wicket gates, with minimum oil pressure, under the maximum head. Pressure oil is supplied from the pressure oil system of the governor. The servomotor cylinders are located on the foundation of the turbine pit. In addition to the governor pressure oil system, an independent emergency pressure oil system is provided to close the wicket gates from any position in the event of failure of the governor.

1.4.10 Bulb Nose

The bulb nose is made of steel plate welded with suitable ribs. It is flange-bolted to the generator casing. The bulb nose is provided with an access for personnel to the inside of the generators. The access is also be used for passage of piping, bus bars of the generator, control cables, and leads for the field coils to the generator.

1.4.11 Main Shaft

The main shaft is made of forged carbon steel with coupling flanges for connection to the turbine at one end and to the generator rotor center at the
other end. The generator rotor is over-hung through at the upstream side guide bearing support. All coupling bolt holes are reamed with the shaft properly aligned with the generator rotor center.

1.4.12 Turbine Guide Bearing

The turbine guide bearing is provided with forced-oil-lubricated type. The turbine guide bearing is supported by the bearing support which is mounted on the inner turbine cone. The bearing shell is made of steel plate lined with high quality Babbitt metal on its inner surface, and is divided into two sections to facilitate assembling and disassembling for maintenance. The bearing shell has oil seal covers for both ends. The lubricating oil has the same grade as the oil of the governor pressure oil and the runner hub oil. The guide bearing is supplied with the oil from the lubricating system.

1.5 Cavitation

1.5.1 Theory on Cavitation

Cavitation is the formation of holes or voids, in water due to the occurrence of low pressures. This boiling like phenomena occurs at all points in a stream flow where the pressure is as low as the vapour pressure of the liquid. The cavities (bubbles) thus formed are filled up with vapour and move millions for seconds. When they collapse, they collapse with a force greater than that off breaking strength of steel causing a dent in the conduit carrying the flow. Cavitation induces vibrations, damage to the materials, unendurable noise, losses in the efficiency and alteration in flow pattern. Hence, hydraulic machineries have to be designed entirely free from cavitation.

Cavitation may be defined as the formation and collapse of cavities, it has also been defined as the co-existence of a vapour or gas phase with a liquid phase. A cavity may be expected to form at any point in the liquid when the local pressure is reduced to that of the vapour pressure of the liquid at the temperature of the stream. This cavitation may be filled with vapor and/or gas such as air. Difference between cavitation due to low pressure and that at boiling is that in cavitation, due to pressure reduction, the thermodynamic condition is practically one of the constant heat with no heat being added or
taken away from the entire system, while in boiling there is continuous addition of the heat.

In the condition for inception of cavitation at the ordinary temperature are:
(a) the liquid should have a nuclei
(b) the flow should be of a real liquid and not as ideal fluid
(c) there should be scope for separation for flow
(d) the flow has to be turbulent not laminar to allow for vortex formation and growth of cavitation bubbles.
(e) The flow is to be a two phase flow with liquid and gas.

1.5.2 Cavitation in Hydro Turbines

Handling of large powers per unit and yet keeping the size of a turbine economically small requires higher running speeds, which means greater pressure differences between the two sides of the vanes of a runner. If the pressure at any point in the vane reaches the vapour pressure for causing cavitation, the vane gets damaged. The average pressure in a hydraulic turbine runner falls from inlet to outlet. The setting of the runner can be designated by \( h_s \) the distance between the tail water level and the centre line of the runner. The pressure at any point in the runner depends on \( h_s \). If \( h_s \) is increased, the pressure on the both sides of vanes becomes low and in particular the minimum pressure on the vane may get reduced below vapor pressure starting cavitation. On the other hand, by suitably reducing the value of \( h_s \) cavitation on the vane can be avoided. But a low value of \( h_s \) involves considerable expenditure in civil engineering works, while a high value of \( h_s \) increases cavitation damaged repair cost involving loss as temporary shutting down of the plant. A compromise value of \( h_s \) between the two is generally struck, as a slight cavitation in the machine does not affect its performances significantly. The parameter most widely used to denote the state of the cavitation is the Thoma cavitation factor \( \vartheta = \frac{(h_a - h_{vp} - h_s)}{H} \quad \text{(1.2)} \)

Where \( h_a \) is atmospheric pressure in meter of water column
\( h_{vp} \) is vapor pressure of the flowing water in meter of water column
\( H \) is head on the turbine in meter of water column
The $h_n$ is considered as positive if the runner centerline is above the tail water level and negative otherwise. There are mainly two approaches to protect the cavitation limit in a turbine i) to identify the different types of cavitation occurring in turbine and define a critical cavitation parameter for each of them and to calculate which of them will seriously affect the machine. ii) to test a geometrically similar model of the machine and establish a critical cavitation limit. To overcome the pitting due to cavitation in turbine, fine graded cast iron, bronze or steel casting with stainless steel overlay in the region of blade trailing edges are used. In addition to using such materials to overcome the effects of the cavitation, other methods like air venting are also used in turbines.

1.5.3 Vibration Induced in Hydro Turbine due to Cavitation

Vibrations are induced in the hydraulic turbines due to intense pressure fluctuations caused by the inception & growth and collapse of bubbles during cavitation. Vibration of the structures of turbine assembly is studied with elastic properties of structure to match the hydrodynamic properties of the flow. There can be resonance when the induced frequency is equal to the natural frequency of the turbine structure and concrete foundation.

Vibration tests are carried out to determine the frequency likely to cause resonance in the turbine supporting structure and the foundation. For the case of cavitation induced in the flow system, the primary forces involved are the pressure forces and inertia forces. The cavitation induces vibration and hydrodynamic pulsations are set up in the hydro turbine due to pressure variations induced by implosion of bubbles / cavities.

In the hydrodynamic pulsations induced by the cavitation, the cavitation forces cause significant changes in the type of flow. To avoid resonant vibrations some means of eliminating the hydraulic excitation force, instead of altering the natural frequencies are made. Suppose when means of eliminating hydraulic excitation force is not possible alteration of natural frequencies for the turbine assembly is carried out by suitably adding stiffness to machine foundation.
1.5.4 Protection of Hydro Turbine against Cavitation

In bulb turbines cavitation starts at guide vane moving area and runner vanes gaps, at higher velocity of flowing water. When turbine runs at speeds different from the designed speed, local cavitation occurs. Leading edges of the all-guiding surfaces are to be examined for all required condition of flow particularly those, which may result in an angle of attack that deviates from the optimum. Smoothness of the surface has to be maintained in the wetted parts of the system to avoid cavitation. Air venting from outside to mix with flow in turbine has minimized cavitation not causing any loss in efficiency of the turbines.

1.6 Water Hammer In Hydro Electric Power Stations

1.6.1 Water Hammer Effects in Small Hydro Scheme

Small hydropower schemes with higher discharges are frequently associated with severe pressure variations due to the relatively small machine inertia compared to large water column inertia. Any flow change either caused by normal or abnormal situations influences the hydro dynamic response and consequently the stability and efficiency of the hydro turbines.

When a hydropower house is equipped with small Kaplan turbines having low inertia and higher specific speeds \( N_s > 500 \), abnormal surge can be easily attained at the runaway condition possibly inducing dangerous over pressures. Therefore serious safety problems can occur after a full-load rejection, when the maximum over pressure is caused by the over speed effect, which can be reached rapidly. The total duration of the guide vane closure is certainly, one of the several important parameters in this type of analysis.

1.6.2 Effect of Water Hammer in Bulb Turbines

The water hammer is very important problem in case of hydroelectric power plants, where the flow of water must be rapidly varied in accordance with the change of load on turbines. The abrupt increase of pressure, which is caused by a rapid closure of the guide vanes in hydro power plants, creates water hammer. Depending upon the rate and magnitude of the velocity change, this can lead to high-pressure fluctuations in runner vane assembly in turbine casing and guide vane assembly in distributor cones. When there is a disturbance in the power grid, the bulb turbine machine de-links from the grid.
The guide vanes of the turbine close within 7-10 seconds. The turbine stops suddenly with a violent force which creates a very high water hammer pressure inside the turbine casing. This creates a very high vibration and noise which are transmitted to the foundation through stay columns.

1.7 Conclusions

The physical dimensions of the bulb turbines are considerably large, and so the security of the machine rigidity has been considered with first priority. In this connection, various investigations on the support methods of the bulb are carried out. Various parts of the turbine and generator have been analysed for structural strength to achieve the best design for fault free operations.