COST EFFECTIVE DESIGN OF SHP PROJECT

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
ALTERNATE HYDRO ENERGY SYSTEMS

By
ISHWAR CHANDRA

ALTERNATE HYDRO ENERGY CENTRE
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE -247 667 (INDIA)
JUNE, 2012

CANDIDATE'S DECLARATION

I hereby declare that the report which is being presented in this dissertation work entitled **"COST EFFECTIVE DESIGN OF SHP PROJECT"** in partial fulfillment of the requirement for the award of the degree of Master of Technology with specialization in Alternate Hydro Energy Systems, submitted in Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee is an authentic record of my own work carried out during a period from July 2011 to June 2012 under the supervision of **Dr. S.K. Singal**, Senior Scientific Officer, Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee.

I have not submitted the matter embodied in this report for the award of any other degree or diploma.

Ishwar Chandra

Date: 14 June, 2012 (ISHWAR CHANDRA)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(Dr. S.K. Singal)
Senior Scientific officer,
Alternate Hydro Energy Centre,
Indian Institute of Technology Roorkee,
Roorkee-247667 (Uttarakhand)

ACKNOWLEDGEMENT

It is my proud privilege to express my sincere gratitude to my guide **Dr. S.K. Singal**, Senior Scientific Officer, Alternate Hydro Energy Centre for his kind cooperation, invaluable guidance & constant inspiration throughout this dissertation work. The assistance he gave is greatly appreciated.

I wish to express my profound gratitude to **Dr. R. P. Saini**, Head, Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee for providing all the facilities, which would have made it possible for me to complete this dissertation work.

I am also grateful to all faculty members and staff of **Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee.**

I extend my thanks to all class mates who have given their full cooperation and valuable suggestion for my dissertation work.

Last but not the least, I would like to express my humble respect and special thanks to my parents and others who are directly or indirectly helped me during completion of this dissertation work.

Ishwar chandra

Dated: 19 June, 2012 **ISHWAR CHANDRA**

ABSTRACT

Small hydropower (SHP) is one of the most renewable, economic, non- consumptive, non-radioactive, non-polluting and environmentally benign sources of energy. Small hydro power development can reduce the load on conventional sources of energy. The cost of small hydro power generation can be maintained at attractive levels, despite periodic modifications in the regime of fiscal incentives through higher efficiencies and improved performance obtained from new hydro turbine designs; larger scale and more efficient manufacturing; better levels of operation and maintenance and development of sites in clusters.

In India, about 5718 potential SHP sites each having capacity up to 25 MW have been identified in various parts of the country. A vast potential of small hydropower is available under the range of small head hydropower schemes. Low head SHP projects are inherently expensive, as the large discharges, which need to be passed through the turbines require large machines. It is therefore always desirable to minimize their capital cost.

In the present study an attempt has been made to discuss various parameters affecting cost of small hydro power plants. The cost of the scheme has been determined for different alternative layouts based on different combinations of components of SHP. A cost effective combination has been suggested based on cost incurred in different alternatives of SHP projects.

A case study has been carried out having capacity 2000 kW at 15m head. Different layouts based on type of low head turbine have been considered and costs have been determined for all options. Based on investment cost and generation cost, the cost effective option has been suggested.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION AND LITERATURE REVIEW

1.1 GENERAL

Energy is a basic requirement for economic development. Every sector of Indian economy - industry, agricultural, transport, commercial and domestic needs input of energy. The installed electricity generating capacity in India at present is nearly 199.627 GW; of this thermal is 65.79%, hydro 19.53%, nuclear 2.39% and renewable 12.27% [1]. According to International Energy Agency, a threefold rise in India's generation capacity is expected by 2020. As the non-renewable fossil energy sources continues to deplete, and realizing the summits held at Brazil and Kyoto, to reduce the greenhouse gas emissions, hydro power has moved towards the top power development option to meet the increasing energy demand. Hydropower is the cheapest, non-polluting and uses renewable resource i.e. water. It is perhaps the oldest renewable energy technique known to mankind - for mechanical energy conversion as well as electricity generation. Hydropower represents use of water resources towards inflation free energy due to absence of fuel cost - with mature technology characterized by highest prime moving efficiency and spectacular operational flexibility. The conventional large hydropower plants have problems like long gestation period, ecological changes, loss due to long transmission lines, submergence of valuable forest and underground.

Hydropower is a prime example of sustainable energy utilization. It can be described as a "beneficiary" of the processes which are necessary to support all life on earth: the heat of the sun evaporates the water in rivers, lakes and oceans and makes it rise into the atmosphere, where it is condensed above cooler regions and returns to earth as rain, hail or snow. Water that is not collected in the oceans or seeps into the ground is collected in lakes, river and streams. The power of water can be captured during its journey to the ocean. This is possible by capitalizing on difference in height, which can be used for power generation in hydropower stations. Hydropower plays an important role in supporting the world economy.

In addition to hydro power being a renewable source of generating power, unlike wood, coal, oil and natural gas during the combustion of which carbon dioxide, sulphur dioxide and methane gases are released into the atmosphere –and consequently contributes to the greenhouse effect – the prudent utilization of hydropower leaves the ecosystem largely untouched. Among the sources of alternative renewable energies, such as wind, solar, geothermal and biomass, hydropower is attractive as other renewable sources like wind and solar are available intermittently. Additionally, this technology has now acquired a very high degree of maturity; the high efficiencies of hydro turbines can, at best, be improved further only in the decimals behind the point. Currently, many hydro turbines operate at over 90 percent efficiency. These are all factors which makes the controlled utilization of hydropower unique.

1.2 SMALL HYDROPOWER

In India development of small hydro power has been taking place since its first hydro installation of 130 kW at Darjeeling in the year 1897. An estimated potential of 15000 MW of small hydro exists in India. However, nearly 15384 MW have been actually identified through 5718 sites. In Himalayan area of northern India, perennial streams with small discharges are available which can be harnessed for small hydro power generation. The advantages of small hydro are low gestation period, low initial cost. No shifting of locals from their land, no loss to environment etc.

1.2.1 Definition of SHP

A SHP station is an installation where hydraulic power is used to generate electricity by means of one or more turbine-generator units. In India the power plants having installed capacity up to 25 MW are considered small hydropower plants. Internationally, there is no concern over capacity of small hydropower projects- It varies from 5 MW to 50 MW.

1.2.2 Classification of Small Hydro Power Plants

The hydropower plants can be classified according to their function as follows [2].

i. Run-of-River
ii. Canal Based
iii. Dam Toe Based

i. Run-of-River Scheme

Run-of-River hydroelectric schemes are those, in which water is diverted towards power house, as it comes in the stream. Practically, water is not stored during flood periods as well as during low electricity demand periods, hence water is wasted. Seasonal changes in river flow and weather conditions affect the plant's output. After power generation water is again discharged back to the stream. Generally, these are high head and low discharge schemes. The typical run-off river scheme is shown in Fig. 1.1.

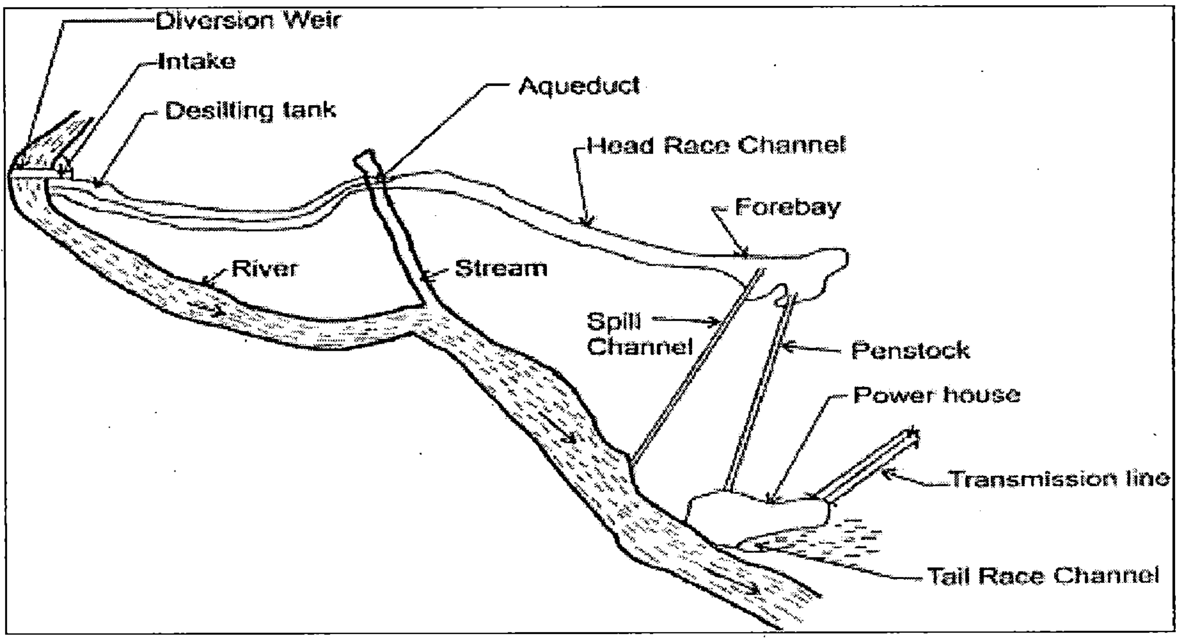

Fig. 1.1 Typical arrangement of run of river scheme [3]

ii. Canal Based Scheme

Canal based small hydropower scheme is planned to generate power by utilizing the fall in the canal. These schemes may be planned in the canal itself or in the bye pass channel. These are low head and high discharge schemes. These schemes are associated with advantages such as low gestation period, simple layout, no submergence and rehabilitation problems and practically no environmental problems. The typical canal based scheme is shown in Fig. 1.2.

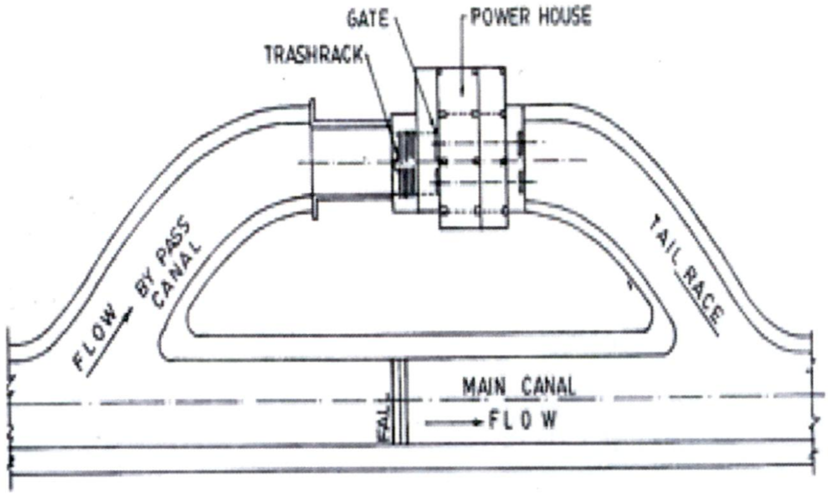

Fig. 1.2 Typical arrangement of canal based scheme [4]

iii. Dam Toe Scheme

In this case, head is created by raising the water level behind the dam by storing natural flow and the power house is placed at the toe of the dam or along the axis of the dam on either sides. The water is carried to the powerhouse through penstock. Such schemes utilize the head created by the dam and the natural drop in the valley. Typical dam toe based scheme is shown in the Fig. 1.3.

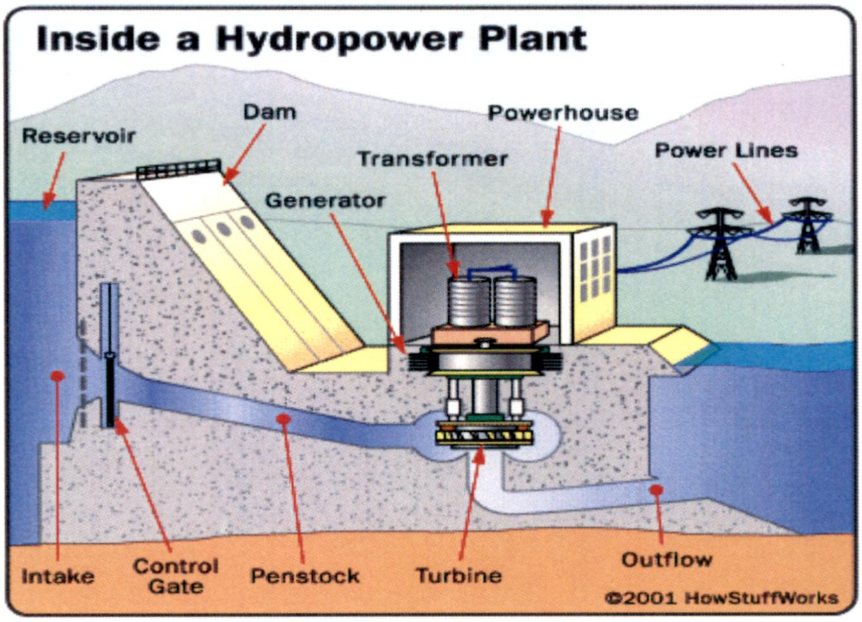

Fig. 1.3 Typical arrangement of dam toe scheme [5]

1.2.3 Classification of SHP Based on Head

The net head and the plant discharge are two important parameters to be considered in the small hydropower design. The following classification is adopted based on hydraulic head under which the turbine will operate. Hydroelectric sites are divided into three categories based on head as low, medium and high; each category requires different design [6].

These suggested limits are not rigid but are merely a means of categorizing the sites.

1. Ultra Low head scheme — Below 3 m head
2. Low head scheme — 3-20 m head
3. Medium — 20-60 m head
4. High head scheme — more than 60 m head.

A large number of sites identified for small hydro development normally in irrigation works are in the low-head category.

1.3 Basic Components of SHP Schemes

Basic components of SHP schemes are broadly categorized into two parts:

i. Civil works

ii. Electromechanical equipment

Most of the components are common in different types of schemes; however, some components are different for different schemes. A broad classification of SHP components is given in Fig. 1.4 as follows

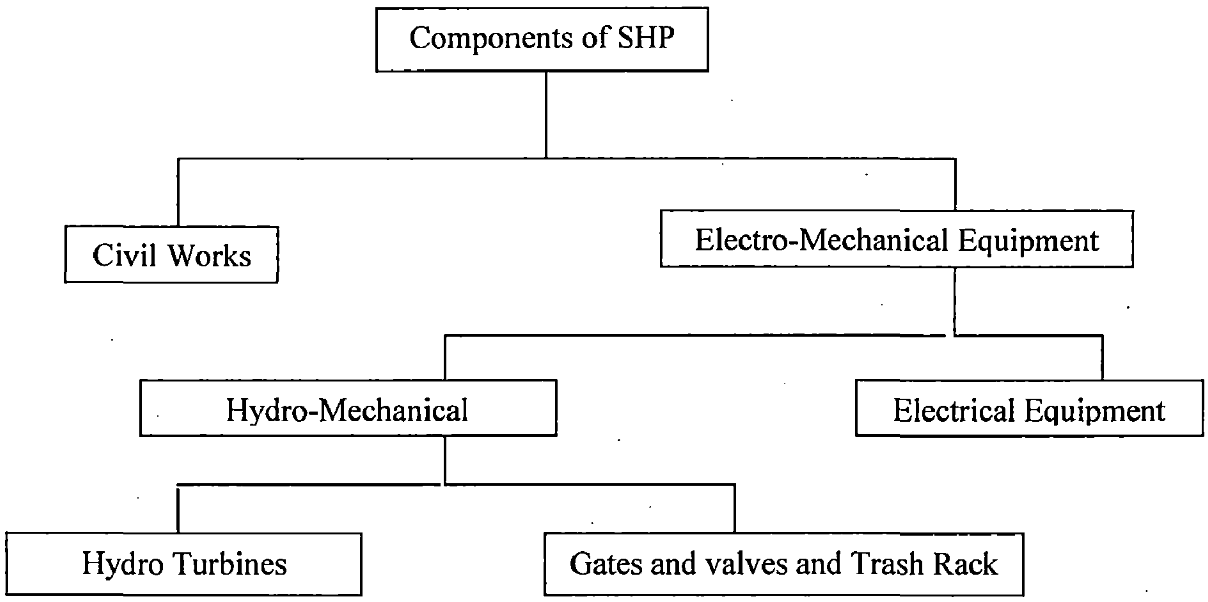

Fig. 1.4 Different components of small hydro power schemes [7]

1.4 LITERATURE REVIEW

Among all the renewable energy sources, small hydropower is considered to be one of the most promising. On the basis of available literature, the gross potential of SHP projects is more than 15 GW. To take investment decision for the development of small hydropower projects, technical feasibility and financial viability are considered to be the foremost requirements.

Alexander and Giddens [8] presented an overview of a program that is in the final stages of developing a modular set of cost-effective micro hydro schemes for site heads below those currently serviced by Pelton Wheels. The rationale has been that there is a multitude of viable low-head sites in isolated areas where micro hydro is a realistic energy option, and where conventional economics are not appropriate, especially in Third World countries. The goals of this project have been to provide low-cost, soundly based turbine design solutions that systematically cover the 0.2–20kW supply, that are uniquely resistant to debris blockage and are easily built by tradesmen of medium skills in regional workshops. The paper presents the results as a matrix of the most cost-effective penstocks matched to modular turbines using established electronic controls. It discusses practical issues of site selection and options for sites where exact matches are not achieved. It has been an object of the program to establish a benchmark for cost-effectiveness in the micro hydro field.

Voros et al. [9] in their work analysed the problem of designing small hydroelectric plants and addressed in terms of maximizing the economic benefits of the investment. An appropriate empirical model describing hydro turbine efficiency was developed. An overall plant model was introduced by taking into account their construction characteristics and operational performance. The hydro geographical characteristics for a wide range of sites have been appropriately analyzed and a model that involves significant physical parameters has been developed. The design problem was formulated as a mathematical programming problem, and solved using appropriate programming techniques. The optimization covered a wide range of site characteristics and three types of commercially available hydro turbines. The methodology introduced an empirical short-cut design equation for the determination of the optimum nominal flow rate of the hydro turbines and the estimation of the expected unit cost of electricity produced, as well as of the potential amount of annually recovered energy.

Anagnostopoulos et al. [10] presented a numerical method is used for the optimal sizing of such a plant that comprises two hydraulic turbines operating in parallel, which can be of different type and size in order to improve its efficiency. The study and analysis of the plant performance is conducted using a newly developed evaluation algorithm that simulates in detail the plant operation during the year and computes its production results and economic indices. A parametric study is performed first in order to quantify the impact of some important construction and operation factors. Next, a stochastic evolutionary algorithm is implemented for the optimization process. The examined optimization problem uses data of a specific site and is solved in the single and two-objective modes, considering, together with economic, some additional objectives, as maximization of the produced energy and the best exploitation of the water stream potential. Analyzing the results of various optimizations runs, it becomes possible to identify the most advantageous design alternatives to realize the project.

US Army Corps of Engineers [11] presented discussion of the general, architectural & structural consideration applicable to the design of hydroelectric power plant structures. Discussions could be used in establishing minimum criteria for the addition of hydro power facilities at existing projects, like location of the power house, switchyard, highway, railroad access and other site features. Location of the powerhouse is determined by the overall project development factors like location of spillway navigation locks and accessibility. For location of switchyard, considerations should be given to the number and direction of outgoing transmission lines, however the most desirable and economical location adjacent to the power house was suggested. Highway and railroad should be easily approachable for easy transportation and thus reducing the cost.

Ogayar [12] one of the most important elements on the recovery of a small hydro-power plant is the electromechanical equipment (turbine–alternator), since the cost of the equipment means a high percentage of the total budget of the plant. The present paper intends to develop a series of equations which determine its cost from basic parameters such as power and net head. These calculations are focused at a level of previous study, so it will be necessary to carry out the engineering project and request a budget to companies specialized on the construction of electro-mechanical equipment to know its cost more accurately. Although there is a great diversity in the typology of turbines and alternators, data from manufacturers which cover all the considered range have been used. The above equations have been developed for the most common of turbines: Pelton, Francis, Kaplan and semi Kaplan for a power range below 2 MW. The obtained equations have been validated with data from real installations which have been subject to analysis by engineering companies working on the assembly and design of small plants.

Thapar [13] presented the existing state of art in respect of relevant alternative technologies available for small low head and micro hydro power plants with particular reference to turbine. Author suggested that the water resources, though renewable, are certainly limited. Their exploitation hence will depend on careful application of technological innovation. Small scale hydro-power development may have only a small impact on the locality in which it is sited can be significant in as much as it can help stimulate growth of rural industry and assure the population of the basic energy needs comprising of domestic, community and agriculture requirement.

Montanari [14] presented an original method for finding the most economically advantageous choice for the installation of micro hydroelectric plants. More precisely, the paper that follows is to be considered in a context defined as "problematic" by those who have the job of constructing water-flow plants with only small head and modest flow rates. With these initial data one can see immediately that the specific energy of the fluid is low and it is therefore necessary to elaborate large masses of water in order to obtain work, and therefore a return, to render such an investment profitable. Traditional plant solutions using Kaplan or Francis type turbines must be rejected because of the high levels of initial investments. Much more simple configurations must be analysed, such as plants with propeller turbines or Michell–Banki turbines, in order to reduce the investment costs.

Gordon et al. [15] discussed about many different types of turbine configurations available for low-head small hydro developments. This article outlines the steps used in conjunction with a computer program, to arrive at the types of units available for the site. The input data for the program includes the flow, desired number of units, the head, the system frequency, the tail water level, and the operating pattern in hours per annum at each flow, as obtained from a flow-duration curve. The program calculates the runner size and setting relative to tail water, speed, power output, provides charts showing turbine efficiency as a function of both flow and power, the power plant kWh output and the turbo-generator water-to-wire cost, for 10 different turbine configurations. The data is then screened for applicability to the site, and the inappropriate units discarded. The remaining units are further compared, and two units are recommended, one based on maximum weighted efficiency, and the other on minimum cost per kWh output.

Morel, T et al. [16] studied about reducing kinetic energy losses in low head hydro power. In order to reduce costs, low-head hydropower plants are using turbines with increasingly higher specific speeds. A negative aspect of this trend is a resulting decrease in turbine efficiency. The present study addresses the issue of the kinetic energy of water leaving the runner and shows that at higher specific speeds it accounts for a large proportion of the available head. This places a special emphasis on the performance of draft tubes which must recover most of this energy in order to make high specific speed machines competitive on an economical basis. The study further reviews available diffuser literature. Several potentially attractive means for the development of highly efficient and compact draft tubes suitable for low-head (high specific speed) applications are identified and discussed.

Mankbadi et al. [17] outlined a method for determining the optimum operating conditions of a turbine-generator unit installed across a low-head irrigation structure for electrical power generation. For given regulator characteristics, the unit rated power and design parameters are determined in such a manner that its cost-benefit ratio is a minimum. The economic feasibility of the micro hydro plant is studied by comparing its lifetime cost to its lifetime benefit. The benefit is taken as the cost of the corresponding energy generated through a diesel-driven generator set. The micro hydro plant is found to be economically competitive over a wide range of inflation and interest rates.

Ronald et al. [18] demonstrated with applications, that the use of a computer-aided preliminary optimization model can help evaluate the overall technical and economic characteristics of low-head hydro installations. The model can provide realistic information on the optimum operational ranges of impulse, reaction and cross flow turbines, as well as the relevant discharge, power output and cost characteristics for various alternative scenarios. The program LOHED analyzes discharge/gross head data to predict available power for a variety of different penstock sizes. It also selects preliminary turbine characteristics based on actual data gathered from various turbine manufacturers. The program FINAN uses the output from LOHED along with some initial cost data for specific equipment and materials, synthesizes a cash flow over the life of the project, and amortizes it to a present value.

Larsen and Johannes [19] presented that the design of hydro intakes is usually based on a desire to achieve low intake losses and an acceptable approach flow distribution to the turbine. Generally, velocities in the intake canal are low, therefore canal losses are small, and the major concerns become flow distribution at the intake and trash rack losses. Model studies are often used to develop an acceptable design, discusses the concerns that should be covered in such studies.

Rao et al. [20] carried out their investigations that a simplified runner profile for a low head axial flow micro hydro turbine, which could be more economical than conventional machine runners with aerofoil-shaped blades, has been developed and tested recently in India. The simplicity of design means that the units could be manufactured in small workshops making them particularly suitable for applications in developing countries. Their article focuses on investigations carried out at the Pune Research Station on the new runner's resistance to cavitation erosion.

Passmore [21] in his paper said that for sources of hydraulic energy where the head is less than about 15 m, plants using small axial-flow turbine/generating units can be a practical means for generation of useful electrical energy. This paper describes the various forms that these generating units may take with particular emphasis on their application for small isolated loads where frequency controls would be necessary.

Banda [22] shows importance of selection of free board in headrace canal design, as it would help to prevent overflow under different flow conditions. As free board should necessarily to keep at its minimum as it contributes to civil cost substantially at one end and simultaneously freeboard should be sufficient otherwise could cause soil erosion and associated environment problems. The author describes various factors to be considered while selecting the freeboard at head race canal design stage, the factors like topography of the canal route, canal size, curve radius, blockage canal, spill sections and surges due to plant shut down etc. And also illustrates how each of those factors is incorporated in the optimization process of hydropower schemes.

Singal et al. [23] developed various curves using ANN (Artificial Neural Networks) model, to determine the various dimension of civil structures of SHP projects located on canal fall based on head and discharge available for power generation at these type of projects. The authors used the data of 10 ongoing SHP projects on canal falls in Bihar state and curves for planning of civil works have been obtained on the basis of ANN model developed. The limitation of these curves is that these may only be used for those small hydropower projects which are located on the canal falls.

Gaur and Majumdar [24] advocated the installation of canal drop in preference to other hydel projects. The authors have recommended the use of axial flow tubular turbine for canal drops. Their company M/s Jyoti Ltd. has standardized runner diameter varying from 600 mm to 2000 mm, upto an output of 3000 kW, with head rang 2.5 m to 20 m and flow rate upto 30 cumecs. Certain measures had been suggested to bring down the cost through proper design and standardization.

Mudgal et al. [25] constructed model of scale 1:100 of low head (canal based) hydropower plant to achieve designated head through model studies. The authors use HEC-RAS (Hydrologic Engineering Centre-River Analysis System) software for design and analysis and results are implemented in the physical model. So the authors concluded that the deviation b/w physical model and HES-RAS ranged from 9% in initial trials to <5% in the final trials, the HES-RAS can be productively used to achieve optimal channel alignment for canal based installation to achieve required head with the acceptable standard of accuracy.

Kar [26] presented the operational features of various types of turbines developed for heads ranging from 3m to 30m and output upto 12 MW, indicating the limitations of each type with respect to head, output, flow quantities etc. standard hydro-mechanical governor or electronic governor has been suggested. The author has suggested governor speeds of 750, 1000 and 1500 rpm for consideration. An important point the author has made is the restriction imposed on a standardized rotor construction on account of very high run away speeds, which may needs further studies. While agreeing to the use of induction generators, the author has suggested a detailed study on the subject, in the absence of sufficient practical information available in the country..

Schilling et al. [27] emphasized the importance of an efficient flow deceleration downstream the runner to recover the corresponding velocity head, as the tubular turbines with increasing specific speed are mostly used in the utilisation of low head hydropower and high amount of kinetic energy flow in these types of turbines. The authors subjected to the joint consideration of draft tube and tail water as flow decelerating elements. The authors have investigated three typical draft tube geometries in a bulb turbine test rig with realistic tail water flow. The authors obtained good results of tail water head recovery, these results may be useful as a guideline for the planning engineer.

Reda and Sami[28] presented a method for estimating the design parameters and operating conditions of a turbine-pump unit installed to utilize the available low head hydro-energy of irrigation structures, as the available low head energy is used to drive a turbine connected to a pump, to lift water for irrigation or domestic purposes. The authors considered the equations governing the operation of the system. The authors concluded that the system can be designed to pump the maximum possible amount of flow at design as well as off-design conditions and the system should be considered when- ever water pumping is needed for irrigation purposes or water supply and where low head hydro is available.

Singal and Saini [29] analyzed the cost of low head run-of-river projects & canal based projects. The authors evaluated the cost of the projects based on the actual quantities of the components and prevailing market rates. The determined costs for different cases have been correlated by regression analysis methods. The authors stated the maximum deviation of ± 11% between the actual costs and the cost predicted based on correlations In case of low head run of river projects and ±12% maximum deviation In case of canal-based SHP schemes. Which may be considered as a good prediction for cost estimate of SHP projects at the planning stage

Singal and Varun [30] presented planning and designs of small hydroelectric schemes as an evolving process leading to safe and cost effective refinements in designs. The major factor for high cost of civil works of the these schemes is conventional designs coming out of designers with a mind set, that of miniaturizing a major hydro model for small/mini hydro, there-by including many of the components not required or used in small hydro operation at all. First and foremost step needed is to break this mindset and reduce the civil cost of small hydro projects by innovative and practical designs. The lesson learnt from the experience and use of new technologies make small hydropower plants economically viable. Use of local materials and site-specific design/solutions make the scheme cost effective and reduce the operation and maintenance cost.

1.5 GAPS IDENTIFIED

From the literature review it has been observed that cost reduction is particularly important in the case of low-head SHP projects as it has significant potential.

i. There is lot of work to be done in head-enhancement techniques for very low head SHP projects.

ii. There is need of research work to be carried out to reduce the penstock installation cost. It includes assembly and laying down technique as well as materials.

iii. There is still lot of work to be done in development of efficient desilters with high head intakes, and of trash racks.

iv. There is lot of work to be done in development of low-head turbines, to create very high guaranteed efficiencies and to reduce the cost of whole power plant.

v. There is lot of work needed in development of fish friendly turbines guaranteeing high turbine performance and low cost.

vi. There is lot of work needed in development of submersible turbo-generator.

vii. There has been lot of work done for cost effective turbine design in micro hydro range but not in the range of SHP i.e. there has been lot of works done for cost effective design of governor, penstock, civil structures including weirs, spillways, penstocks etc for micro hydro range but not for SHP range.

1.6 OBJECTIVES OF THE PRESENT WORK

Due to diversification in layout/configuration of small hydro plant, numbers of cost equations were developed to suit the site conditions. It was found that number of contributions exists for determining the installation cost using the head and capacity as cost influencing parameter. Similarly different optimization approaches have been used and implemented to obtain the optimum investment required for installation of the plant. The problem associated with small hydro is initial capital cost which becomes the overriding issue. Each proposed site requires individual engineering considerations for civil works as well as for equipment. The cost of small hydro power plant would depend largely on proper selection of turbine, good planning of the layout of the scheme on optimization basis, competent hydrological and power potential studies, careful and correct designs of structures, proper estimates with realistic rates and use of construction techniques appropriate to small hydro and efficient execution. On the basis of available literature, it is seen that cost of turbines used in high head range have less contribution in total cost as compared to the cost of turbines used in low head range as in case of low head range physical sizes are bigger. From the study it is found that for the cost effective design of small hydro power project methods have been carried out by using simple techniques; however it is recommended to use evolutionary algorithm and other new techniques for the cost effective design of small hydro power project. The main objectives are as following:

i. Study of various cost reduction measures in components of SHP project.
ii. Selection of a component for cost effective design.
iii. Analysis for various options for selected component.

CHAPTER 2

COMPONENTS AND THEIR SELECTION FOR SMALL HYDRO POWER

2.1 GENERAL

The Components of small hydro power plants can be divided into two categories civil components and electro mechanical components. While selecting the components, the following points should be kept in mind.

2.1.1 Reliability

The risk and acceptability of the outage has to be assessed in relation to the electrical market and to the cost of providing increased reliability. The acceptability of the outage depends on the degree of dependence of the consumers on an able supply of electricity. Small hydro scheme to the small isolated system has low requirement for reliability while larger isolated systems like urban areas have higher requirement for the reliability. Simple and low cost components may be used for low requirement of reliability.

2.1.2 Construction

The selection of component should take into account the range of resources available for the construction of small schemes. The choice of materials is less for remote undeveloped areas as compared to urban areas. Special construction techniques such as those necessary for large dams, canals should be avoided and locally available materials should be used as far as possible.

2.1.3 Cost

The significance of the components in relation to total the scheme must be reflected in engineering studies for selection of components at the reconnaissance stage. As there is large uncertainty about the cost of civil works, these form the major part of the engineering studies at the reconnaissance stage.

2.2 COMPONENTS OF RUN OF RIVER SHP PROJECT

Run-of-River hydroelectric schemes are those, in which water is diverted towards power house, as it comes in the stream. Practically, water is not stored during flood periods as well as during low electricity demand periods, hence water is wasted. Seasonal changes in river flow and weather conditions affect the plant's output. After power generation water is again discharged back to the stream. Generally, these are high head and low discharge schemes. The typical run of river scheme is shown in Fig. 2.1.

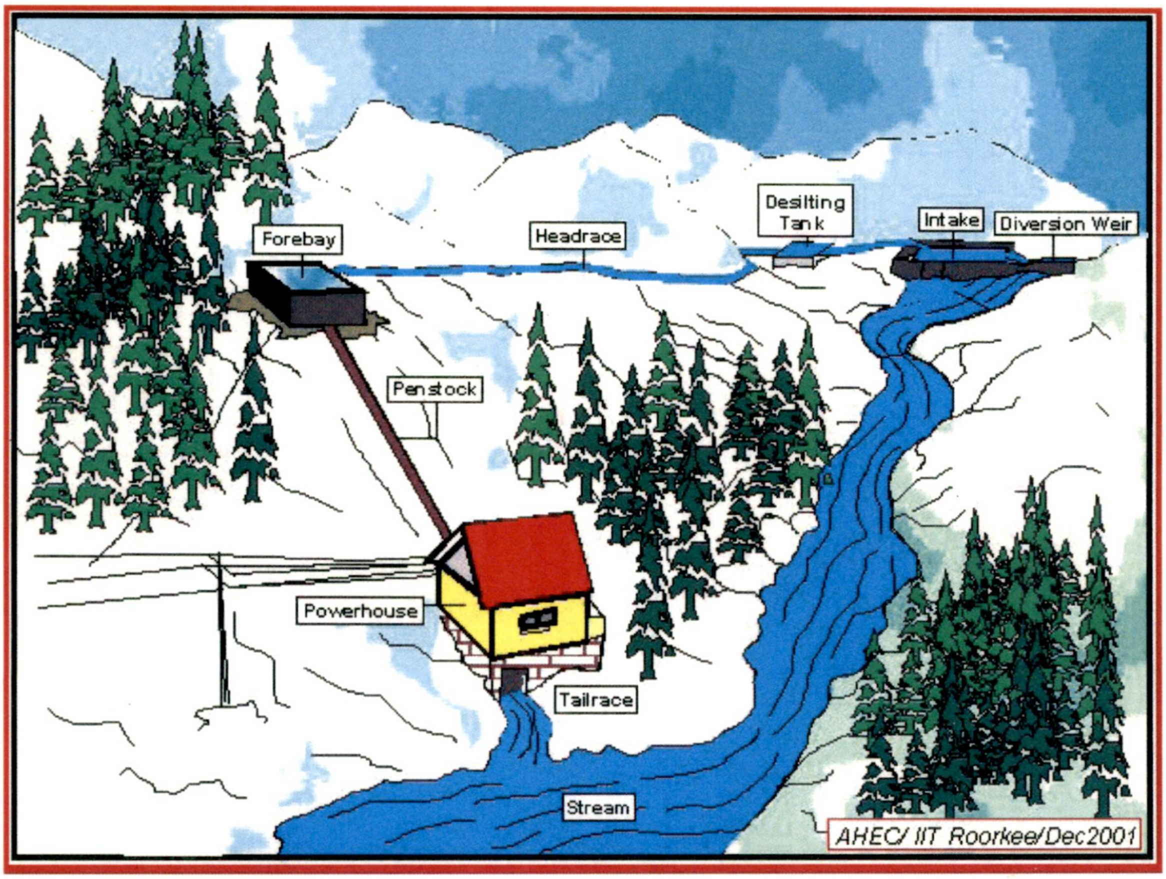

Fig.2.1 Typical arrangement of run of river scheme

The basic components of run of river small hydropower project can be broadly classified as:

a) Civil works
b) Electromechanical equipment

Civil works consists of the following subcomponents:

i. Diversion weir and intake
ii. Desilting tank
iii. Head race channel
iv. Forebay tank
v. Penstock
vi. Powerhouse building
vii. Tail race channel

The electromechanical equipment consists of the following subcomponents:

i. Turbines with governing system
ii. Generator with excitation system, switch gear, control, and protection equipment
iii. Electrical and mechanical auxiliaries
iv. Main transformer and switchyard equipment

2.2.1 Intakes

The side, front and bottom intakes are mostly used for small hydro schemes. The side and front intakes are suitable for river with sand and silt bed load. The bottom one is more appropriate for mountain streams. The demanders may be provided to reduce the suspended load so as to reduce bear on turbines and blocking of penstock or head race.

Basic functions of intakes are-

i. Assured water supply.
ii. Suitable quality of water.
iii. Control over supply of water.
iv. Safety against floods.

An important part of any SHP is also an water intake structure. Nevertheless, they paid insufficient attention. This is evidenced by the whole council of operational difficulties or failure of objects already constructed and the overall stagnation in their design and research. The greatest deficiencies in the design of intake structures arise when schematic download already completed structures. At one flow may one type of intake structure have very good results, but at another flow, even if partly similar, the same type may show poor results. Operational issues adversely affecting mainly small hydropower plants with a low output level and even becoming a limiting factor for their further development.

i. Trench Weir

Trench weirs are commonly adopted in boulder streams for diverting water for use in hydropower, irrigation and water supply schemes etc. Here, a trench is built across the river below its bed level. The top level of this trench is covered with bars to prevent the entry of sediment into the trench. Discharge characteristics of this weir apart from flow conditions also depend on the geometric characteristics of the bars used. Generally round bars are used, however, from a structural consideration, flat bars are preferred over round bars as flat bars have more flexural rigidity.

Conventional types of raised-crest weir are not suited for boulder streams for diverting water for use in hydro power generation, irrigation, water supply etc. The raised-crest weirs cause changes in the flow conditions on the upstream. As a result sediment de-position occurs on upstream of the crest and the intake also gets choked up. Further, severe erosion occurs downstream of the weir leading to breaches in the weir .
The most suitable type of diversion weir adopted in boulder streams therefore is a trench weir, which overcomes the above mentioned problems. It is simply a trench built across the stream below its bed level. The top of the trench weir is covered with bottom rack bars. Water while flowing over it, passes through the bottom racks and enters into the trench and is collected in an intake well located at one of the banks of the trench. The top edge of the trench weir is almost flush with the natural bed surface of the stream. The bottom racks which consist of heavy rounded steel bars or flats are laid on edge and placed parallel with the river flow on the river bed level.

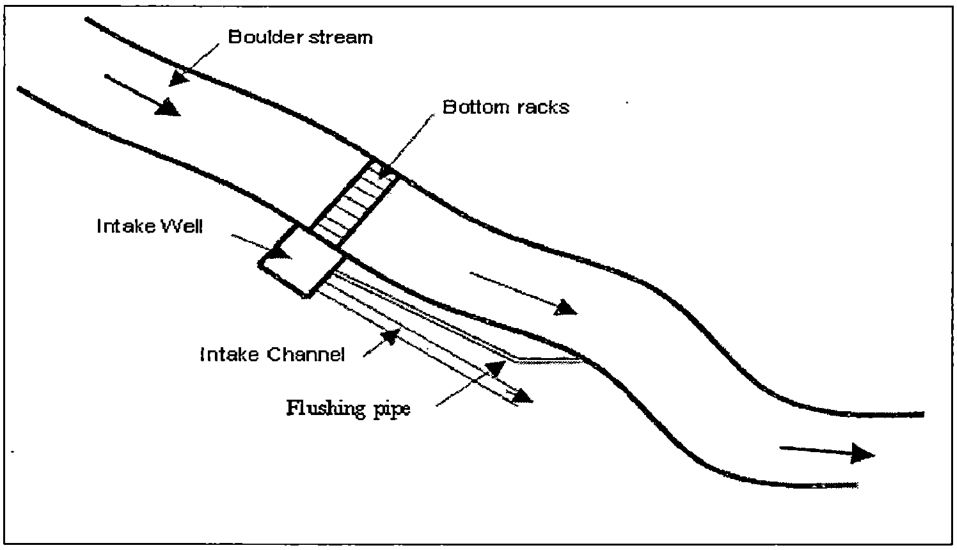

Fig.2.2 Definition sketch of trench weir [31]

ii. Rock fill weir

In a rock fill type weir, in addition to the main weir wall, there are a number of core walls. The space between the core walls is filled with the fragments of rock (called rock fill). A rock fill weir requires a lot of rock fragments and is economical only when a huge quantity of rock fill is easily available near the weir site. It is suitable for fine sand foundation. The old Okhla Weir across the Yamuna River is a rock fill weir. Such weirs are also more or less obsolete these days.

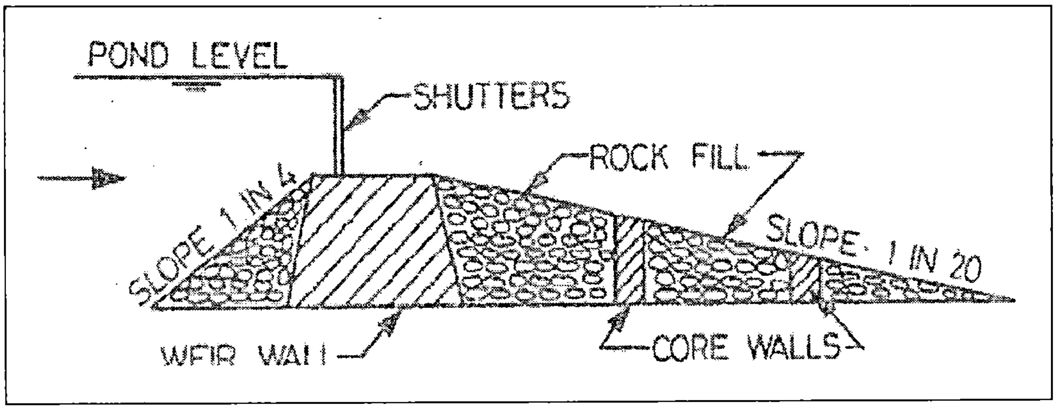

Fig. 2.3 Rock fill Weir

iii. **Vertical drop weir**

A vertical drop weir consists of a masonry wall with a vertical (or nearly vertical) downstream face and a horizontal concrete floor. The shutters are provided at the crest, which are dropped during floods so as to reduce afflux. The water is ponded up to the top of the shutters during the rest of the period. Vertical drop weirs were quite common in early diversion head works, but these are now becoming more or less obsolete. The vertical drop weir is suitable for hard clay foundation as well as consolidated gravel foundations, and where the drop is small. The upstream and downstream cuts off walls (or piles) are provided up to the scour depth. The weir floor is designed as a gravity section.

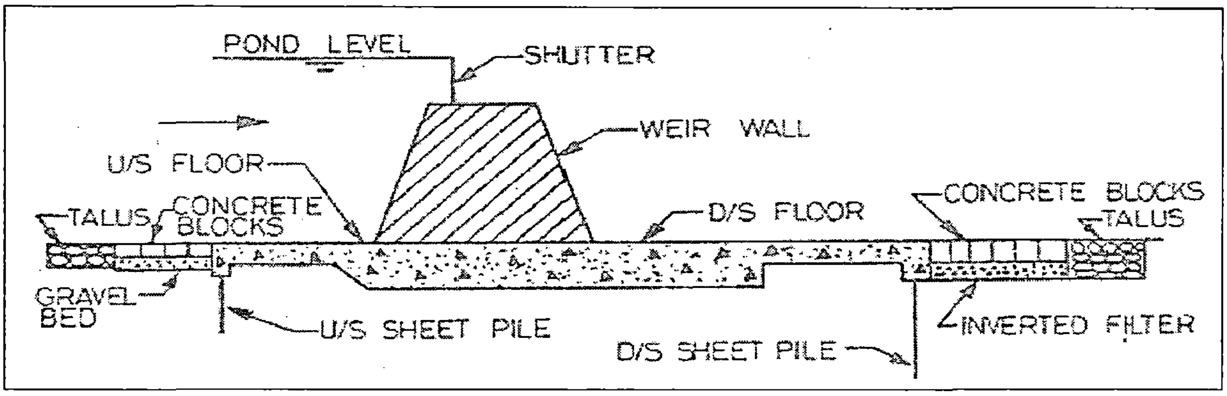

Fig. 2.4 Vertical drop weir

iv. **Concrete weir with sloping glacis**

Concrete sloping weirs (or glacis weirs) are of relatively recent origin. The crest has glacis (sloping floors) on upstream as well as downstream. There are sheet piles (or cut off walls) driven upto the maximum scour depth at the upstream and downstream ends of the concrete floor. Sometimes an intermediate pile is also driven at the beginning of the upstream glacis or at the end of downstream glacis. The main advantage of a sloping weir over the vertical drop weir is that a hydraulic jump is formed on the d/s glacis for the dissipation of energy. Therefore, the sloping weir is quite suitable for large drops. [4]

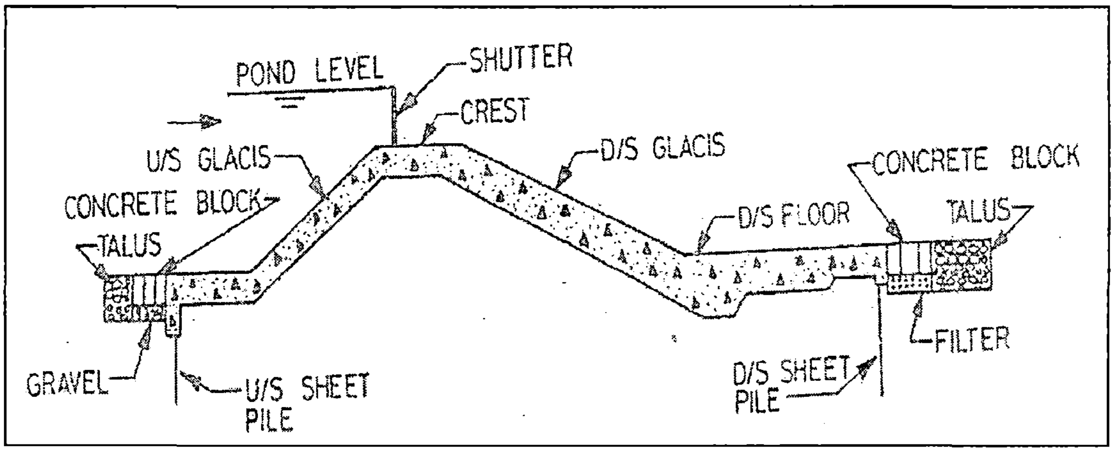

Fig. 2.5 Concrete weir with sloping glacis

v. Coanda weir

There is a growing need on water resources projects to screen water to remove and salvage fine debris and small aquatic organisms. This presents significant challenges for traditional screen technologies. As the target of the screening effort is reduced in size, screen openings generally must also be reduced and screen areas increased to obtain suitably low flow velocities through the screen. In most cases, maintenance effort required to keep screens clean is dramatically increased when finer material must be screened, even if velocities are kept low. One screen design that offers potential for economically screening fine materials with a minimum of clogging and cleaning maintenance is the Coanda-effect screen , also known as the static inclined screen. This self-cleaning screen with no moving parts has been successfully used for debris and fish exclusion at several prototype sites.

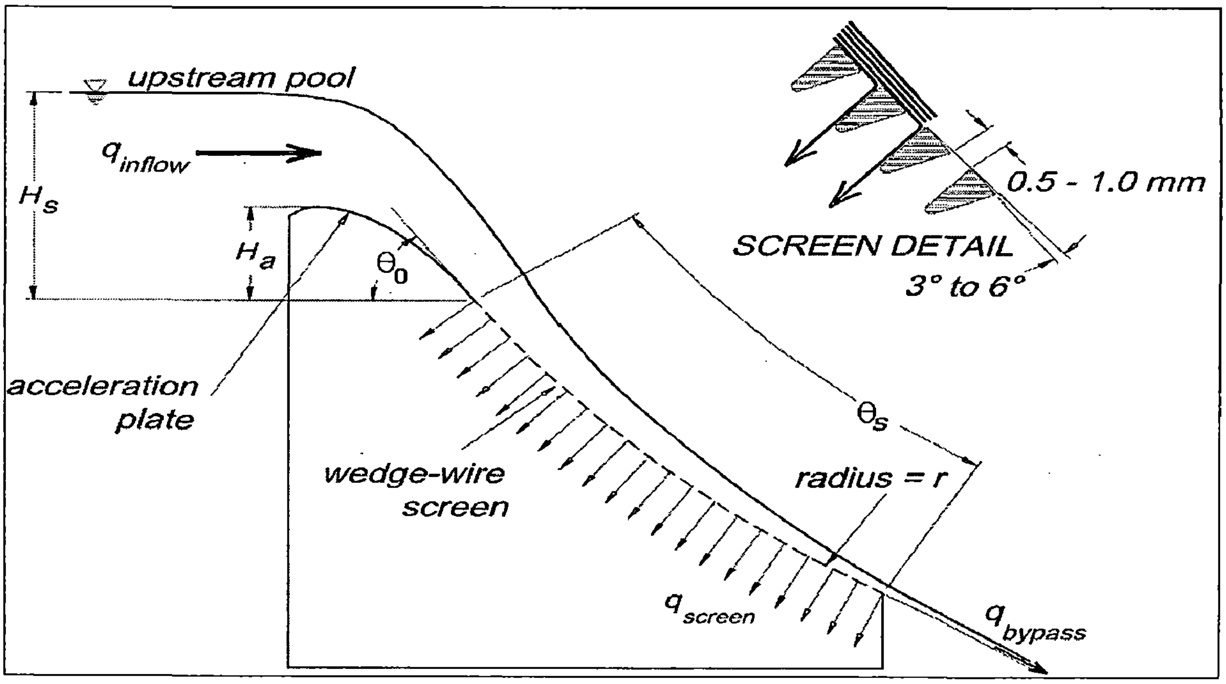

Fig. 2.6 Features, typical arrangement and design parameters for coanda-effect screen[32]

vi. Inflated weir

Inflatable weirs are another method, capable of remote control, is the *inflatable weir,* which employs a reinforced rubber bladder instead of concrete, steel or wood flashboards. This offers an alternative to more conventional methods of weir construction, with the inherent advantages of low initial cost, simple operation and minimal maintenance. In effect, inflatable weirs are flexible gates in the form of a reinforced, sheet-rubber bladder inflated by air or water, anchored to a concrete foundation by anchor bolts embedded into the foundation. Like any other gate, the inflatable weir needs a mechanism by which it is opened and closed. The weir is raised when filled with water or air under pressure. An air compressor or a water pump is connected, via a pipe, to the rubber bladder. When the bladder is filled the gate is raised; when it is deflated the weir lies flat on its foundation, in a fully opened position. The system becomes economic when the width of the weir is large in relation to the height. When the management and operational safety of the system is rather critical, the use of inflatable. Weirs can give substantial advantages over conventional systems. An electronic sensor monitors the upstream water level and the inner pressure of the bladder.

A microprocessor maintains a constant level in the intake entrance by making small changes in the inner pressure of the bladder. To avoid flooding land, a similar device can regulate the inflatable weir regulated to correspond to a pre-set upstream water level. Inflatable gate control systems can be designed to fully deflate the bladder automatically in rivers prone to sudden water flow surges. On a typical weir, two meters high and thirty meters wide, this can be done in less than thirty minutes. Photo illustrates a new type of inflatable weir - patented by Obermeyer Hydro - where the sheet rubber incorporates a steel panel that behaves as a flashboard, which is quickly and easily moved in the event of sudden floods. By controlling the pressure in the rubber blade the steel panels may be more or less inclined, varying the level of the water surface. The system incorporates an additional advantage: the rubber blade is always protected against boulders carried during flood flows (buoyancy causes heavy boulders to lose a portion of their weight in water, making it easier for the flood flow to carry them downstream)

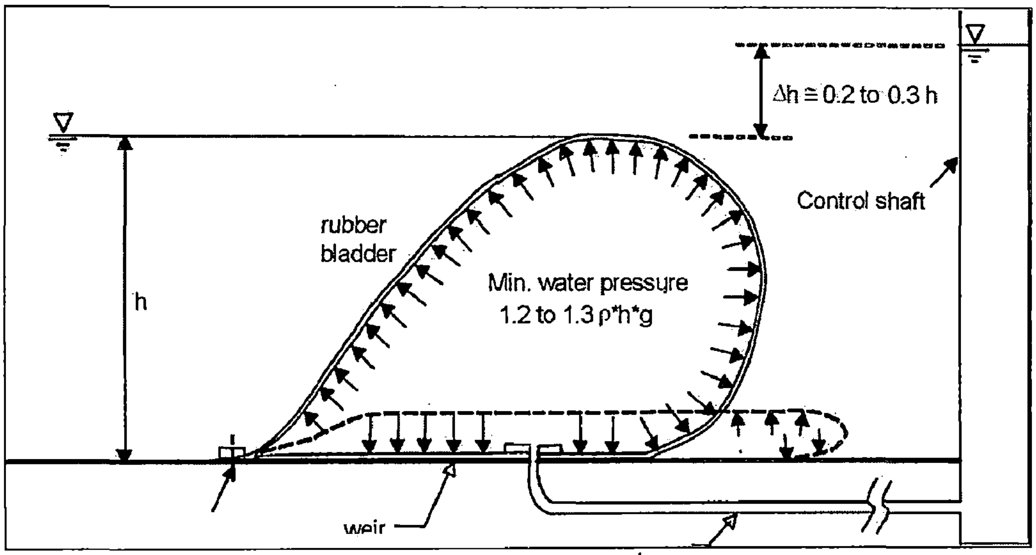

Fig. 2.7 Inflated Weir [33]

vii. Labyrinth weir

In some small hydropower schemes (e.g. small schemes in an irrigation canal) there is not enough space to locate a conventional spillway. In these cases, U shaped or labyrinth weirs should help to obtain a higher discharge in the available length. A labyrinth weir is made of thin vertical reinforced concrete, and appears in plan view as a series of trapezoids. In a typical installation, the total crest length is about four times the structure length, the nappe depth is half the wall height, and the discharge capacity is roughly double that of a traditional weir.

2.2.2 Forebay tank

A forebay tank is normally located at the downstream end of the water conductor system and provides a transition between the power canal and penstock. It is usually located on a ridge on a firm foundation respecting topographical and geological conditions. Upstream from the forebay tank the waterway is characteristically open channel flow whereas downstream penstock flow is under pressure.

These are two main functions:

i. Provide for adjustment of turbine discharge according to load demand.

ii. Provide a volume of stored water to permit water level control of turbine operation.

Flow adjustment: the fore bay tank and escape weir facilitate the adjustment of turbine discharge due to system load changes by diverting surplus flow over the escape weir back into the river. Normally in this mode of operation requires that canal flow be greater than plant demand flow.

Water level control: For small hydro plants connected to the grid it is convenient to match turbine output to available flow, thereby maximizing use of available water. This is achieved by means of a water level control system whereby the turbine load is adjusted to equalize available flow in the power canal with turbine flow. The fore bay tank acts as a buffer to adjust for errors in turbine setting and actual inflow into the fore bay tank. This requires that water levels be measured in the fore bay tank and tailrace and transmitted in real time to the turbine governor which adjusts turbine output (and flow) so as to keep forebay water levels within a prescribed water level range.

2.2.3 Penstock

The penstocks made of mild steel constitute major expenses and hence to minimize its length, head race might be used. A stop valve must be provided at the entry to avoid the problems of water hammer. The optimum size of head race may be obtained by an analysis of construction and annual cost of the energy lost due to friction in the head race over the economic life span of the project.

Conventional penstocks for small hydro and larger installations have usually been made of prestressed concrete or high pressure steel, but steel is expensive and it can be demonstrated that in most cases of prestressing for small hydro units this needs not to be so. The techniques of prestressing concrete are suitable when adequate facilities exist nearby but in the hinterlands of many developing countries such facilities do not exist and in any event the scarcity of cement and the expense of its transportation may well increase the capital cost of civil works.

Some of the materials that are currently being used with great cost reductions in penstocks are PVC, wood, fibre glass reinforced polyester, polyethylene and asbestos cement.

i. PVC penstock

PVC pipes can be supplied to withstand heads of over 150 meters so long as an appropriate method of making joints is utilized to guarantee proper sealing. Although in many developing countries it is not possible, to obtain PVC pipes in excess of 5 meters long with more than a 12 inch internal diameter, it is possible and even desirable where required to run two pipes in parallel in order to approximate a larger diameter penstock. But PVC has a low impact resistance and becomes fragile from prolonged exposure to sunlight ultraviolet radiation, so it is recommended that such penstocks be installed underground to increase the life of the installation.

Among the many advantages of using PVC in small hydro installations are the ease of adaptation to the desired penstock profile because each pipe length can readily accommodate up to five degree flexure and joints need no welding so that by comparison with metal penstocks, the cost of welding is virtually obviated.

Another advantage which leads to a lowering of cost results from the low weight of PVC piping compared to steel. This has implications for transportation costs and, of course, facilitates installation.

Another advantage of the lower weight of PVC and by extension other plastic is the reduction in the need for supports and anchoring.

Of course, installation time may be reduced by as much as a factor of 5 which may be very critical as far as controlling costs especially since it can be demonstrated that the installation costs for a PVC penstock are in most instances as much as half of those for a steel penstock for comparable purposes.

ii. Wood Stave Penstock

The wood penstock is an old and well tried type of conduit with numerous good points. It requires a minimum of levelling and foundation work and may undulate through rugged terrain with a curve radius as little as 60 times the pipe diameter. The smoothness of the pipe interior which often increases with time, unlike steel, ensures very low friction losses. If manufactured from quality materials and professionally assembled such penstocks will normally have a long life.

It is to be noted that the steel hoops are the carriers of the water pressure. In many developing countries wood for penstocks is still in relatively great abundance so that at $2 or even $1.50 per lb. for steel the need to critically examine possibilities for using wood penstocks in a given application is clear and should not be neglected.

iii. Polyethylene Penstock

Polyethylene pipe is sold in lengths requested by the customer at diameters up to 12 inches and can withstand heads up to 150 meters.

Joints are made with special steel accessories. When this material is used in small hydro plants it is recommended that the longest possible individual pipe lengths be used in order to reduce the number of joints because such joints may result in unacceptably high levels of pressure drop. The high flexibility of polyethylene penstocks results in reduced need for excavations and fills to smooth out undulations in the terrain and in most cases surface modifications may be generally kept to a minimum or avoided.

Very little anchoring is necessary for polyethylene penstocks, and because pipe lengths may be selected to facilitate ease of transportation, and because relatively large diameters of pipes can be supplied at lengths up to 50 meters, there is really little or no justification for using metal penstocks.

iv. Fibreglass Reinforced Polyester

Penstocks for heads up to 150 meters and an internal diameter of 80 inches can also be made from fibre glass polyester pipe. It is recommended that for low head applications where the total length of the penstock is not great, the use of fibreglass polyester should be considered because capacity for capacity the cost of steel and steel fabrication for these low pressures far exceeds the cost of the equivalent fibreglass penstock.

v. Asbestos Cement Penstock

Asbestos cement penstocks need to be considered again in low head applications. The main advantages of using asbestos cement piping are due to the following:

I. Ready adaptation to overland profile because deviations of up to 5 degrees can be easily accommodated at joints without causing leaks.

ii. There is no need for expansion joints since the unions can be designed to obviate most expansion effects.

Table 2.1 Comparison of different types of materials for penstock [3]

material	friction	weight	corrosion	cost	pressure
ductile iron	****	*	****	**	****
asbestos cement	***	****	****	***	*
concrete	*	*	*****	***	*
wood stave	***	***	****	**	***
GRP	*****	*****	***	*	*****
uPVC	*****	*****	****	****	*****
mild steel	***	***	***	****	*****
HDPE	*****	*****	*****	**	*****

***** = excellent,

* = poor

2.3 COMPONENTS OF CANAL BASED SHP PROJECT

Canal based small hydropower scheme is planned to generate power by utilizing the fall in the canal. These schemes may be planned in the canal itself or in the bye pass channel. These are low head and high discharge schemes. These schemes are associated with advantages such as low gestation period, simple layout, no submergence and rehabilitation problems and practically no environmental problems. The typical canal based scheme is shown in Fig.2.8.

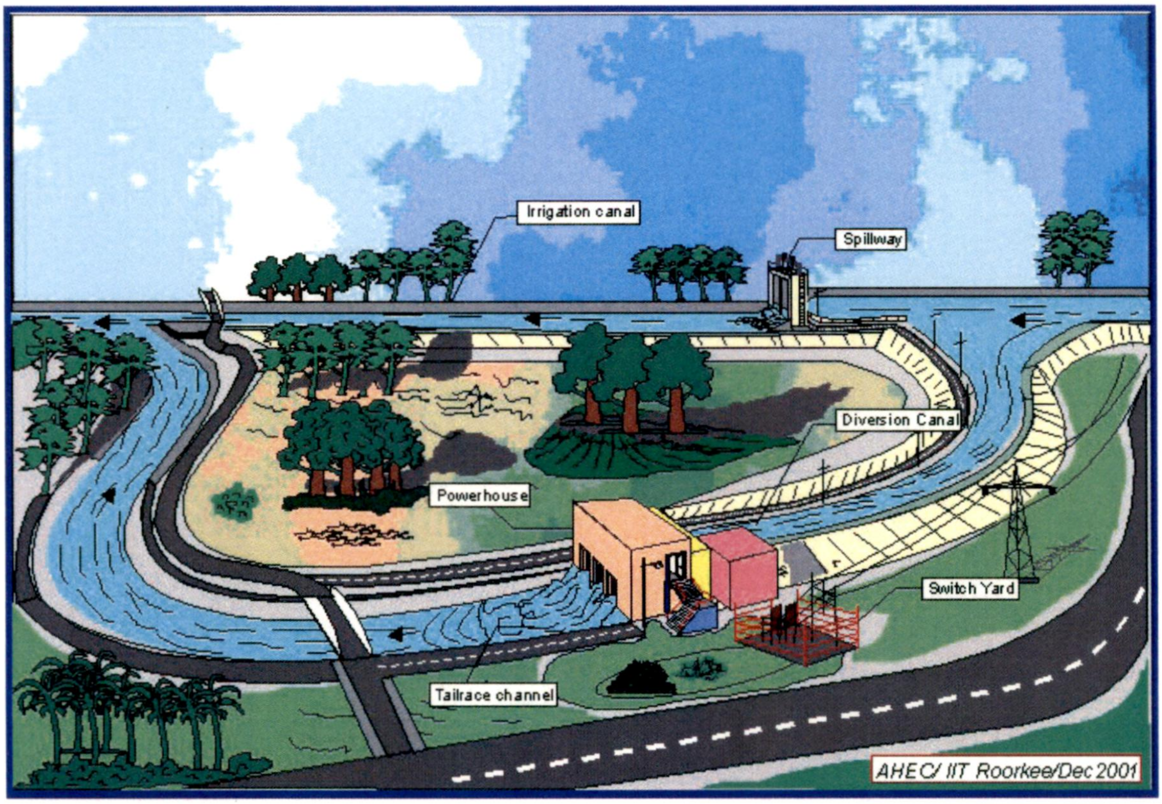

Fig.2.8 Typical arrangement of canal based scheme

The basic components of canal based small hydropower project can be broadly classified as -

a) Civil works

b) Electromechanical equipment

Civil works consists of the following subcomponents:

i. spillway

ii. Main canal

iii. Diversion canal

iv. Powerhouse building

v. Tail race channel

The electromechanical equipment consists of the following subcomponents:

i. Turbines with governing system

ii. Generator with excitation system, switch gear, control, and protection equipment

iii. Electrical and mechanical auxiliaries

iv. Main transformer and switchyard equipment

2.3.1 Power Channel

Power Channel or headrace carries the design flow of water from intake to the fore bay. It may also incorporate one or more desilting basins and spillways.

i. Simple earthen or unlined.
ii. Stone masonry in mud mortar channel
iii. Stone masonry in cement mortar channel.
iv. Concrete channel
v. Concrete channel and pipes.

In most cases, earthen open canals are used; however, in some cases, parts of headrace/canal may be a pipe or lined with cement mortar. Sometimes, portions of the canal may have been raised above ground as an aqueduct of concrete to cross a gully or some other similar difficult area. The usual sources of damage to the canal are excessive flow, depositing of silt, landslides, rain water coming or sometimes animals and humans. The damage may be in the form of leakage from the pipe or canal, or, blockade due to silt or other foreign materials. The banks or the bed may be eroded which may eventually result in the part of the canal falling down. The pipe may be blocked or may have been damaged and leaking.

Inspection of the power canal to assess the extent of drainage should not just be confined to the canal or pipe but also the area around them including the upper and under-sides and signs of leakage, slip or other type of degradation ,lust be assessed. All of the affected area would have to be repaired in an appropriate way to avoid a serious break down in future depending upon type and extent of damage.

2.3.2 Spillways

A dam failure can have severe effects downstream of the dam. During the lifetime of a dam different flow conditions will be experienced and a dam must be able to safely accommodate high floods that can exceed normal flow conditions in the river by orders of magnitude. For this reason carefully designed overflow passages are incorporated in dams or weirs as part of the structure. These passages are known as *spillways.* Due to the high velocities of the spilling water, some form of energy dissipation is usually provided at the base of the spillway.

The large majority of small hydro schemes are of the run-of-river type, where electricity is generated from discharges larger than the minimum required to operate the turbine. Spillways can be subdivided into *fixed* and *mobile* structures smaller fixed structures are generally referred to as weirs, whereas larger structures are often referred to as spillways. Spillways are often divided into un gated and gated spillways, corresponding to fixed and mobile structures, the un gated spillway in fact being a large-scale weir.

i. Ungated spillways

Fixed storage structures, such as weirs and ungated spillways have the advantage of security, simplicity, easy maintenance, and are cost effective. However, they cannot regulate the water level and thus both the water level and energy production fluctuates as a function of discharge. Mobile storage structures such as gated spillways can regulate the water level such that it stays more or less constant for most incoming flow conditions. Depending on gate configuration and discharge capacity they may also be able to flush accumulated sediment downstream. These structures are generally more expensive than fixed structures, for both construction and maintenance, and their functioning is more complicated.

ii. Gated spillway

The installation of mobile elements on dams or weirs allows control of the flow conditions without changing the water level. This is performed by means of gates, which are designed such that, when the gate is fully open (and the structure functions as if it where fixed) the discharge has to pass the structure without noticeable water level increase upstream. Gate operation needs permanent maintenance and an external energy source. As a result, there is a risk that the gate remains blocked during floods.

iii. Siphon spillways

Alternatively where space available for the spillway is limited, a siphon spillway or a shaft spillway may be used. Both solutions help to keep the upstream water level within narrow limits. When the water level rises above the elbow of the siphon, water begins to flow down the conduit just as in an overflow, but it is when it rises further that the siphon is primed and increases the discharge considerably. Usually siphons are primed when the water level reaches or passes the level of the crown, but there are designs where priming occurs when the upstream level has risen only to about one third of the throat height.

If badly designed, the siphon process can become unstable. At the beginning the siphon discharges in a gravity mode, but when the siphon is primed the discharge suddenly increases. Consequently the reservoir level drops, the siphon is de-primed and the discharge is reduced. The level of the reservoir increases anew until the siphon primes again, and the cycle of events is repeated indefinitely, causing severe surges and stoppages. Multiple siphons with differential crest heights or aerated siphons can be the solution to this problem. When the siphon is primed the flow through a siphon spillway is governed, as in penstocks, by Bernoulli's equation.

If the pressure at the crown of the siphon drops below the vapour pressure, the water vaporises forming a large number of small vapour cavities, which entrained in the flow, condense again into liquid in a zone of higher pressure. This phenomenon is known as cavitation and it can be extremely damaging. To avoid it, the distance between the crown of the siphon and the maximum level at the reservoir, depending on height above sea level and prevailing barometric pressure, should normally not exceed 5 m.

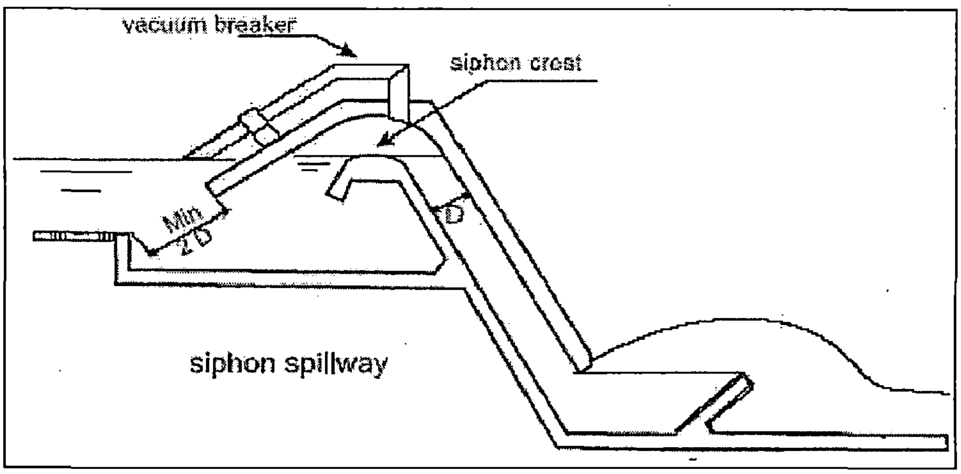

Fig. 2.9 Siphon spillway [33]

2.4 COMPONENTS OF DAM TOE SHP PROJECT

Dam toe schemes are those in which water is stored in the river by constructing a dam across the river and the power is generated by controlled flow from the storage.dam toe powerhouse is common in India. In dam toe scheme, the intake system forms the part of the main dam. The typical layout of dam based small hydropower scheme is shown in fig. 2.10.

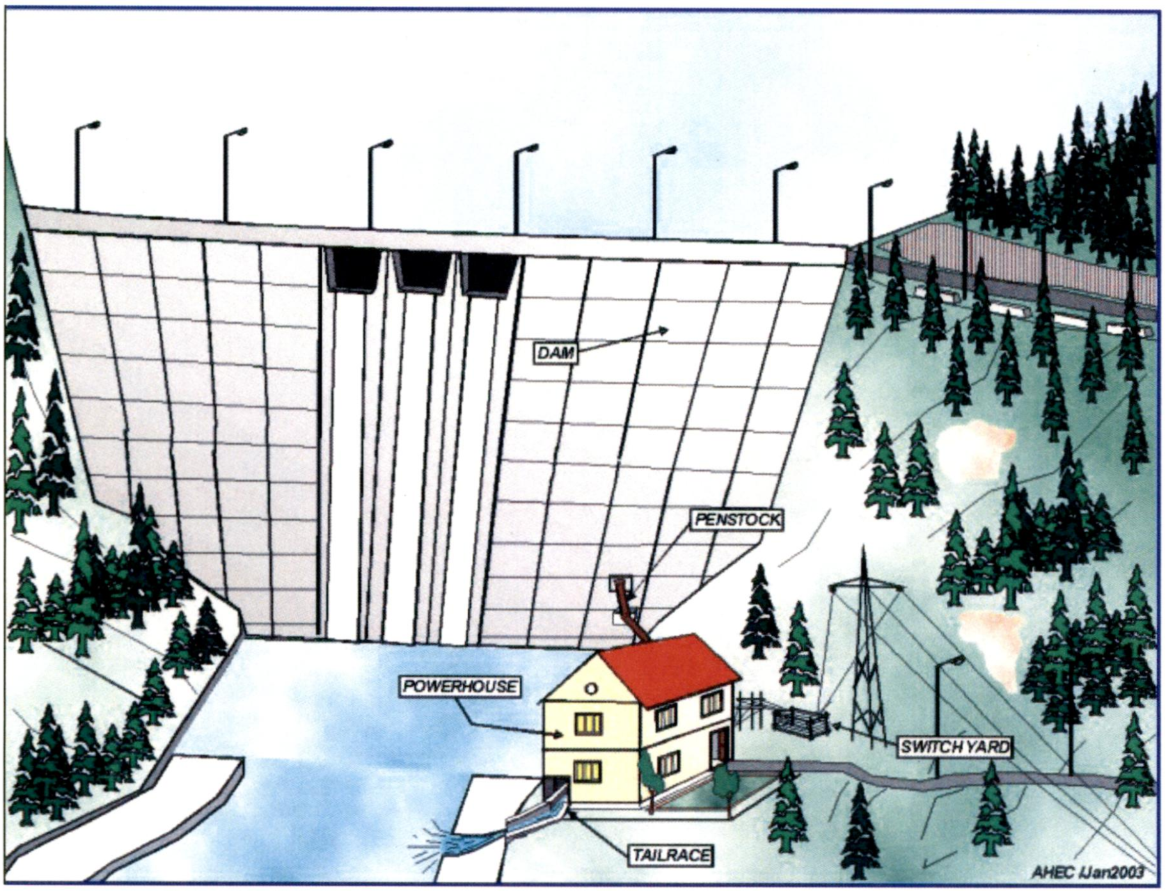

Fig. 2.10 Typical arrangement of dam toe scheme

The basic components of run-of-river small hydropower project can be broadly classified as -

a) Civil works

b) Electromechanical equipment

Civil works consists of the following subcomponents:

i. Dam

ii. Penstock
iii. Powerhouse building
iv. Tail race channel

The electromechanical equipment consists of the following subcomponents:

i. Turbine with governing system
ii. Generator with excitation system
iii. Mechanical and electrical auxiliaries
iv. Main transformer and switchyard Equipment

2.4.1 Dam

The dam types known at present are as follows:

i. Embankment Dam

Embankment dams are made from compacted earth, and have two main types, rock-fill and earth-fill dams. Embankment dams rely on their weight to hold back the force of water, like the gravity dams made from concrete .there are following types of embankment dams.

a) Homogeneous Earth fill Dam
b) Earth fill With Toe Drain Dam
c) Zoned Earth fill Dam
d) Earth fill With Horizontal Drain Dam
e) Earth fill With Vertical And Horizontal Drains Dam
f) Earth And Rock fill, Central Core Dam (CCRD)
g) Earth And Sand-Gravel, Central Core Dam
h) Earth And Rock fill, Inclined Core Dam (ICRD)
i) Concrete Face Rock fill Dam (CFRD)
j) Bituminous Concrete Face Earth And Rock fill Dam
k) Steel Face Rock fill Dam
l) Thin Membrane Face Earth And Rock fill Dam

ii. Concrete Gravity Dam

In a gravity dam, the force that holds the dam in place against the push from the water is Earth's gravity pulling down on the mass of the dam. The water presses laterally (downstream) on the dam, tending to overturn the dam by rotating about its toe (a point at the bottom downstream side of the dam). The dam's weight counteracts that force, tending to rotate the dam the other way about its toe. The designer ensures that the dam is heavy enough that gravity wins that contest. In engineering terms, that is true whenever the resultant of the forces of gravity and water pressure on the dam acts in a line that passes upstream of the toe of the dam.

a) Lean roller compacted concrete (RCC) dam
b) Medium-paste RCC dam
c) High-paste content RCC dam
d) The faced symmetrical hard fill dam (FSHD)
e) Roller compacted dam (RCD)
f) Conventional concrete gravity dam (CCD)
g) Prestressed dam

iii. Arch Dam

The arch dam, stability is obtained by a combination of arch and gravity action. If the upstream face is vertical the entire weight of the dam must be carried to the foundation by gravity, while the distribution of the normal hydrostatic pressure between vertical cantilever and arch action will depend upon the stiffness of the dam in a vertical and horizontal direction.

a) Thin arch dam
b) Conventional concrete arch gravity dam
c) RCC arch gravity dam
d) Cupola (double-curvature arch) dam

2.4.2 Power House

It houses the turbine, generator and control panels. It should be as simple as possible. The significant parameters affecting the cost of power house i.e. super structures and substructures can be related to number and capacity of turbine and generators. The separate ancillary building for office and workshop should be constructed if required.

i. Power house building is a big hall
ii. Accommodate machine (turbines Generators etc.)
iii. Sufficient height to accommodate crane operations
iv. Sufficient space for maintenance
v. Sufficient space for control operations
vi. It can be constructed as a steel structure
vii. It can be constructed as Reinforce concrete formed structure

For remote hilly sites prefab buildings can be used which are easy to transport and quick installation In a small hydropower scheme the role of the powerhouse is to protect the electromechanical equipment that convert the potential energy of water into electricity, from the weather hardships. The number, type and power of the turbo-generators, their configuration, the scheme head and the geomorphology of the site determine the shape and size of the building.

The following equipment will be displayed in the powerhouse:

i. Inlet gate or valve
ii. Turbine
iii. Speed increaser (if needed)
iv. Generator
v. Control system
vi. Condenser, switchgear
vii. Protection systems
viii. DC emergency supply
ix. Power and current transformers

Figure is a schematic view of an integral intake indoor powerhouse suitable for low head schemes. The substructure is part of the weir and embodies the power intake with its trash rack, the vertical axis Kaplan turbine coupled to the generator, the draft tube and the tailrace. The control equipment and the outlet transformers are located in the generator fore bay. In order to mitigate the environmental impact the powerhouse can be entirely submerged. In this way the level of sound is sensibly reduced and the visual impact is nil.

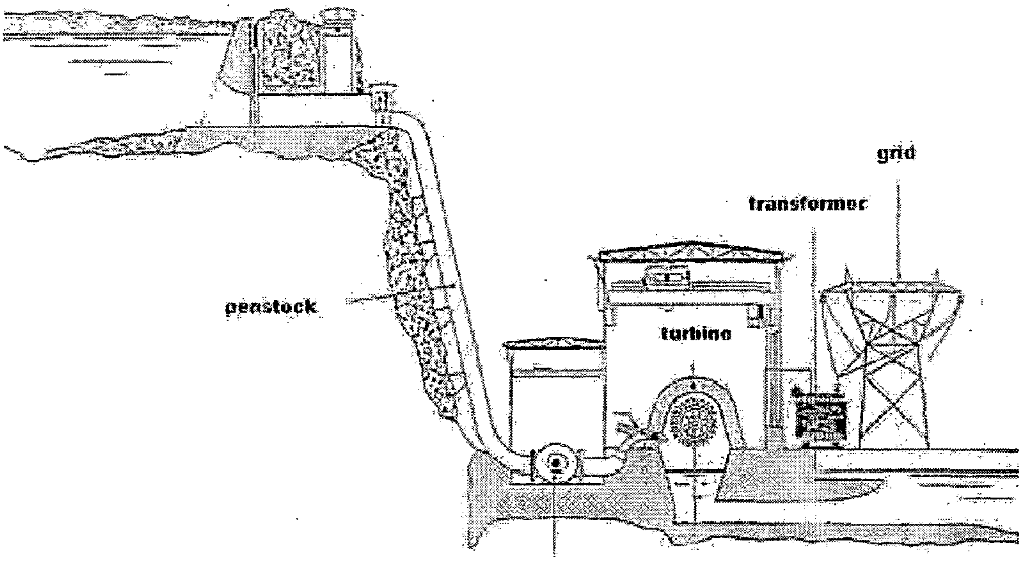

Fig.2.11 schematic view of high and medium head power house

2.4.3 Tail race channel

For discharging water after the generation of electricity in the power house, either a tail race channel or a tail race tunnel will be required. The design of tail race channel will follow the same principles as of any hydraulic channel. The tailrace channel of adequate capacity and sufficient slope is provided to clear the discharges from the machines swiftly.

After passing through the turbine the water returns to the river trough a short canal called a tailrace. Impulse turbines can have relatively high exit velocities, so the tailrace should be designed to ensure that the powerhouse would not be undermined. Protection with rock riprap or concrete aprons should be provided between the powerhouse and the stream. The design should also ensure that during relatively high flows the water in the tailrace does not rise so far that it interferes with the turbine runner. With a reaction turbine the level of the water in the tailrace influences the operation of the turbine and more specifically the onset of cavitation. This level also determines the available net head and in low head systems may have a decisive influence on the economic results.

2.5 ELECTRO-MECHANICAL COMPONENTS

These include turbine, generator and control equipments and consume the major part of the total cost of the project and affect the output level.

2.5.1 Turbine

The selection of hydro turbine for small hydro depends on the head and discharge available. A low head installation requires flow of water mostly in plains on canal falls and cross drainage works while high head would require low discharge as in hilly areas. The type and size should be selected out of standard instead of designing an optimum turbine for each site from economic considerations. The cost per kW generation of power will increase with decrease in size. Thus it becomes necessary to simplify the design and construction even at the cost of little loss in hydraulic efficiency to bring the over all cost low. The cost increases disproportionately with the size of machine head.

The horizontal shaft Bulb and Tubular turbines are used for very heads upto 25m. The Bulb turbine is preferred over Tubular turbine because it is economical in civil works. The tubular turbines are designed in the different variants like Kaplan, Semi - Kaplan, Propeller and Propeller with fixed guide vanes to cover a wide range of operational requirements. It is relatively expensive because separate power houses for turbine and generator are required. The Straight flow turbine is used for extreme low heads. This turbine requires area 45-55% less than that of Bulb and S-tubular turbines. The cost of Straight flow turbine including installation is 15-20% lower than Bulb turbine taking o account the civil work and maintenance. The efficiency of straight flow turbine is little lower than Bulb turbine except at full load. Hence the energy production cost from Straight flow turbine is low as compared to other turbine for very low heads.

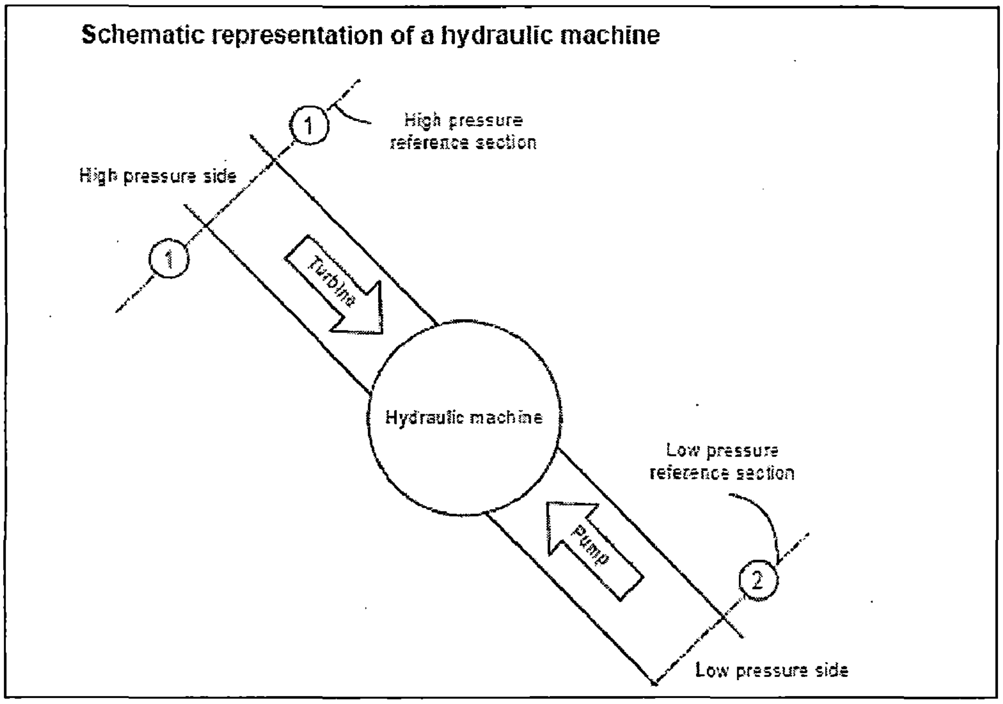

Fig 2.12 Schematic representation of a hydraulic machine[34]

Classification of turbines

Hydro turbines are classified on the following basis

1. Depending upon head and discharge
   i. High head and low discharge turbines
   ii. Low head and high discharge turbines
2. According to action of water over the moving blades
   i. Impulse turbine
   ii. Reaction turbine
3. According to the direction of flow of water over runner
   i. Tangential flow (Pelton, Turgo, Cross flow)
   ii. Radial flow (old Francis, Girad)
   iii. Mixed flow (modern Francis)
   iv. Axial flow (Propeller, Kaplan)
   v. Diagonal flow (Deriaz)

4. According to the position of shaft
    i. Horizontal
    ii. Vertical
5. Based on specific speed
    i. High specific speed turbines
    ii. Medium specific speed turbines
    iii. Low specific speed turbines

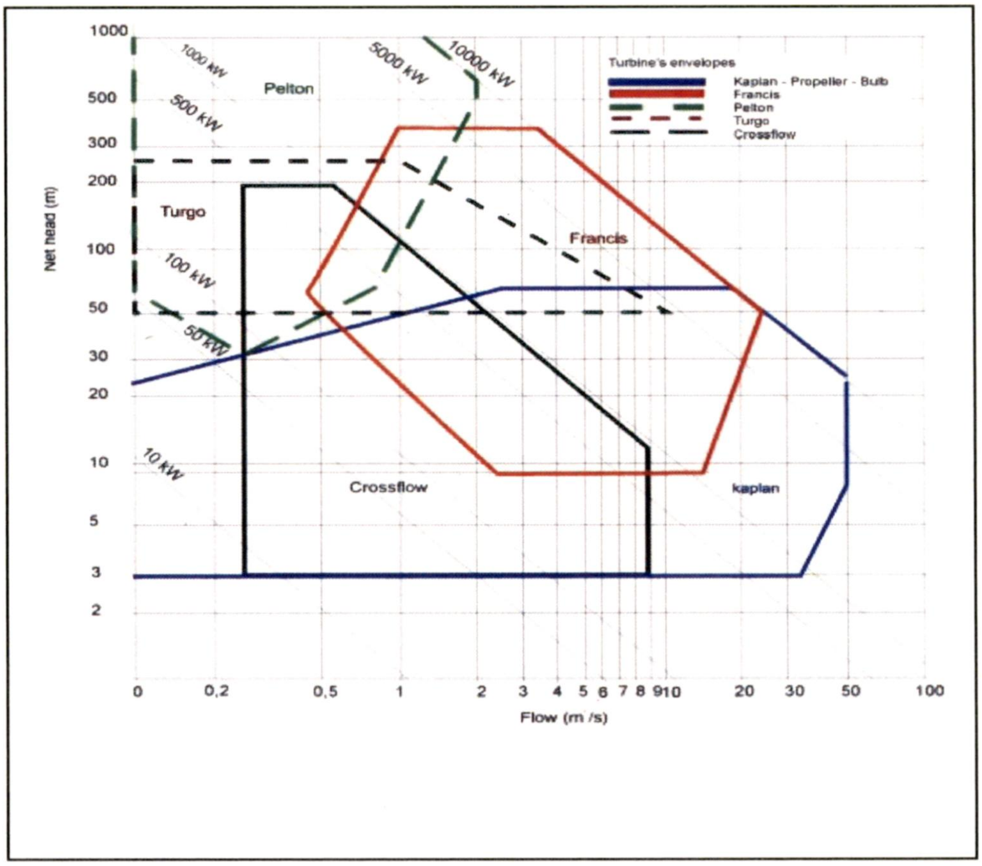

Fig. 2.13 Operating ranges of different types of turbines [34]

Table 2.2 Turbine performance characteristics [34]

S. no	Turbine type	Head application Min	Head application Max	Head variation (%) Min	Head variation (%) Max	Load variation (%) Min	Load variation (%) Max
1	**IMPLUSE TURBINE**						
	Turgo impulse	40	200	90	110	40	115
	Pelton turbine	100	500	90	10	40	115
	Cross flow turbine	1	200	60	125	30	115
	REACTION FLOW (Mixed flow)						
	Francis horizontal	10	250	65	125	60	115
	Francis vertical	10	250	65	125	60	115
	Francis open flume	2	8	90	110	50	115
3	**REACTION FLOW** (Axial flow)						
	Vertical fixed blade propeller	2	25	85	100	80	115
	Vertical adjustable propeller (Kaplan)	16	40	65	125	40	115
	Tubular fixed blade with wicket gates	2	25	75	115	75	115
	(Horizontal propeller)	2	25	85	110	85	115
	Bulb (Horizontal propeller)	2	25	50	140	30	115
	Rim (Horizontal propeller)	2	25	65	125	85	115

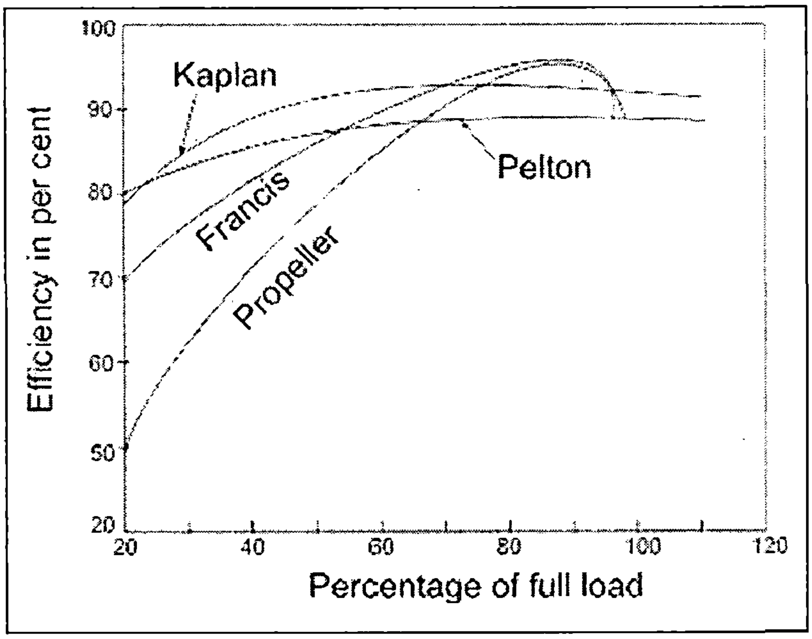

Fig. 2.14 Variation of efficiency with load [34]

1. Impluse turbine

Impulse turbines are generally more suitable for micro-hydro applications compared with reaction turbines because they have the following advantages:

a) More rugged
b) Easier to operate and maintain
c) No pressure points around the shaft
d) Easier fabrication
e) Better part load efficiency

i. Pelton turbine

The only hydraulic turbine of the impulse type in common use, is named after an American engineer Later A Pelton, who contributed much to its development around the year 1880. Therefore this machine is known as Pelton turbine or Pelton wheel.

A set of specially designed buckets mounted on the periphery of a circular disk forms the runner of the Pelton turbine shows in fig .the water jet gushing out from the nozzles of the turbine strikes the buckets and the runner is turned. The buckets are split into two halves so that the central area does not act as a dead spot incapable of deflecting water away from the oncoming jet.

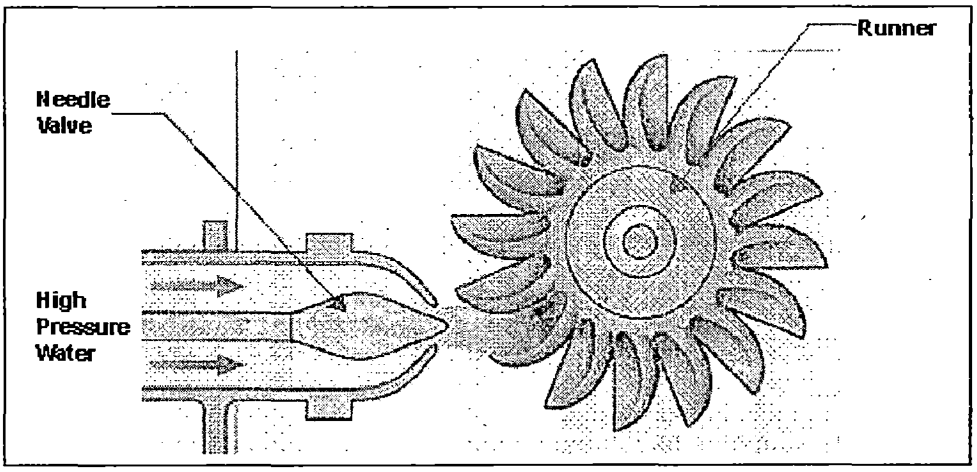

Fig. 2.15 Pelton Turbine[34]

In large hydro plants, Pelton turbines are usually employed for heads above 150 m.. at lower heads, they have slower rotational speeds(RPM). If the runner size is increased considerably and the generator could run at lower speeds, then Pelton turbines could be effectively used for lower heads.

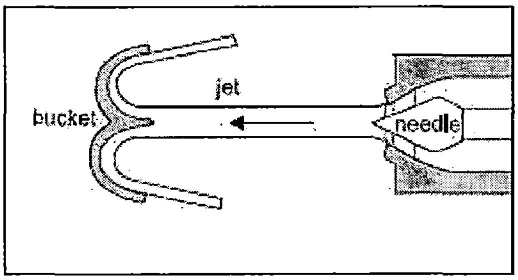

Fig. 2.16 Bucket shape of Pelton Turbine [34]

ii. Turgo impluse

Turgo impulse turbines are designed for higher speeds and these could be used for middle head applications .they are slightly different from Pelton turbines.

The jets are designed such that the water discharged from the buckets does not interfere with the incoming jet. This facilitates higher rotational speeds. A Turgo impulse turbine could be mounted horizontally or vertically and is very efficient at part loads.

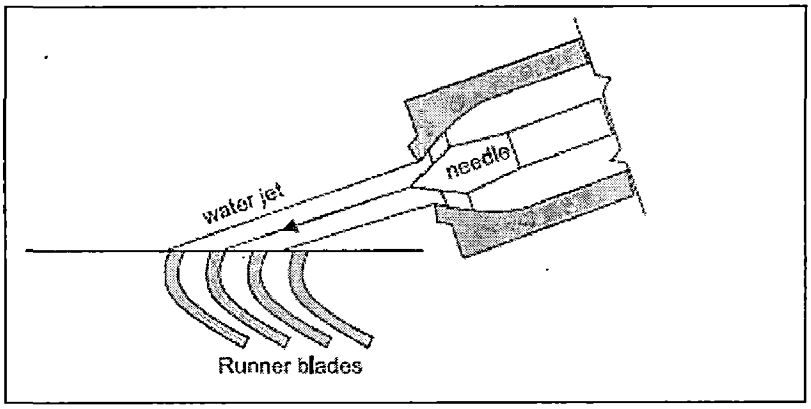

Fig. 2.17 Turgo Impulse Turbine [34]

iii. Cross flow turbine

The cross flow turbine, also known as the Mitchell-Banki turbine, consists of a drum shaped governor with two parallel disks that are connected near the rims by a series of curved blades. The cross flow turbine is limited only to horizontal shafts, whereas other impulse turbines could have both horizontal and vertical shafts.

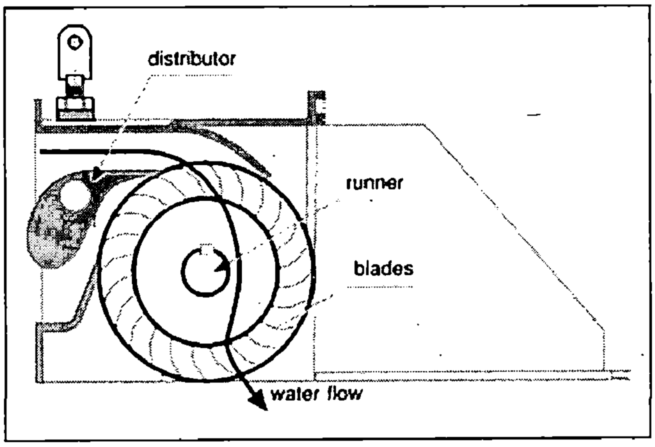

Fig. 2.18 Cross flow Turbine [34]

2. **Reaction turbines**

Reaction turbines are of two types Francis and propeller. A special case of the propeller turbine is the Kaplan. The specific speed of reaction turbines is always higher than that of impulse turbines and these are therefore, very popular amongst the medium and low head plants.

These turbines require improved fabrication as they involve more profiled blades that are large in size and intricately arranged in specially designed casings. These involve extra expenses but ensure that these turbines would have high efficiency.

i. **Francis turbine**

Francis turbines can either be volute-cased or open-flume machines. The spiral casing is tapered to distribute water uniformly around the entire perimeter of the runner and the guide vanes feed the water into the runner at the correct angle. The runner blades are profiled in a complex manner and direct the water so that it exits axially from the centre of the runner. In doing so, the water imparts most of its pressure energy to the runner before leaving the turbine via a draft tube.

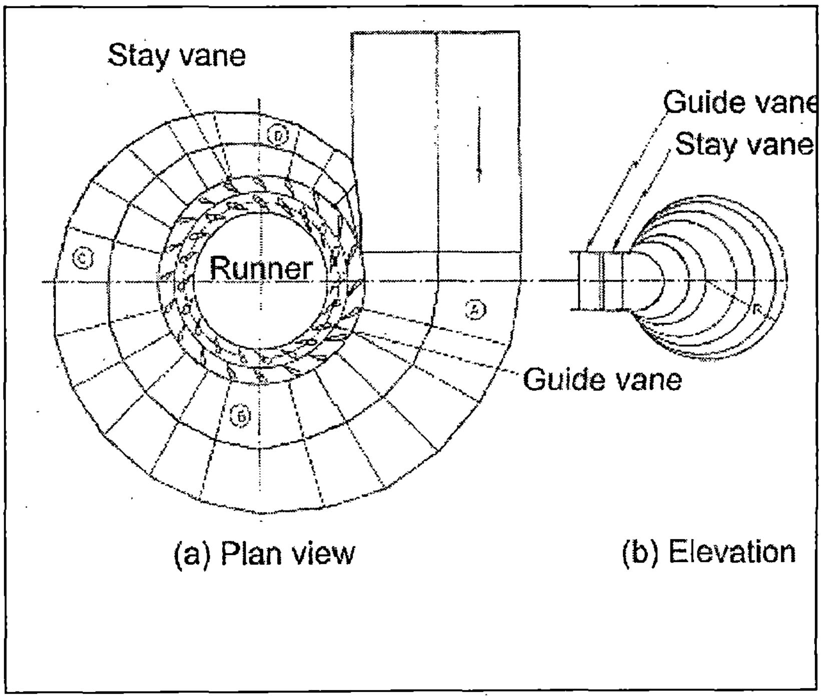

Fig. 2.19 Francis Turbine [34]

ii. Propeller turbine

The basic propeller turbine consists of a propeller, fitted inside a continuation of the penstock tube. The turbine shaft passes out of the tube at the point where the tube changes direction. The propeller usually has three to six blades, three in the case of very low head units and the water flow is regulated by static blades or swivel gates ("wicket gates") just upstream of the propeller. This kind of propeller turbine is known as a fixed blade axial flow turbine because the pitch angle of the rotor blades cannot be changed. The part-flow efficiency of fixed-blade propeller turbines tends to be very poor

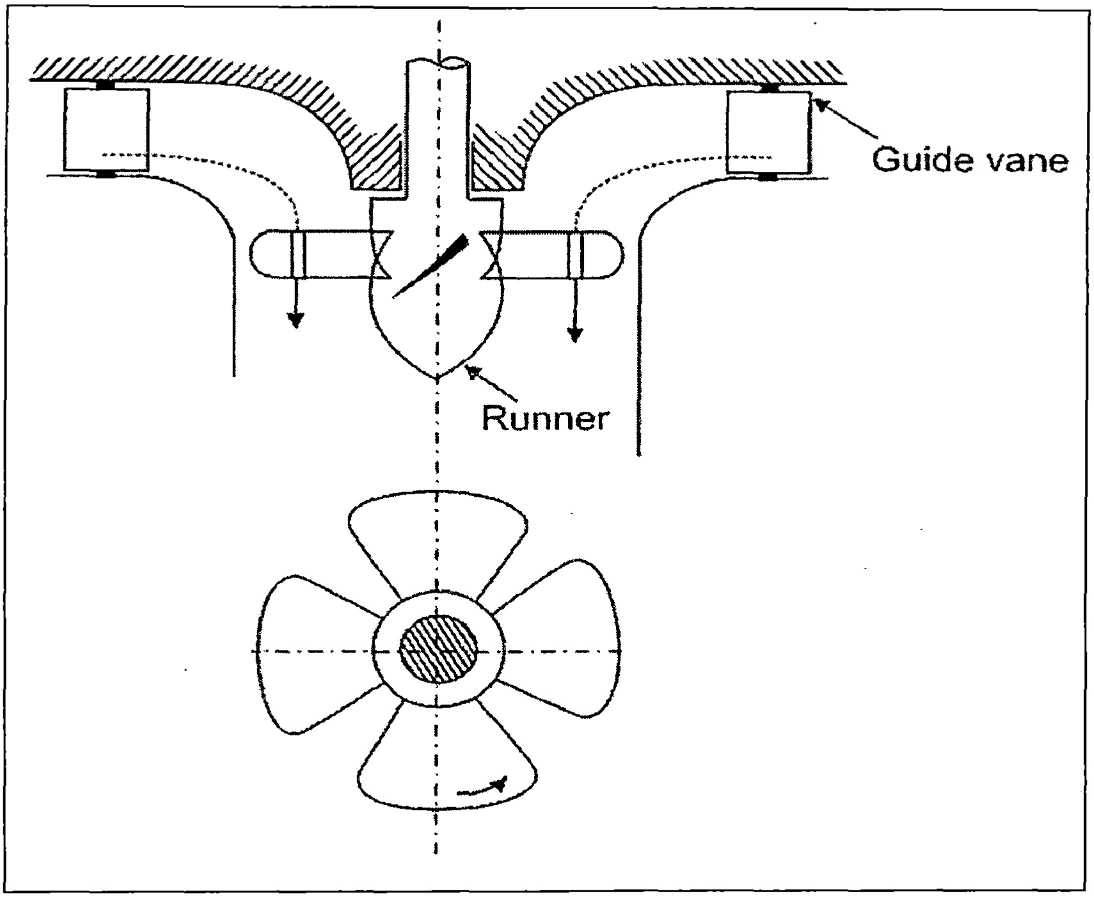

Fig. 2.20 Propeller Turbine [34]

iii. Bulb turbine

The bulb turbine is a reaction turbine of Kaplan type which is used for extremely low heads. The characteristic feature of this turbine is that the turbine components as well as the generator are housed inside a bulb, from which the name is developed. The main difference from the Kaplan turbine is that the water flows in a mixed axial-radial direction into the guide vane cascade and not through a scroll casing. The giude vane spindles are normally inclined to 60^0 in relation to the turbine shaft and thus results in a conical guide vane cascade contrary to other types of turbines. The runner of a bulb turbine may have different numbers of blades depending on the head and water flow. The bulb turbines have higher full-load efficiency and higher flow capacity as compared to Kaplan turbine. It has a relatively lower construction cost. The bulb turbines can be utilized to tap electrical power from the fast flowing rivers on the hills Figure shows the schematic of a Bulb Turbine Power Plant.

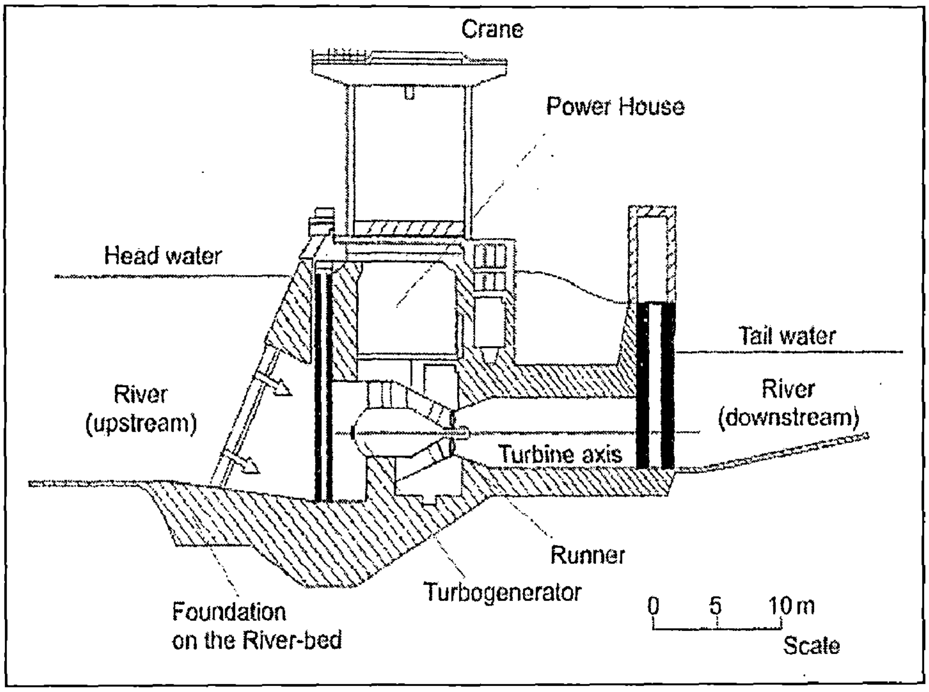

Fig.2.21 Schematic view of Bulb Turbine Power Generating Station [34]

2.5.2 Generator

Synchronous or induction generators are used to convert the mechanical energy output of the turbine into electrical energy. Economics and other considerations discussed will determine which type should be used for a specific site. Both types are generally air-cooled for small hydroelectric power plant applications. Most installations utilize synchronous generators. Induction generators are only used when system conditions and economics permit. The basic parameters to be considered in the selection of a suitable electrical generator are

a) Type of electrical output desired; constant-frequency utility grade alternate current, or direct current.
b) Hydraulic turbine mode; constant – speed operation, nearly constant – speed (± 5 percent) operation, or variable speed operation.
c) Type of electrical load, interconnection with an existing utility grid, or an isolated system supplying a variety of house hold or industrial loads

i. Synchronous generator

The principal advantage of a synchronous generator for small hydroelectric plant applications is its capability to operate with either a leading or lagging power factor, by control of its excitation. Most generators are required to furnish reactive power. They should have a power factor rating required by the local load, or the connecting utility power system, or both, which commonly ranges between 0.9 and 0.95. Some applications may require a machine with an even lower power factor.

Another advantage of the synchronous generator is its ability to establish its own operating voltage and maintain frequency while operating isolated. Thus, if the interconnection to the power system is severed, the generator may continue supplying the station and local load, hydraulic conditions permitting. To utilize this benefit requires accurate and responsive speed and power output control (governor) and voltage and reactive power control (automatic voltage regulator).

Synchronous generators require direct current field excitation. Excitation for smaller, higher speed units is generally provided by direct-driven brushless exciters. Larger, slower speed generators generally utilize static exciters with solid-state equipment that converts alternating current to direct current.

Synchronous machine technology for generating constant frequency alternating current from a constant speed prime mover is well known. The generator runs at constant speed, called the synchronous speed, and it is related to the number of poles P in the machine and the output frequency f.

Both horizontal–axis and vertical-axis synchronous generators are use in small hydro electric systems, depending on the turbine type and the location of the unit. A flywheel is used to smooth out speed variations due to sudden changes in load. And a damper winding located in the rotating field assists in satisfactory parallel operation of the unit with utility grids.

ii. **Induction generators**

The advantages of an induction generator are lower installed and maintenance costs from elimination of the exciter, voltage regulator, and synchronizer. The disadvantages are its inability to provide reactive power or volt age control or to be used as an isolated power source, as well as its lower efficiency throughout the operating range.

The induction generator draws its excitation (magnetizing) current from the electrical system. A standard squirrel cage motor may, in some instances, be used as an induction generator providing the rotor can withstand the turbine runaway speed. In addition, since no motor-starting torque is required, the rotor is designed to have low resistance and consequently lower rotor losses. Power is generated by operating the turbine at a speed higher than the synchronous speed of the generator.

Reactive excitation current and system restraints can limit the size of an induction generator. As with induction motors, power factor correction capacitors can be added, to maintain the power factor within acceptable limits. The capacitor should be connected only when the generator is operating at rated load. The capacitor must be disconnected from the generator when the generator is disconnected from the power system, to avoid voltage rises that may occur at Over-speed conditions.

The controls should be designed so that, if an induction generator with power factor correction capacitors or cables or lines becomes suddenly separated from a synchronous system, (a) there is no possibility of operating the induction generator as a self-excited generator, from the capacitance of power factor correction capacitors, cables, or long lines, and (b) there is an adequate time delay before reclosure to permit the generators open circuit voltage to decay to less than 25% of rated voltage.

Induction generators are simpler than synchronous alternators. They are easier to operate, control and maintain they have no synchronization problems, and they are cheaper to build. An induction generator can be designed as such but normally an induction motor would be used. Because induction motors are the most common types of electrical machine, their production on a large scale makes their use as induction generators attractive.

2.5.3 Transformer

The transformer is a highly efficient device to step the voltage from generator level to transmission and distribution level. Efficiencies are generally in the range of 99 %.For small and mini hydroelectric installation, a single two winding, oil filled sub stations type transformer is required. The main variable for transformer cost is the capacity of the unit for power transformer (KVA), voltage levels are in the next variable in cost as higher voltage requires more insulation levels. Normal voltage for small and mini hydroelectric plant is 4160 volts or less, depending on the system transformer costs are included with switchyard costs.

2.5.4 Switch gear and protection equipment

The switchgear provides the means for connecting and disconnecting the generator to and from the power system during normal start-up and shutdown, and protects and isolates the generator from the power system in the event of malfunctions, such as short circuits, over voltage, etc.

The generator output voltage will determine the voltage class of the circuit breaker selected for the application. Normal generator voltages are 480 V, 2.3 kV, 4.16 kV, 6.9 kV and 13.8 kV. Normally, a circuit breaker is used for switching the generator. Alternatively, a lower-cost contactor, particularly suitable for repetitive switching duty, could be used when available for the required voltage. If a contactor is used, fuses should be utilized for interruption of short circuit currents.

CHAPTER 3

COST EFFECTIVE DESIGN FOR SHP PROJECT

3.1 GENERAL

Small hydro power site are not identified as standard site and every site has different site parameters. Because of non-standardization of component of a SHP, cost becomes critical issue. The exploitation of many hydro–energetic resources, especially those with low power water flows (less than 50 kW), has over time become economically unfavorable. The increase in the availability of energy over recent decades has made it economically unviable to use plant configurations that exploit courses of water with low head and modest flow rates, with significant torrential characteristics. Today, the legislation covering energy is setting out ever clearer directives concerning the use of renewable resources in the place of those of high environmental impact. In the light of these changes, the possibility of using the largest number of hydro energetic resources available would appear to be of great interest.

The exploitation of hydro-energetic resources usually involves plant solutions using Pelton, Francis or Kaplan turbines, depending on the head and flow rates that are available. Literature exists describing the methods to evaluate the best plant configuration to adopt from the economic point of view. It should be noted that plants functioning with Pelton turbines are economically advantageous even with powers less than 5 kW, with Francis turbines the minimum powers are around 50 kW, whereas the minimum powers that are economically interesting for Kaplan type turbines are greater than about 100 kW [4]. This means that, whereas it is possible to create low power plants with average specific energies and low flow rates, it is not possible to use Francis or Kaplan turbines in sites with the small head and low average flow rates

3.2 COST INVOLVED IN SMALL HYDROPOWER PROJECT

Basic components of SHP schemes are categorized into two parts: (i) civil works and (ii) electromechanical equipment. The major components of civil works consist of intake, penstock, power house building, and tail race channel. The electromechanical components are turbines with governing system, generator with excitation system, electrical and mechanical auxiliary, and transformer and switchyard equipment.

Existing literature describe that the cost of components of civil works as well as that of electromechanical equipment mainly depends on the installed capacity and head of the scheme. The cost is divided in two parts.

3.2.1 Investment Cost

It consists following

i. Civil works costs

Consist of the construction and hydro-structural costs of the project, including a reservoir dam, the water penstock structure, the power house, the tailrace structure, the access road and any future unpredicted costs taken from the preliminary designs of a feasibility study.

ii. Electro-mechanical equipment costs

Include turbines, generators, governors, gates, control systems, a power substation, electrical, and mechanical auxiliary equipment, etc.

iii. Power transmission line costs

Include a power transmission line for delivering generated energy from the power plant to power transmission network. The transmission line cost depends on the location, type of existing system (overhead line or cable system), and the capacity of HPP as well as length of transmission lines, which have a very high effect on the project costs.

iv. Indirect costs

Include Engineering and Design (E&D), Supervision and Administration (S&A), and inflation costs during the construction period.

v. Engineering & Design costs

These costs are affected by many parameters, such as type, size and location where the project is being constructed. The E&D costs are usually expressed as a percentage of construction costs, including civil and equipment costs, and the amount of this percent differs from one location to another. Recently, a case study on these HPPs has shown that this figure could range from 5% for small and medium sized projects, to 8%, for very large sized projects.

vi. **Supervision & Administration costs**

These costs include the purchase of land, management, inspection and supervision costs, and other miscellaneous costs in the region. Similar to the E&D costs, the S&A costs are expressed as a percentage of the construction costs.

vii. **Inflation costs during construction**

To precisely calculate the investment cost of a project, it is necessary to take into account the inflation rate during the course of the project and adjust the investment cost with respect to the inflation rate. The inflation rate of future years should be determined by obtaining the average of previous years' inflation rate.

3.2.2 Annual Cost

In addition to investment costs, annual costs should be calculated to obtain the net benefit of a project. Annual costs include depreciation of equipment, Operating & Maintenance (O&M), and replacement and renovation costs.

i. **Depreciation of Equipment**

In the economical analysis of the project, depreciation and other factors affecting the equipment should be considered.

ii. **Operation & Maintenance Costs**

Include salary/wages of personnel, labour, insurance, tax, duties, landscape, and consumable materials. These costs are increased only by the annual inflation coefficient. A 5% inflation rate is used in the economical calculations. The costs which are related to the salary/wage and consumable materials make up one percent of annual investment costs, and insurance, tax, duties, charges, and unpredicted cases are also taken as one percent of annual investment costs. It should be noted that in order to calculate investment costs, the interest rate during construction should also be considered.

iii. **Replacement And Renovation Costs**

The main parts of the HPP, such as generator windings, turbine runners and other parts will eventually need replacement and renovation. To estimate the costs for large and medium sized power plants, the percentage of renovation and replacement should be determined for different sections separately.

3.3 PLANNING FOR COST EFFECTIVE DESIGN

Cost of any SHP project is depends upon site parameter which is vary from site to site. By analyzing different factors like hydraulic and electromechanical components causes to the rise in unit cost of power output. Among them some component are site specific like:

a) Flow characteristics
b) Site selection and basic design
c) Civil works
d) Hydraulic turbine
e) Power transmission system

While some cost are not site specific like:

a) Mechanical and electrical control system
b) Engineering and administrative charges

In hydropower projects, there are uncertainties on account of water availability that affect the availability of energy. Thus, there is an uncertainty in projection of the benefits from the project and the other uncertainty factor is the cost estimation. The cost of the project depends on location, construction period and cost of materials, availability of construction equipment, and labour cost. The project cost estimates are subject to a considerable degree of variation and fluctuation. The benefits also have a high degree of uncertainty.

Prior to 1991, small hydropower projects in India were only developed in the government sector as government departments were the licensee to generate, transmit, and distribute electrical energy. From 1991 onward, power generation was opened to the private sector as well and government departments were streamlined as companies. Since then it has become the commercial sector and repayment of investments is of prime concern; therefore, financial analysis has been attempted to evaluate the schemes for evolving an optimum solution. In this context, financial analysis has been carried out to evaluate various layouts. An important part of establishing financial feasibility is the anticipated borrowing cost. The cost of capital is the return expected by potential investors and other market and economic costs. The costs are the sum of the real interest rate that compensates the lender for surrendering the use of funds, the purchasing power, the risk premium that compensates for expected inflation, the business and financial risk, and the market-ability risk associated with low liquidity of long-term debt.

3.3.1 Selection of Number of Unit

The assumed site is of 2000kW capacity, 15 m head.

Taking generator efficiency 95% and turbine efficiency 92%, we calculate required discharge and specific speed, and find out the no. of unit to be installed.

$$\text{Discharge required for 2000 kW generations} = \frac{2000}{9.81 \times 0.95 \times 0.92 \times 15}$$

$$= 15.55\ m^3/s$$

Case 1: Considering no. of unit 1 and 1500 rpm.

Specific speed = 2273

As 2273 is more than 1000 so the above case is not suitable.

Case 2: Considering no. of unit 2 and 1500 rpm.

Specific speed = 1607

As 1312 is more than 1000 so the above case is not suitable.

Case 3: Considering no. of unit 3 and 1500 rpm.

Specific speed = 1312

As 1312 is more than 1000 so the above case is not suitable.

Case 4: Considering no. of unit 4 and 1500 rpm.

Specific speed = 1137

As 1137 is more than 1000 so the above case is not suitable.

Case 5: Considering no. of unit 5 and 1500 rpm.

Specific speed = 1017

As 1017 is more than 1000 so the above case is not suitable.

Case 6: Considering no. of unit 6 and 1500 rpm.

Specific speed = 928

As 928 is less than 1000 so the above case is possible but as no. of unit is 6 so it is not economical.

As taking no. of 6 no. of unit is not economical so we go for 1000 rpm.

Case 7: Considering no. of unit 1 and 1000 rpm.

Specific speed = 1515

As 1515 is more than 1000 so the above case is not suitable.

Case 8: Considering no. of unit 2 and 1000 rpm.

Specific speed = 1072

As 1072 is more than 1000 so the above case is not suitable.

Case 9: Considering no. of unit 3 and 1000 rpm.

Specific speed = 875

As 875 is less than 1000 so the above case may be considered.

3.3.2 Cost Calculation of Diversion Channel [35]

The correlation use for the cost calculation of diversion channel is given as:

$$C_1 = 9904P^{-0.2295}H^{-0.0623} \tag{3.1}$$

Where C_1 = cost per kW of diversion channel.

Using Eqn. (3.1) cost of diversion channel is 37.63 lacs.

3.3.3 Cost Calculation of Spillway[35]

The correlation use for calculating the cost of spillway is given as:

$$C_4 = 36778P^{-0.2306}H^{-0.0644} \tag{3.2}$$

Where C_4 = cost per kW of spillway.

Using Eqn. (3.2) cost of spillway is 137.94 lacs.

3.3.4 Cost Calculation of Power House Building[35]

If the powerhouse building is founded on rock, the excavation work will remove the superficial weathered layer, leaving a sound rock foundation. If the powerhouse building is to be located on fluvial terraces near the riverbanks that do not offer a good foundation then the ground must be reinforced.

It houses the turbine, generator and control panels. It should be as simple as possible. The significant parameters affecting the cost of power house i.e. super structures and substructures can be related to number, capacity and type of turbine and generators. The correlation used for calculation of cost of power house is varying according to types of turbine use.

Case 1: When tubular semi Kaplan turbine is used

The correlation use for cost calculation of powerhouse building for tubular turbine is given as:

$$C_3 = 105555P^{-0.2380}H^{-0.0602} \quad (3.3)$$

Where C_3 = cost per kW of powerhouse building.

Using Eqn. (3.3) cost of powerhouse building (for tubular semi Kaplan turbine) is 381.60 lacs.

Case 2: When vertical semi Kaplan turbine is used

The correlation used for cost calculation of powerhouse building for vertical semi Kaplan turbine is given as:

$$C_3 = 94594P^{-0.2377}H^{-0.0622} \quad (3.4)$$

Where C_3 is cost per kW of power house building.

Using Eqn. (3.4) cost of powerhouse building (for vertical semi Kaplan turbine) is 340.80 lacs.

Case 3: When bulb semi Kaplan turbine is used

The correlation use for determining cost of powerhouse building when vertical semi Kaplan turbine is used is given as:

$$C_3 = 85805P^{-0.2371}H^{-0.0595} \quad (3.5)$$

Where C_3 =cost per kW of powerhouse building

Using Eqn. (3.5) cost of powerhouse building (for bulb semi Kaplan turbine) is 312.28 lacs.

Case 4: When tubular propeller turbine is used

The correlation used for determining cost of powerhouse building when tubular propeller turbine is used is given as:

$$C_3 = 103890P^{-0.2386}H^{-0.0604} \quad (3.6)$$

Where C_3 =cost per kW of powerhouse building.

Using Eqn. (3.6) cost of powerhouse building (for tubular propeller turbine) is 373.92 lacs.

Case 5: When vertical propeller turbine is used

The correlation used for determining cost of powerhouse building when vertical propeller turbine is used is given as:

$$C_3 = 93133P^{-0.2382}H^{-0.0624} \tag{3.7}$$

Where C_3 =cost per kW of powerhouse building.

Using Eqn. (3.7) cost of powerhouse building (for vertical propeller turbine) is 334.26 lacs.

Case 6: When bulb propeller turbine is used

The correlation used for determining cost of powerhouse building when bulb propeller turbine is used is given as:

$$C_3 = 82122P^{-0.2384}H^{-0.0604} \tag{3.8}$$

Where C_3 =cost per kW of powerhouse building.

Using Eqn. (3.8) cost of powerhouse building (for bulb propeller turbine) is 295.96 lacs.

Case 7: When tubular Kaplan turbine is used

The correlation used for determining cost of powerhouse building when tubular Kaplan turbine is used is given as:

$$C_3 = 111756P^{-0.2389}H^{-0.0605} \tag{3.9}$$

Where C_3 =cost per kW of powerhouse building.

Using Eqn. (3.9) cost of powerhouse building (for tubular Kaplan turbine) is 401.34 lacs.

Case 8: When vertical Kaplan turbine is used

The correlation used for determining cost of powerhouse building when vertical Kaplan turbine is used is given as:

$$C_3 = 100998P^{-0.2387}H^{-0.0607} \tag{3.10}$$

Where C_3 =cost per kW of powerhouse building.

Using Eqn. (3.10) cost of powerhouse building (for vertical Kaplan turbine) is 362.98 lacs.

Case 9: When bulb Kaplan turbine is used

The correlation used for determining cost of powerhouse building when bulb Kaplan turbine is used is given as:

$$C_3 = 91039P^{-0.2383}H^{-0.0603} \quad (3.11)$$

Where C_3 =cost per kW of powerhouse building

Using Eqn. (3.11) cost of powerhouse building (for bulb Kaplan turbine) is 328.40 lacs.

3.3.5 Cost Calculation of Turbine with Governing System [35]

The cost of turbine with governing system varies with types of turbine so further we have nine cases.

Case 1: Cost of turbine with governing system when tubular semi Kaplan turbine is used

The correlation use for cost calculation of generator & excitation system when tubular semi Kaplan turbine is use is given as:

$$C_6 = 63346P^{-0.1913}H^{-0.2171} \quad (3.12)$$

Where C_6= cost per kW of turbine with governing system

Using Eqn. (3.12) cost of turbine with governing system (for tubular semi Kaplan turbine) is 202.86 lacs

Case 2: Cost of turbine with governing system when vertical semi Kaplan turbine is used

The correlation use for cost calculation of generator & excitation system when vertical semi Kaplan turbine is use is given as:

$$C_6 = 62902P^{-0.1835}H^{-0.2032} \quad (3.13)$$

Where C_6= cost per kW of turbine with governing system

Using Eqn. (3.13) cost of turbine with governing system (for vertical semi Kaplan turbine) is 216.50 lacs.

Case 3: Cost of turbine with governing system when bulb semi Kaplan turbine is used

The correlation use for cost calculation of generator & excitation system when bulb semi Kaplan turbine is use is given as:

$$C_6 = 67015P^{-0.1824}H^{-0.2092} \quad (3.14)$$

Where C_6= cost per kW of turbine with governing system

Using Eqn. (3.14) cost of turbine with governing system (for bulb semi Kaplan turbine) with is 186.56 lacs

Case 4: Cost of turbine with governing system when tubular propeller turbine is used

The correlation use for cost calculation of generator & excitation system when tubular propeller turbine is use is given as:

$$C_6 = 61153P^{-0.1961}H^{-0.2111} \quad (3.15)$$

Where C_6= cost per kW of turbine with governing system

Using Eqn. (3.15) cost of turbine with governing system (for tubular propeller turbine) with is 192.93 lacs.

Case 5: Cost of turbine with governing system when vertical propeller turbine is used

The correlation use for cost calculation of generator & excitation system when vertical propeller turbine is use is given as:

$$C_6 = 59264P^{-0.1817}H^{-0.2106} \quad (3.16)$$

Where C_6= cost per kW of turbine with governing system

Using Eqn. (3.16) cost of turbine with governing system (for vertical propeller turbine) with is 205.60 lacs.

Case 6: Cost of turbine with governing system when bulb propeller turbine is used

The correlation use for cost calculation of generator & excitation system when bulb propeller turbine is use is given as:

$$C_6 = 64017P^{-0.1850}H^{-0.2031} \quad (3.17)$$

Where C_6= cost per kW of turbine with governing system

Using Eqn. (3.17) cost of turbine with governing system (for bulb propeller turbine) with is 221.84 lacs.

Case 7: Cost of turbine with governing system when tubular Kaplan turbine is used

The correlation use for cost calculation of generator & excitation system when tubular Kaplan turbine is use is given as:

$$C_6 = 70170P^{-0.1853}H^{-0.2053} \quad (3.18)$$

Where C_6= cost per kW of turbine with governing system

Using Eqn. (3.18) cost of turbine with governing system (for tubular Kaplan turbine) with is 241.25 lacs.

Case 8: Cost of turbine with governing system when vertical Kaplan turbine is used

The correlation use for cost calculation of generator & excitation system when vertical Kaplan turbine is use is given as:

$$C_6 = 73624P^{-0.1872}H^{-0.2105} \quad (3.19)$$

Where C_6= cost per kW of turbine with governing system

Using Eqn. (3.19) cost of turbine with governing system (for vertical Kaplan turbine) with is 246.52 lacs.

Case 9: Cost of turbine with governing system when bulb Kaplan turbine is used

The correlation use for cost calculation of generator & excitation system when bulb Kaplan turbine is use is given as:

$$C_6 = 75048P^{-0.1873}H^{-0.2086} \quad (3.20)$$

Where C_6= cost per kW of turbine with governing system

Using Eqn. (3.20) cost of turbine with governing system (for bulb Kaplan turbine) with is 252.42 lacs.

3.3.6 Cost Calculation of Generator & Excitation System [35]

Generators transform mechanical energy into electrical energy. Although most early hydroelectric systems were of the direct current variety to match early commercial electrical systems, nowadays only three-phase alternating current generators are used in normal practice. Depending on the characteristics of the network supplied, the producer can choose between:

a. Synchronous generator
b. Asynchronous generator

The cost of generator & excitation system varies with types of turbine so further we have three cases.

Case 1: Cost of generator and excitation system when tubular semi Kaplan turbine is used

The correlation use for cost calculation of generator & excitation system when tubular semi Kaplan turbine is use is given as:

$$C_6 = 66268P^{-0.1882}H^{-0.2070} \qquad (3.21)$$

Where C_6= cost per kW of generator & excitation system

Using Eqn. (3.21) cost of generator & excitation system (for tubular semi Kaplan turbine) is 222.55 lacs.

Case 2: Cost of generator and excitation system when vertical semi Kaplan turbine is used

The correlation use for cost calculation of generator & excitation system when vertical semi Kaplan turbine is use is given as:

$$C_6 = 70299P^{-0.1826}H^{-0.2125} \qquad (3.22)$$

Where C_6= cost per KW of generator & excitation system

Using Eqn. (3.22) cost of generator & excitation system (for vertical semi Kaplan turbine) is 241.22 lacs.

Case 3: Cost of generator and excitation system when bulb semi Kaplan turbine is used

The correlation use for cost calculation of generator & excitation system when bulb semi Kaplan turbine is use is given as:

$$C_6 = 78258P^{-0.1833}H^{-0.2051} \qquad (3.23)$$

Where C_6= cost per kW of generator & excitation system

Using Eqn. (3.23) cost of generator & excitation system (for bulb semi Kaplan turbine) is 269.78 lacs.

Case 4: Cost of generator and excitation system when tubular propeller turbine is used

The correlation use for cost calculation of generator & excitation system when tubular propeller turbine is use is given as:

$$C_6 = 66268P^{-0.1882}H^{-0.2070} \quad (3.24)$$

Where C_6= cost per kW of generator & excitation system

Using Eqn. (3.24) cost of generator & excitation system (for tubular propeller turbine) is 222.55 lacs.

Case 5: Cost of generator and & excitation system when vertical propeller turbine is used.

The correlation use for cost calculation of generator & excitation system when vertical propeller turbine is use is given as:

$$C_6 = 70299P^{-0.1826}H^{-0.2125} \quad (3.25)$$

Where C_6= cost per kW of generator & excitation system

Using Eqn. (3.25) cost of generator & excitation system (for vertical propeller turbine) is 241.22 lacs.

Case 6: Cost of generator and & excitation system when bulb propeller turbine is used

The correlation use for cost calculation of generator & excitation system when bulb propeller turbine is use is given as:

$$C_6 = 78258P^{-0.1833}H^{-0.2091} \quad (3.26)$$

Where C_6= cost per kW of generator & excitation system

Using Eqn. (3.26) cost of generator & excitation system (for bulb propeller turbine) is 269.78 lacs.

Case 7: cost of generator and excitation system when tubular Kaplan turbine is used

The correlation use for cost calculation of generator & excitation system when tubular Kaplan turbine is use is given as:

$$C_6 = 72121P^{-0.1868}H^{-0.2082} \quad (3.27)$$

Where C_6= cost per kW of generator & excitation system

Using Eqn. (3.27) cost of generator & excitation system (for tubular Kaplan turbine) is 243.63 lacs

Case 8: cost of generator and excitation system when vertical Kaplan turbine is used

The correlation use for cost calculation of generator & excitation system when vertical Kaplan turbine is use is given as:

$$C_6 = 77693P^{-0.1840}H^{-0.2096} \quad (3.28)$$

Where C_6= cost per kW of generator & excitation system

Using Eqn. (3.28) cost of generator & excitation system (for vertical Kaplan turbine) is 266.26 lacs.

Case 9: cost of generator and & excitation system when bulb Kaplan turbine is used

The correlation use for cost calculation of generator & excitation system when bulb Kaplan turbine is use is given as:

$$C_6 = 85417P^{-0.1880}H^{-0.2096} \quad (3.29)$$

Where C_6= cost per kW of generator & excitation system

Using Eqn. (3.29) cost of generator & excitation system (for bulb Kaplan turbine) is 285.21 lacs.

3.3.7 Cost Calculation of Electrical and Mechanical Auxiliary [35]

In small hydropower it also involves some auxiliary in for operation & maintenance. Operation of Auxiliaries and other system installed in power station like:-

a) Turbine Governor Oil Pressure Unit
b) Cooling water system
c) Drainage & Dewatering system
d) AVR & excitation system
e) Generator neutral grounding system
f) Station compressors
g) Station illumination & emergency lighting
h) Station D.C. control system
i) Generator fire extinguishing system
j) EOT cranes

So in order to calculate the cost involve in auxiliary, which is also varies according to the selection of turbine is further classified in three cases:

Case 1: Cost of electrical and mechanical auxiliary when tubular semi Kaplan turbine is used

In this Case correlation used for cost calculation is given as:

$$C_7 = 35930P^{-0.1831}H^{-0.2098} \quad (3.30)$$

Where C_7 = cost per kW of auxiliary

Using Eqn. (3.30) cost of electrical and mechanical auxiliary (for tubular semi Kaplan turbine) is 123.79 lacs.

Case 2: Cost of electrical and mechanical auxiliary when vertical semi Kaplan turbine is used

In this case correlation used for cost calculation is given as:

$$C_7 = 37171P^{-0.1848}H^{-0.2094} \tag{3.31}$$

Where C_7 = cost per kW of auxiliary

Using Eqn. (3.31) cost of electrical and mechanical auxiliary (for vertical semi Kaplan turbine) is 126.79 lacs.

Case 3: Cost of electrical and mechanical auxiliary when bulb semi Kaplan turbine is used

In this case correlation used for cost calculation is given as:

$$C_7 = 39223P^{-0.1800}H^{-0.1586} \tag{3.32}$$

Where C_7 = cost per kW of auxiliary

Using Eqn. (3.32) cost of electrical and mechanical auxiliary (for bulb semi Kaplan turbine) is 142.13 lacs.

Case 4: Cost of electrical and mechanical auxiliary when tubular propeller turbine is used

In this case correlation used for cost calculation is given as:

$$C_7 = 34124P^{-0.1897}H^{-0.2196} \tag{3.33}$$

Where C_7 = cost per kW of auxiliary

Using Eqn. (3.33) cost of electrical and mechanical auxiliary (for tubular propeller turbine) is 109.68 lacs.

Case 5: Cost of electrical and mechanical auxiliary when vertical propeller turbine is used

In this case correlation used for cost calculation is given as:

$$C_7 = 34852P^{-0.1865}H^{-0.2120} \tag{3.34}$$

Where C_7 = cost per kW of auxiliary

Using Eqn. (3.34) cost of electrical and mechanical auxiliary (for vertical propeller turbine) with various head and power is calculated 116.75 lacs.

Case 6: Cost of electrical and mechanical auxiliary when bulb propeller turbine is used

In this case correlation used for cost calculation is given as:

$$C_7 = 37513P^{-0.1831}H^{-0.2115} \tag{3.35}$$

Where C_7 = cost per kW of auxiliary

Using Eqn. (3.35) cost of electrical and mechanical auxiliary (for bulb propeller turbine) is 128.51 lacs.

Case 7: Cost of electrical and mechanical auxiliary when tubular Kaplan turbine is used

In this case correlation used for cost calculation is given as:

$$C_7 = 37168P^{-0.1840}H^{-0.2156} \tag{3.36}$$

Where C_7 = cost per kW of auxiliary

Using Eqn. (3.36) cost of electrical and mechanical auxiliary (for tubular Kaplan turbine) is 125.32 lacs.

Case 8: Cost of electrical and mechanical auxiliary when vertical Kaplan turbine is used

In this case correlation used for cost calculation is given as:

$$C_7 = 39199P^{-0.1805}H^{-0.2072} \tag{3.37}$$

Where C_7 = cost per kW of auxiliary

Using Eqn. (3.37) cost of electrical and mechanical auxiliary (for vertical Kaplan turbine) is 138.33 lacs.

Case 9: Cost of electrical and mechanical auxiliary when bulb Kaplan turbine is used

In this case correlation used for cost calculation is given as:

$$C_7 = 40096P^{-0.1847}H^{-0.2156} \tag{3.38}$$

Where C_7 = cost per kW of auxiliary

Using Eqn. (3.38) cost of electrical and mechanical auxiliary (for bulb Kaplan turbine) with various head and power is calculated 134.58 lacs.

3.3.8 Cost Calculation of Transformer and Switchyard Equipment [35]

In many countries the electricity supply regulations place a statutory obligation on the electric utilities to maintain the safety and quality of electricity supply within defined limits. The independent producer must operate his plant in such a way that the utility is able to fulfil its obligations. Therefore various associated electrical devices are required inside the powerhouse building for the safety and protection of the equipment.

Switchgear must be installed to control the generators and to interface them with the grid or with an isolated load. It must provide protection for the generators, main transformer and station service transformer.

The correlation use for the cost calculation of transformer & switchyard is found out as:

$$C_7 = 18739P^{-0.1803}H^{-0.2075} \quad (3.39)$$

Where C_8 = cost per kW of transformer & switchyard

Using Eqn. (3.39) cost of transformer & switchyard with various head and power is calculated 66.16 lacs.

CHAPTER 4
RESULT ANALYSIS OF SHP PROJECT

4.1 ANALYSIS METHODOLOGY

The cost of the project depends on location, construction period and variation in cost of materials, availability of construction equipment, and variation in labour cost. The total project cost includes cost of civil works, cost of electromechanical equipment, cost of other miscellaneous items, and other indirect costs. The cost of components of civil works as well as that of electromechanical equipment mainly depends on the installed capacity and head of the scheme.

In case of low head SHP scheme, as cost of turbine has higher proportion of total cost of the scheme. Also selection of a particular type of turbine for a given site is a site specific task. As the cost of SHP project varies according to the selection of types of turbine. Basically the cost of powerhouse, cost of turbine, cost of generator and cost of auxiliary will differ for different selection of turbine. So various turbines can be studied for optimal installation of SHP projects on the basis of turbine selection.

In the present study a typical site having specification as head of 15m and capacity 2000 kW has been considered and overall cost of the schemes for different turbines has been analyzed. All types of turbines for low head namely tubular semi Kaplan, vertical semi Kaplan, bulb semi Kaplan, tubular propeller, vertical propeller, bulb propeller, tubular Kaplan and vertical Kaplan turbine have been studied for the optimal installation of the chosen site based on turbine selection.

4.2 COST ESTIMATION

Based on Analysis done in Chapter-3, cost of different components for the considered site with head 15 m and capacity 2000 kW using different turbines has been calculated. Various cases have been shown as follows. The base year of cost calculation is financial year 2007-08.

Case 1: Cost of SHP project when tubular semi Kaplan turbine is used

Cost calculation of various components of SHP project when tubular semi Kaplan turbine in use has been calculated as done in Chapter-3 and results data are tabulated as shown in Table 4.1.

Table 4.1 Various cost calculations for assumed site specification (for tubular semi Kaplan turbine)

Types of Cost	**Cost (Lacs)**
Cost of Diversion Channel(C_1)	37.63
Cost of Spillway(C_2)	137.94
Cost of Powerhouse Building (C_3)	381.60
Cost of Tubular Semi Kaplan Turbine(C_4)	202.86
Cost of Generator With Excitation System(C_5)	222.55
Cost of Electrical& Mechanical Auxiliary(C_6)	123.79
Cost of Transformer & Switchyard System(C_7)	66.16
Total Cost of Civil Work($C_c=C_1+C_2+C_3$)	557.17
Total Cost of Electromechanical Work($C_{e\&M}=C_4+C_5+C_6+C_7$)	615.36
Total cost (civil work + electromechanical)	1172.53

Case 2: Cost of SHP project when vertical semi Kaplan turbine is used

Cost calculation of various components of SHP project when vertical semi Kaplan turbine in use has been calculated as done in Chapter-3 and results data are tabulated as shown in Table 4.2.

Table 4.2 Various cost calculations for assumed site specification (for vertical semi Kaplan turbine)

Types of Cost	Cost (Lacs)
Cost of Diversion Channel(C_1)	37.63
Cost of Spillway(C_2)	137.94
Cost of Powerhouse Building (C_3)	340.80
Cost of vertical Semi Kaplan Turbine(C_4)	216.50
Cost of Generator With Excitation System(C_5)	241.22
Cost of Electrical& Mechanical Auxiliary(C_6)	126.79
Cost of Transformer & Switchyard System(C_7)	66.16
Total Cost of Civil Work($C_c=C_1+C_2+C_3$)	516.37
Total Cost of Electromechanical Work($C_{e\&M}=C_4+C_5+C_6+C_7$)	650.67
Total cost (civil work + electromechanical)	1167.04

Case 3: Cost of SHP project when bulb semi Kaplan turbine is used

Cost calculation of various components of SHP project when bulb semi Kaplan turbine in use has been calculated as done in Chapter-3 and results data are tabulated as shown in Table 4.3.

Table 4.3 Various cost calculations for assumed site specification (for bulb semi Kaplan turbine)

Types of Cost	Cost (Lacs)
Cost of Diversion Channel(C_1)	37.63
Cost of Spillway(C_2)	137.94
Cost of Powerhouse Building (C_3)	312.28
Cost of bulb Semi Kaplan Turbine(C_4)	186.56
Cost of Generator With Excitation System(C_5)	269.78
Cost of Electrical& Mechanical Auxiliary(C_6)	142.13
Cost of Transformer & Switchyard System(C_7)	66.16
Total Cost of Civil Work($C_c=C_1+C_2+C_3$)	487.85
Total Cost of Electromechanical Work($C_{e\&M}=C_4+C_5+C_6+C_7$)	664.63
Total cost (civil work + electromechanical)	1152.48

Case 5: Cost of SHP project when vertical propeller turbine is used

Cost calculation of various components of SHP project when vertical propeller turbine in use has been calculated as done in Chapter-3 and results data are tabulated as shown in Table 4.5.

Table 4.5 Various cost calculations for assumed site specification (for vertical propeller turbine)

Types of Cost	Cost (Lacs)
Cost of Diversion Channel(C_1)	37.63
Cost of Spillway(C_2)	137.94
Cost of Powerhouse Building (C_3)	334.26
Cost of vertical propeller Turbine(C_4)	205.60
Cost of Generator With Excitation System(C_5)	241.22
Cost of Electrical& Mechanical Auxiliary(C_6)	116.75
Cost of Transformer & Switchyard System(C_7)	66.16
Total Cost of Civil Work($C_c=C_1+C_2+C_3$)	509.83
Total Cost of Electromechanical Work($C_{e\&M}=C_4+C_5+C_6+C_7$)	629.73
Total cost (civil work + electromechanical)	1139.56

Case 6: Cost of SHP project when bulb propeller turbine is used

Cost calculation of various components of SHP project when bulb propeller turbine in use has been calculated as done in Chapter-3 and results data are tabulated as shown in Table 4.6.

Table 4.6 Various cost calculations for assumed site specification (for bulb propeller turbine)

Types of Cost	**Cost (Lacs)**
Cost of Diversion Channel(C_1)	37.63
Cost of Spillway(C_2)	137.94
Cost of Powerhouse Building (C_3)	295.96
Cost of bulb propeller Turbine(C_4)	221.84
Cost of Generator With Excitation System(C_5)	269.78
Cost of Electrical& Mechanical Auxiliary(C_6)	128.51
Cost of Transformer & Switchyard System(C_7)	66.16
Total Cost of Civil Work($C_c=C_1+C_2+C_3$)	471.53
Total Cost of Electromechanical Work($C_{e\&M}=C_4+C_5+C_6+C_7$)	686.29
Total cost (civil work + electromechanical)	1157.82

Case 7: Cost of SHP project when tubular Kaplan turbine is used

Cost calculation of various components of SHP project when tubular Kaplan turbine in use has been calculated as done in Chapter-3 and results data are tabulated as shown in Table 4.7.

Table 4.7 Various cost calculations for assumed site specification (for tubular Kaplan turbine)

Types of Cost	**Cost (Lacs)**
Cost of Diversion Channel(C_1)	37.63
Cost of Spillway(C_2)	137.94
Cost of Powerhouse Building (C_3)	401.34
Cost of Tubular Kaplan Turbine(C_4)	241.25
Cost of Generator With Excitation System(C_5)	243.63
Cost of Electrical& Mechanical Auxiliary(C_6)	125.32
Cost of Transformer & Switchyard System(C_7)	66.16
Total Cost of Civil Work($C_c=C_1+C_2+C_3$)	576.91
Total Cost of Electromechanical Work($C_{e\&M}=C_4+C_5+C_6+C_7$)	676.36
Total cost (civil work + electromechanical)	1253.27

Case 8: Cost of SHP project when vertical Kaplan turbine is used

Cost calculation of various components of SHP project when vertical Kaplan turbine in use has been calculated as done in Chapter-3 and results data are tabulated as shown in Table 4.8.

Table 4.8 Various cost calculations for assumed site specification (for vertical Kaplan turbine)

Types of Cost	Cost (Lacs)
Cost of Diversion Channel(C_1)	37.63
Cost of Spillway(C_2)	137.94
Cost of Powerhouse Building (C_3)	362.98
Cost of vertical Kaplan Turbine(C_4)	246.52
Cost of Generator With Excitation System(C_5)	266.26
Cost of Electrical& Mechanical Auxiliary(C_6)	138.33
Cost of Transformer & Switchyard System(C_7)	66.16
Total Cost of Civil Work($C_c=C_1+C_2+C_3$)	538.55
Total Cost of Electromechanical Work($C_{e\&M}=C_4+C_5+C_6+C_7$)	717.27
Total cost (civil work + electromechanical)	1255.82

Case 9: Cost of SHP project when bulb Kaplan turbine is used

Cost calculation of various components of SHP project when bulb Kaplan turbine in use has been calculated as done in Chapter-3 and results data are tabulated as shown in Table 4.9.

Table 4.9 Various cost calculations for assumed site specification (for bulb Kaplan turbine)

Types of Cost	**Cost (Lacs)**
Cost of Diversion Channel(C_1)	37.63
Cost of Spillway(C_2)	137.94
Cost of Powerhouse Building (C_3)	328.40
Cost of bulb Kaplan Turbine(C_4)	252.42
Cost of Generator With Excitation System(C_5)	285.21
Cost of Electrical& Mechanical Auxiliary(C_6)	134.58
Cost of Transformer & Switchyard System(C_7)	66.16
Total Cost of Civil Work(C_c=C_1+C_2+C_3)	503.97
Total Cost of Electromechanical Work($C_{e\&M}$=C_4+C_5+C_6+C_7)	738.37
Total cost (civil work + electromechanical)	1242.34

4.3 COST OF CIVIL AND ELECTROMECHANICAL COMPONENT

Cost of civil and electromechanical component is calculated for various types of turbine It has been found out that cost of civil work will be least by using bulb propeller turbine, and electromechanical cost will be least by using tubular semi Kaplan turbine.

Table 4.10 Civil and electromechanical cost of project for different turbine.

Type of turbines	Civil Cost(Lacs)	Electro Mechanical Cost (Lacs)	Total Cost (Lacs)
Tubular semi Kaplan	557.17	**615.36**	1172.53
Vertical semi Kaplan	516.37	650.67	1167.04
Bulb semi Kaplan	487.85	664.63	1152.48
Tubular propeller	549.49	722.86	1272.35
Vertical propeller	509.83	629.73	**1139.56**
Bulb propeller	**471.53**	686.29	1157.82
Tubular Kaplan	576.91	676.36	1253.82
Vertical Kaplan	538.55	717.27	1255.82
Bulb Kaplan	503.97	738.37	1242.34

4.4 CALCULATION OF MISCELLANEOUS COST

Miscellaneous cost of any SHP project depends upon the types of scheme, types of turbine etc. and mathematically it is assumed that miscellaneous cost is 0.13 times of sum of cost of civil work cost and electromechanical cost.

$$C_{misc.} = 0.13(C_C + C_{e\&m}) \quad (4.1)$$

Where C_{misc} =miscellaneous cost per kW

Using Eqn. (4.1) cost of miscellaneous items for different turbines has been calculated and results are tabulated as shown in Table 4.11.

Table 4.11 Miscellaneous cost of project for different turbine.

Types turbines	**C_{misc}(Rs)**
Tubular semi Kaplan	152.43
Vertical semi Kaplan	151.72
Bulb semi Kaplan	149.82
Tubular propeller	165.41
Vertical propeller	**148.14**
Bulb propeller	150.52
Tubular Kaplan	162.93
Vertical Kaplan	163.26
Bulb Kaplan	161.50

4.5 TOTAL COST ESTIMATION FOR FINANCIAL YEAR 2007-08

Total cost will be sum of cost of civil works, electromechanical equipment and miscellaneous items and is given as

$$C_T = Cc + C_{e\&m} + C_{misc.} \quad (4.2)$$

Using Eqn. (4.2) total cost for different turbines has been calculated and results are tabulated as shown in Table 4.12.

Table 4.12 Total cost of the project for different turbines for financial year (2007-08)

Types turbines	**C_T(Rs)**
Tubular Semi Kaplan	1324.96
Vertical Semi Kaplan	1318.76
Bulb Semi Kaplan	1302.30
Tubular Propeller	1437.76
Vertical Propeller	**1287.70**
Bulb Propeller	1308.34
Tubular Kaplan	1416.19
Vertical Kaplan	1419.08
Bulb Kaplan	1403.84

4.6 TOTAL COST ESTIMATION FOR FINANCIAL YEAR 2011-12

As above calculation is based on 2007-08 financial year, it is to be escalated to current financial year 2011-12 by considering 5 % annual increment.

$$C = 1.22 * C_T \qquad (4.2)$$

Using Eqn. (4.2) total cost for current year has been calculated and results are tabulated as shown in Table 4.13.

Table 4.13 Total cost of the project for different turbines for financial year (2011-12)

Types turbines	**C_T(lacs) (2007-08)**	**C (Lacs) (2011-12)**
Tubular Semi Kaplan	1324.96	1616.45
Vertical Semi Kaplan	1318.76	1608.88
Bulb Semi Kaplan	1302.30	1588.80
Tubular Propeller	1437.76	1754.07
Vertical Propeller	**1287.70**	**1571.00**
Bulb Propeller	1308.34	1596.17
Tubular Kaplan	1416.19	1727.76
Vertical Kaplan	1419.08	1731.28
Bulb Kaplan	1403.84	1712.70

4.7 COST ESTIMATION FOR POWER GENERATION

Annual cost has been taken as 16% of the project cost.

$$C_G = 0.16*C \tag{4.3}$$

Using Eqn. (4.3) generation cost has been calculated and results are tabulated as shown in Table 4.14.

Table 4.14 Annual generation cost of the project for different turbines

Types turbines	**C (Lacs) (2011-12)**	$C_{G\ (lacs)}$
Tubular Semi Kaplan	1616.45	258.63
Vertical Semi Kaplan	1608.88	257.42
Bulb Semi Kaplan	1588.80	254.21
Tubular Propeller	1754.07	280.65
Vertical Propeller	1571.00	251.36
Bulb Propeller	**1596.17**	**225.39**
Tubular Kaplan	1727.76	276.44
Vertical Kaplan	1731.28	277.00
Bulb Kaplan	1712.70	274.03

4.8 COST OF ENERGY GENERATION PER UNIT

Energy generation by using different turbines at their maximum efficiency is calculated, annual energy generation is highest by using bulb Kaplan turbine, annual energy generation cost will be lowest by using vertical propeller turbine but energy generation per unit cost will be lowest by using bulb propeller turbine.

Table 4.15 Generation cost per unit of the project for different turbines

Types Turbines	**Maximum Efficiency**	**Energy Generation (kWh)*1000**	**Annual Generation Cost(Lacs)**	**Generation Cost Per Unit(Rs)**
Tubular Semi Kaplan	0.90	14979.6	258.63	1.73
Vertical Semi Kaplan	0.89	14813.16	257.42	1.74
Bulb Semi Kaplan	0.91	15146.04	254.21	1.68
Tubular Propeller	0.89	14813.16	280.65	1.89
Vertical Propeller	0.88	14646.72	**251.36**	1.72
Bulb Propeller	0.90	14979.6	225.39	**1.50**
Tubular Kaplan	0.92	15312.48	276.44	1.81
Vertical Kaplan	0.91	15146.04	277.00	1.83
Bulb Kaplan	0.93	**15478.92**	274.03	1.77

It is seen from table that energy generation cost is 1.5 Rs per kWh which is lowest by using bulb propeller turbine, thus the optimum choice.

CHAPTER 5
CONCLUSIONS

In the present study efforts have been made to work out cost effective solution for SHP projects. A case study having capacity 2000 kW at 15 m head is considered for developing the methodology for cost effective design of SHP project. There are 9 types of turbine which can be used in low head schemes. Thus nine types of layouts are considered for study, It has been found that

(1) Cost of diversion channel and cost of spillway will be same for all considered layouts.

(2) Cost of power house building will be minimum at 295.96 lacs by using bulb propeller turbine among all 9 options.

(3) Cost of turbine will be 186.56 lacs by using bulb semi Kaplan turbine, which is minimum turbine cost among all 9 options.

(4) Cost of generator with excitation system will be 222.55 lacs by using tubular semi Kaplan turbine or tubular propeller which is minimum cost among all 9 options.

(5) Cost of electrical & mechanical auxiliary will be 116.75 lacs by using vertical propeller turbine, which is minimum electrical & mechanical auxiliary cost among all 9 options.

(6) Cost of transformer and switch yard system will be 66.16 lacs which is same for all considered layouts.

(7) Cost of civil works will be 471.53 lacs by using bulb propeller turbine, which is minimum civil works cost.

(8) Cost of electro-mechanical equipment will be 615.36 lacs by using tubular semi Kaplan turbine which is minimum electro-mechanical cost.

(9) Total cost of plant including civil work and electro-mechanical equipment will be 1139.56 lacs by using vertical propeller turbine which is minimum total cost.

(10) Total cost of the project for current financial year (2011-12) including civil work, electro-mechanical equipment and miscellaneous items will be 1571.00 lacs by using vertical propeller turbine which is minimum.

(11) Annual generation cost of plant will be 225.39 lacs by using bulb propeller turbine which is minimum annual generation cost.

(12) By considering efficiency for all 9 turbines, total energy generation will be 15312.48 MWh by using bulb propeller turbine; which is maximum.

(13) Generation cost per kWh will be 1.50 Rs by using bulb propeller turbine which is minimum per unit cost.

Therefore for the considered SHP site with bulb propeller tubular would be economical.

REFERENCES

[1] http://www.powermin.nic.in/indian_electricity_scenario/introduction.htm and file:///D:/prog-smallhydro.htm [Accessed on April 2012]

[2] Nigam P.S. (1985), Hand Book of Hydro Electric Engineering, Nem Chand and Brothers, Roorkee, India.

[3] Singhal S.K. , Saini R.P. and Raghuvanshi C.S., "Analysis for cost estimation of low head run of river small hydro power schemes ",Energy for Sustainable Development (2010) pp.117-126.

[4] Singal S. K. and Saini R. P., "Analysis for quick estimation of canal based small hydro power schemes", special focus renewable energy, IEEMA journal, September 2008, pp.77-78.

[5] http://en.wikipedia.org/wiki/File:Hydroelectric_dam.png [Accessed on April 2012]

[6] Micro Hydro Power Resource Assessment Handbook, Asian and Pacific Centre for Transfer of Technology Of the United Nations – Economic and Social Commission for Asia and the Pacific (ESCAP), September 2009, pp.31-33.

[7] Varshney S R, Hydro power structures, Roorkee, India: Nem chand & Brothers:2001

[8] Alexander K.V., Giddens E.P. " Micro hydro: cost-effective, modular systems for low heads" Renewable Energy 33, 2008, pp. 1379–1391.

[9] Voros N. G., Kiranoudis C. T. and Maroulis Z. B., "Short-cut design of small hydroelectric plants", Renewable Energy 19 (2000), pp. 545-563.

[10] Anagnostopoulos John S. , and Papantonis Dimitris E., "Optimal sizing of a run-of-river small hydropower plant", Energy Conversion and Management 48(2007) pp. 2663–2670.

[11] Dept. of the army, US army corps of Engineers, Washington, DC."Engineering and design of hydroelectric power plant structure". Engineer manual 1110-2-3001, April 1995.

[12] Ogayar B. and Vidal P.G. "Cost determination of the electro-mechanical equipment of a small hydro-power plant" Renewable Energy 34 (2009) pp. 6-13.

[13] Thapar O.D. and Das Devadutta , "Small Scale and Low Head Hydroelectric Station Equipment", Technical paper Published by AHEC Scientists,1983.

[14] Montanari R. , "Criteria for the economic planning of a low power hydro electric plant." Renewable Energy 28 (2003), pp. 2129-2145.

[15] Gordon J. L. and Eng. P. "Turbine selection for small low-head hydro developments", pre-conference workshop, Innovative Small Hydro Technologies, Natural Resources Canada, Water Power XIII, July 29, 2003, Buffalo, New York, U.S.A.

[16] Morel, T.; Arndt R. E. A., "Potential for Reducing Kinetic Losses in Low-Head Hydropower", Conference Article, Small Hydro Power Fluid Machinery, 1984, pp.57-65.

[17] Mankbadi R.R. and Mikhail S., "Operation and Economical Feasibility of a Turbine-Generator Micro Hydro Plant", Energy Vol.10, No.6, 1985 pp. 777-784.

[18] L. Ronald Schikevitz and Yucel "Computer-Aided Preliminary Optimizational Model for Low Head Micro-Hydro Installations", Water for Resource Development, Proceedings of the Conference, 1984, pp. 746-750.

[19] Larsen and Johannes, "Intakes for Low Head Hydro Plants", Hydraulics and Hydrology in the Small Computer Age, Proceedings of the Specialty Conference, 1985, pp. 956-960.

[20] Rao, G.J., Prasad R. and Kulkani B.S., "Simplified turbine runner shows good cavitation resistance", International Water Power and Dam Construction, v 40, August 1988, pp. 20-22.

[21] Passmore R., "Hydroelectric Generating Units of Small Capacity for Low Operating Heads", Proceedings of the Society of Photo-Optical Instrumentation Engineers, 1980. pp.1-13

[22] Banda A.M. Samarakoon , "Selection of freeboard in headrace canals of small hydropower schemes", International conference on small hydropower- Hydro Sri lanka, October 2007.

[23] Singhal M.K., Singh Ajit and Singh S.P. "Computer aided planning for civil works of canal based hydro projects", International conference on small hydropower- Hydro Sri anka, October 2007.

[24] Majumdar A.N. and Gaur R.K. "Design and standardisation of small hydel station, Seminar on small hydro stations", volume-2 general reports and discussions central board of irrigation and power, January 1983,pp.119-122.

[25] Mudgal B.V. and G. Ravi kumar, "Hydraulic design of headrace and tailrace channel for a low head hydro power plant using partial analysis", International conference on small hydropower- Hydro Srilanka, October 2007.

[26] Kar R.N., "Some aspects of low head small hydro electric installations, Seminar on small hydro stations", volume-2 general reports and discussions central board of irrigation and power, January 1983, pp.119-122.

[27] Schneider Ch., Knapp W. and Schilling R., "Optimised tail water and draft tube design of low head small hydro", International water power and dam construction conference, Kuala lumpur, October 1996

[28] Mankbadi R. Reda and Mikhail A.Sami , "A turbine-pump system for low-head hydropower", Energy Convers. Mgmt Vol. 25, No. 3.,1985, pp. 339-344,

[29] Singal S.K. and Saini R.P., "Analytical approach for development of correlations for cost of canal-based SHP schemes", International Conference on small Hydropower- Hydro Sri Lanka, October 2007.

[30] Singal S.K. and Varun," Small Hydro Power Technology" proceedings of international conference on energy and environment March 19-21, 2009 ISSN: 2070-3740.

[31] http://www.ahec.org.in/links/hshs/presentations/links/technical%20papers/case%20studies/dr%20z%20ahmad_recent%20advances%20in%20the%20design%20of%20trench%20weir.pdf. (accessed on march 2012)

[32] "Design guidance for coanda-effect screens", U.S. department of the interior bureau of reclamation, Water Resources Research Laboratory Denver, Colorado, July 2003.

[33] "Guide on How to Develop a Small Hydropower Plant", European Small Hydropower Association – ESHA, 2004.

[34] IS: 12800 (Part 3) (1991), "Guidelines for the Selection of Hydraulic Turbine, Preliminary Dimensioning and Layout of Surface Hydro- Electric Power House (Small, Mini and Micro Hydro-Electric Power

[35] Singhal S.K., Saini R.P. and Raghuvanshi C.S., "Cost Optimisation based on Electro-mechanical Equipment of Canal Based low head small hydropower scheme",the open renewable energy journal (2008), pp.26-35.