OPTIMIZATION IN SMALL HYDRO POWER PLANTS

A DISSERTATION

Submitted in partial fulfillment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
WATER RESOURCES DEVELOPMENT

By

CHIRNJEEWEE CHATAUT

DEPARTMENT OF WATER RESOURCES DEVELOPMENT AND MANAGEMENT
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE - 247 667 (INDIA)
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CANDIDATE'S DECLARATION

I hereby declare that the dissertation titled **"Optimization in Small Hydropower Plants"** which is being submitted in partial fulfillment of the requirements for the award of Degree of Master of Technology in **Water resources Development (Electrical)** at Department of Water Resources Development and Management (WRD&M), Indian Institute of Technology, Roorkee is an authentic record of my own work carried out during the period of July, 2006 to June, 2007 under the supervision and guidance of **Professor Devadutta Das,** WRD&M, IIT, Roorkee.

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

Chataut

Place: Roorkee
Dated: 26 June, 2007

Chirnjeewee Chataut

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

Devadutta Das

Devadutta Das
Professor
WRD&M, IIT, Roorkee
Roorkee-247667
(India)

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ABBREVIATIONS

AC	Alternating Current
ASG	Asynchronous Generator
AVR	Automatic Voltage Regulator
CBIP	Central Board of Irrigation and Power
CTs	Current Transformers
cumecs	Cubic Meter per Second
DC	Direct Current
E&D	Engineering & Design
E/M	Electromechanical
E/M	ESHA – European Small Hydropower Associations
FDC	Flow Duration Curve
fn	Function
hrs	Hours
HDPE	High Density Polyethylene Pipe
IRR	Internal Rate of Return
IS	Indian Standard
KN	Kilo Newton
KW	Kilo Watt
KWh	Kilo Watt Hour
LDC	Load Duration Curve
MU	Million Unit
MW	Mega Watt
MWh	Mega Watt Hour
MS	Mild Steel
NPV	Net Present Value
Ns	Specific Speed
O&M	Operation & Maintenance
PID	Proportional, Integral & Derivative
PLF	Plant Load Factor
PTs	Potential Transformers
RCC	Reinforced Cement Concrete

ROE	Return on Equity
ROI	Return on Investment
rpm	Revolution per Minute
S&A	Supervision & Administration
SG	Synchronous Generator
SHP	Small Hydropower Project
SHPP	Small Hydro Power Plant
SPSS	Software Package for Statistical Science
WCS	Water Conductor System

ABSTRACT

The hydro power is renewable source of energy and widely used in the world. Mainly the small hydro is renewable, non-polluting and environmentally benign source of energy. There is not a standard definition of small hydro, its upper limit varies from 5 MW to 50 MW, in India upper limit is 25 MW.

The small hydro power plants are generally run-of-river type. The important issues in planning SHPPs in mountainous region are selection of major components like diversion structure, water conveyance system, type of generating equipment etc. Proper selection of the major components of SHPPs reduces the operation & maintenance cost as well as minimizes the energy losses at the time of operation. A water conductor of a small hydropower plant is a major component of civil works involving large chunk of land, cost and time–span for installation. Due to its length it is also important in respect of stability and geophysical conditions of site, felling of trees, safety of houses, fields, orchards and roads, maintenance and repair cost, ecological and environmental considerations. Therefore it is important that a most economical, sound and optimally suitable system should be adopted for the water conductor system. A comparative study is carried out in the five operational small hydropower plants of the Uttaranchal State of India for the selection of best water conductor system in the long run. It is found that the tunnel is best option than the open channel comparing the construction cost and energy loss amount.

Similarly, other most important issue in planning SHPPs is to determine the optimal installation capacity and optimal energy value. Stream discharge, head, power transmission system, cost of civil works & electro-mechanical equipment and load & demand characteristics are the main input to calculate the optimal economic and reliable installed capacity of SHPPs. The power is directly proportional to head and discharge, for the particular site the head of run-of-river SHPP can be considered almost constant and discharge is varying in whole year, thus the stream discharge plays important role to finalize the installed capacity for economic energy generation. For the determination of installed capacity of the project, the different 36 capacities are calculated on the basis of available 10 daily average discharges of the selected year and on the basis of minimum unit generation cost for first year of operation, the optimal economic installed capacity can be fixed. The unit generation cost can be calculated from the annual cost and annual

energy generation. Annual cost of project is interest on loan, operation & maintenance cost, depreciation, return on equity, taxes etc and annual energy can be estimated for any restricted power from the available discharge in a year. In this study annual cost for first year of operation is converted into the percentage of project cost and project cost is computed from the developed relationship of cost, head and capacity of different projects.

INTRODUCTION

1.1 SMALL HYDROPOWER PLANTS

The amount of power available at a given site is decided by the volumetric flow of water and the hydraulic head or water pressure. In hydro schemes, the turbines that drive the electrical generators are directly powered either from a reservoir or from the 'run of the river'. Generally, in the hills small hydro power projects are 'run of the river' type. Small Hydro-Power Plants (SHPPs) have found special importance due to their relatively low administrative and executive costs, and a short construction time compared to large hydro power plants.

The important issues in planning SHPPs in mountainous region are selection of major components like diversion structure, water conveyance system, type of generating equipment etc. Proper selection of the major components of SHPPs reduces the operation maintenance cost as well as minimizes the energy losses at the time of operation. One of the most important issues in planning Small Hydro-Power Plants of the "run-off river" type is to determine the optimal installation capacity of the SHPP and estimate its optimal annual energy value. These SHPPs are in the "run-of-the river" category because their generated capacity is based on the deviated water flow of river runoff and consists of a diversion structure, conveyance of water system, head pond (if possible), forebay, penstock, power house, and tailrace structure of the body of the SHPP as well as other electrical and mechanical equipment. The deviated flow of a river reaches the forebay after running in a path to the diverted point, and then enters into the SHPP structure via penstock pipes. The amount of energy generated during different daily hours and/or different seasons of the year are the most important issues. In other words, calculating the optimal installation capacity optimal designed flow is one of the most important factors in planning SHPPs.

A flow duration curve at the project site is the basis for the determination of turbine installed capacity. The capacity to be installed for a turbine is a problem of economics. That installed capacity is the best one which shows maximum net return in terms of power production on the basis of available flows.

1.2 CLASSIFICATION OF SHPs

The hydropower plants are generally classified in to two categories, run-of-river type and storage type. The small hydropower plants are generally run-of-river type and broadly classified in to three categories (i) SHP on canal fall, (ii) power house located at dam toe and (iii) power house located remotely. There is no general international consensus on the definition of small hydropower. The upper limit varies country wise from 5 to 50 MW. The following table shows upper power limit of small hydropower of some countries.

Table 1.1 Upper limits of SHPs in different countries [17]

Name of Country	**Upper Limit of SHP**
USA	5 MW
Iran	10 MW
Nepal	10 MW
Sweden	15 MW
Colombia	20 MW
Australia	20 MW
India	25 MW
China	25 MW
Philippines	50 MW
New Zealand	50 MW
Sri Lanka	50 MW

Classification of SHP Based on Head

Table 1.2 Classification of SHP according to head [17]

High Head	70 m and above
Medium Head	30 m to 70 m
Low Head	3 m to 30 m
Ultra Low Head	Below 3 m

Classification of SHP Based on Capacity in India

Table 1.3 Classification of hydropower schemes in India according to capacity. [17]

Type of Scheme	Unit Rating	Station Max Capacity
Pico	5KW&Below	5KW
Micro	6KW to 100KW	100KW
Mini	101KW to 1000 KW	3000 KW
Small	1000 KW to 5000 KW	25000 KW

1.3 ADVANTAGES OF SHPPs

Small hydropower has been technically feasible for decades. Given a favorable site, it can be economically attractive, sometimes even offering the least-cost method of generating electricity. In areas of low population density, and long transmission distances to the main centre of population can often nullify the low cost advantages at the hydropower plant. Small hydropower has the ability to generate electricity instantly, to supply both base and peak load generation, has a long life, is easy to maintain and is highly reliable.

- A sustainable resource. It meets the needs of the present without compromising the ability of future generations to meet their own needs.
- An efficient resource. It can satisfy energy demand with no depletion of the resource and with little impact on the environment.
- A clean resource. It does not involve a process of combustion, thus avoiding polluting and greenhouse gas emissions.
- A renewable resource. The fuel for hydropower is water, which is not consumed in the electricity generation process.
- Reduce global warming through the use of renewable, perennial, non-fossil fuel based energy sources.
- Protect biodiversity in these regions by reducing deforestation.
- Reduce migration of population from remote hilly areas to urban centers, consequently effecting reduction in pollution in the urban areas.

1.4 SCOPE OF STUDY

Project planning involves proper analysis of stream flow and waterpower study, determination of optimal installed capacity, proper selection of major components. Selection of economical water conductor system for run-of-river small hydropower plants in hilly area is important and difficult. Existing SHPPs of Uttaranchal State and similar areas mostly having the open channel water conductor system and long shutdown of plants due to the problem in channel is faced therefore it is important to study about the average annual losses due to the problem in the open channel and compare with head race tunnel for same to select most economical system for long run.

To fulfill the power demand in the hilly or mountainous region SHPPs are the best energy sources. Still there is large unutilized small hydropower resource in

Uttaranchal State and similar neighboring area therefore it is important to make a simple, quick and cost effective planning and design procedure. For the preliminary planning and design selection of optimal economic installed capacity is very important and to get optimal installed capacity minimum unit generation cost at maximum return is needed.

1.5 METHODOLOGY OF STUDY

The study is done from the field data which are collected from the various SHPPs of the Uttaranchal State of India by the field visit and various sources. For the economical selection of water conductor system Microsoft Excel software is used, for the construction of a model to estimate the per unit capacity cost for the selection of optimum economical installed capacity SPSS (software package of statistical science) software is used.

1.6 ORGANIZATION OF THE DISSERTATION

Chapter – 1	presents the introduction and classification of small hydropower plants, scope of the study and methodology.
Chapter – 2	presents the theoretical description about the design and planning of the small hydropower plants.
Chapter – 3	deals with the main components of the small hydropower plants.
Chapter – 4	presents the case study of some small hydropower plants in Uttaranchal State of India for the selection of economical water conductor system.
Chapter – 5	presents the computational procedure for optimal unit generation cost to finalize the optimal economic capacity of the SHPPs.
Chapter – 6	presents the conclusions and recommendations made from the study.

THEORETICAL DESCRIPTION

2.1 RELATION OF WATER POWER TO HYDROLOGY

Acquiring a set of reliable hydrological data for a reasonable length of time for assessing the pattern of stream flows at different times in respective years, is the most essential requirement for a dependable formulation of a hydroelectric project, be it big or small. Besides the pattern of stream flows, other hydrologic inputs required for the design of project components are design flood, water quality and sediment transportation. It is necessary first to collect the minimum essential hydrologic data and secondly, make analyses to establish a reliable flow quantity and other hydrologic inputs. The small hydropower projects need to acquire satisfactory information with minimum time and cost.

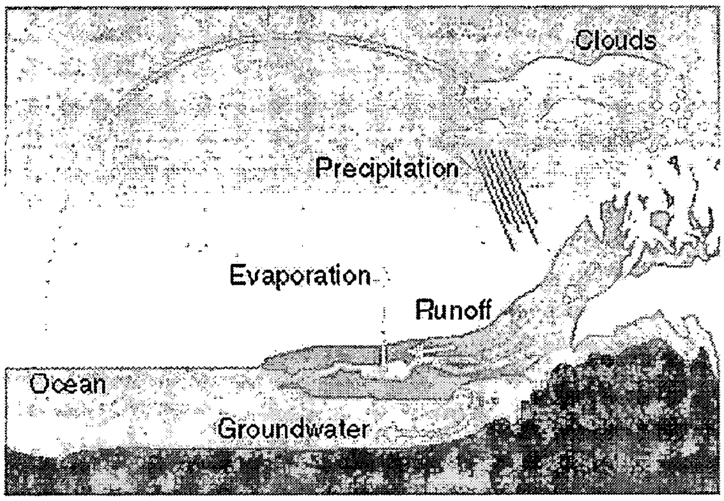


Fig. 2.1 Typical Hydrological Cycle

2.1.1 Stream Gauging

The stream gauging is necessary to know about the water availability which is varying in a year. For the selection of gauging site following point should be kept in mind. [1]

- The river bank and bed should be reasonably straight.
- The site should be accessible at all time of the year.

- Water should be flow in the single channel.
- It should be near to the intake site.

At the gauging site a device is installed is called gauge. The gauges are broadly two categories (i) non- recording or manually observed gauges and (ii) self recording gauges. As per the requirement we can use any type, generally for small hydroelectric project simple staff gauge is used.

2.1.2 Discharge Measurement

The discharge measurement of stream flow can be done by various methods, some methods are as follows [15]

- Area velocity method
- Moving boat method
- Dilution technique
- Electromagnetic method
- Ultrasonic method
- Flow measuring structure (indirect method)
- Slope – Area method (indirect method)

Generally for the small hydro power the area velocity method is used.

In this method,

$$Q = A*V$$

Where,

Q – Stream discharge in m^3/sec

A – Cross-sectional area of stream in m^2

V – Velocity of stream water in m/sec

The measurement of velocity is an important aspect of many direct stream flow measurement technique. A mechanical device, called current meter consisting essentially of rotating element is probably the commonly used instrument for accurate determination of the stream velocity field. Approximate stream velocity can be determined by floats.

In some cases, the discharge measurement, particularly high flood discharges may not be possible by the current meter. The flood may rise or fall so quickly that the stream gauging party may not be able to reach the site in time and take measurements by current meter or by floats. This is particularly for small or flashy streams. In such circumstances, the flood discharge estimate has to be made after the flood has passed by the area slope method by making use of flood marks left by the flowing water. This method is also applicable to ungauged stream.

In Area Slope method,

$$Q = A*V$$

For calculation of velocity Manning's formula is used,

$$V = (R^{2/3}*S^{1/2})/n$$

Where,

R – Hydraulic mean radius in m

S – Hydraulic gradient, dimension less

n – Rugosity coefficient

$R = A/P$

A – Cross-sectional area of stream in m^2

P – Weighted perimeter in m

For applying any technique, various points to be kept in mind for ensuring accuracy of results. The nature of river, site conditions are varies project to project thus we should consult the manuals, guide lines as per requirements.

2.1.3 Water Availability Assessment

The purpose of water availability assessment for any type of hydroelectric projects is to compute stream flow series over a period of time. This flow series is utilized to fix the installed capacity of the power house and to evaluate energy generation.

The hydrologic techniques to be adopted for inflow studies would cater to the following data situations: [1]

(a) Long term measurement of river flow, say over 20 - 25 years.

(b) Short term measured river flow, say 5 to 10 years and long term rainfall records in the relevant catchments.

(c) Short term measured river flows but no records of rainfall in the relevant catchments. There are two situations.

(i) Data available for a period of 5 – 10 years.

(ii) Data collected for a minimum period of two lean and one flood seasons.

The long term measured river flow, the power potential may be assessed considering the entire flow series. But for short term measured river flow data we have to use regression or regional specific discharge approaches.

2.1.4 Design Flood Estimation

Flood estimation is an essential part of any water resource project. The design flood for a small hydroelectric project is either a 50 year or 100 years return period flood. For estimating the design flood, one of the standard flood frequency methods may be used. Two most widely used methods are

(i) Gumbel's extreme value type I distribution (EVI)

(ii) Pearson type III distribution

In India, the Gumbel's method is generally used and this method is recommended for the small hydro projects. [1]

2.2 ASSESSMENT OF POWER POTENTIAL AND OPTIMIZATION OF INSTALLED CAPACITY

The FDC provides a means of selecting the right design discharge, and by taking into account the reserved flow and the minimum technical turbine flow, an estimate of the plant capacity and the average annual energy output. The design flow has to be identified through an optimization process, studying a range of different flows, which normally gives an optimum design flow significantly larger than the difference between the mean annual flow and the reserved flow. Once the design flow is defined and the net head estimated, power potential and optimal installed capacity can be fixed.

2.2.1 Power Potential and Energy Output

Power potential is a function of head and discharge quantity of water at any point of time and is determined by using the following formula. [1]

$$P = 9.81 * Q * H * \eta$$

Where,

P – Power in KW

Q – Discharge in m^3/sec

H – Net head in m

η – Over all unit efficiency

The power potential of small hydropower schemes is directly proportional to the head, efficiency of plant and discharge. For the particular site head can be considered constant due to the large head and small discharge in the case of run-of-river scheme in hilly areas.

The average annual energy production (E in kWh) is a function of: [3]

$E = fn (Q_{median}, H_n, \eta_{turbine}, \eta_{generator}, \eta_{gearbox}, \eta_{transformer}, y, h)$

Where:

Q_{median} = flow in m_3/s for incremental steps on the flow duration curve

H_n = specified net head

$\eta_{turbine}$ = turbine efficiency, a function of Q_{median}

$\eta_{generator}$ = generator efficiency

$\eta_{gearbox}$ = gearbox efficiency

$\eta_{transformer}$ = transformer efficiency

y = specific weight of the water (9.81 KN/m_3)

h = number of hours for which the specified flow occurs.

The energy production can be calculated by dividing the useable area into vertical 5% incremental strips starting from the origin. The final strip will intersect the FDC at Q_{min} or $Q_{reserved}$ which ever is larger. For each strip Q_{median} is calculated, the corresponding $h_{turbine}$ value is defined for the corresponding efficiency curve, and the energy contribution of the strip is calculated using the equation:

$E = W \text{ x } Q_{median} \text{ x } H \text{ x } \text{Ç}_{turbine} \text{ x } \text{Ç}_{generator} \text{ x } \text{Ç}_{gearbox} \text{ x } \text{Ç}_{transformer} \text{ x } \text{Õ} \text{ x } h$

Where: W = strip width = 0.05 for all strips except the last one that should be calculated

h = number of hours in a year

y = specific weight of the water (9.81 KN/m_3)

The average annual energy production is then the sum of the energy contribution for each strip. The capacity of each turbine (KW) will be given by the product of their design flow (m^3/s), net head (m), turbine efficiency (%), and specific weight of the water (KNm^3).

2.2.2 Head

(i) Gross Head

It is the different in elevation between the water level in forebay/dam and the water level in tailrace.

(ii) Net Head

Net head is the gross head less all losses between forebay/dam and tailrace level except those chargeable to the turbine. Turbine chargeable losses are scroll case and draft tube losses.

(iii) Design Head

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

(iv) Rated Head

It is normally the same as the design head. Some organizations however define the rated head as the net head at which the output at full gate opening of the turbine produces the rated output of the generator. The turbine name plate is given at this head.

Small hydropower schemes of run-of-the river in hilly area generally have large head and small discharge, thus head can be taken as constant. Small change in head according to the change in discharge is not affect the output considerably. Generally, the head is considered constant for the run-of-the river schemes for a particular site.

2.2.3 Discharge

It is well known that the stream flow varies over a water year. Thus the discharge is the main component which affects the installed capacity of project. One of the popular methods of studying variation in discharge is through flow duration curve. A flow duration curve of stream is a plot of discharge against the percent of time the flow was equaled or exceeded. This curve is also known as the discharge frequency curve. The stream flow data is arranged in a descending order of discharging class intervals the number of individual value is very large, the data used can be daily, weekly, ten daily or monthly values.

$$P_p = \frac{m}{N+1} * 100\%$$

Where,

m - Order no of the discharge or class value or rank

P_p - Percentage probability of the flow magnitude being equaled or exceeded

N – No of data points are used

The FDC shows how flow is distributed over a period (usually a year). The vertical axis gives the flow, the horizontal axis gives the percentage of the year that the flow exceeds the value given on the y-axis. Hence, for example, the FDC can immediately indicate the level of flow which will be available for at least 50% of the year (known as Q_{50}). The flow exceeded for 95% of the year (Q_{95}) is often taken as the characteristic value for minimum river flow.

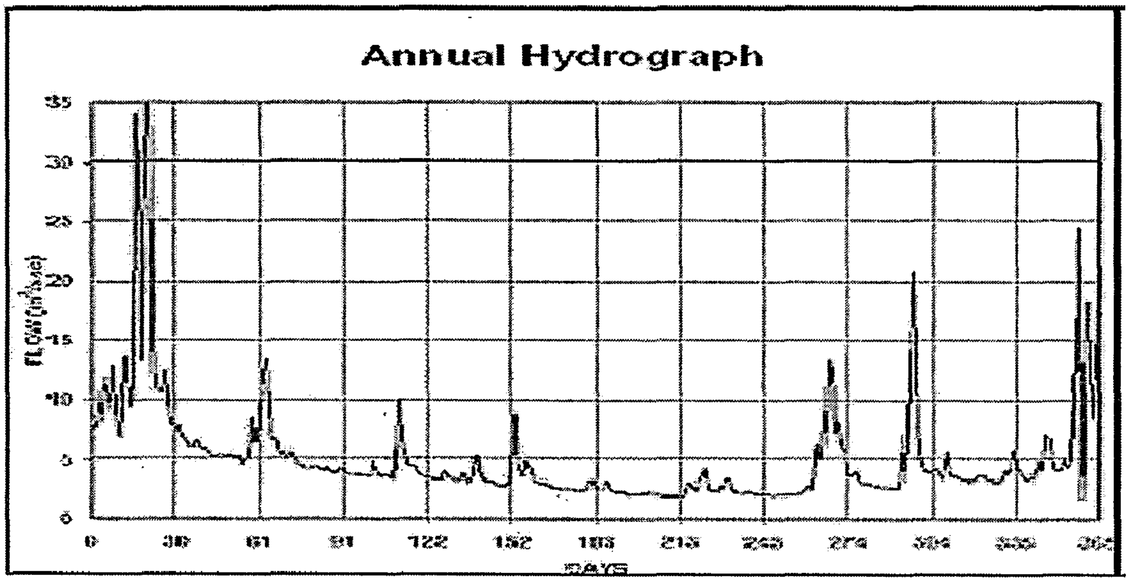


Fig. 2.2 Typical annual hydrograph [19]

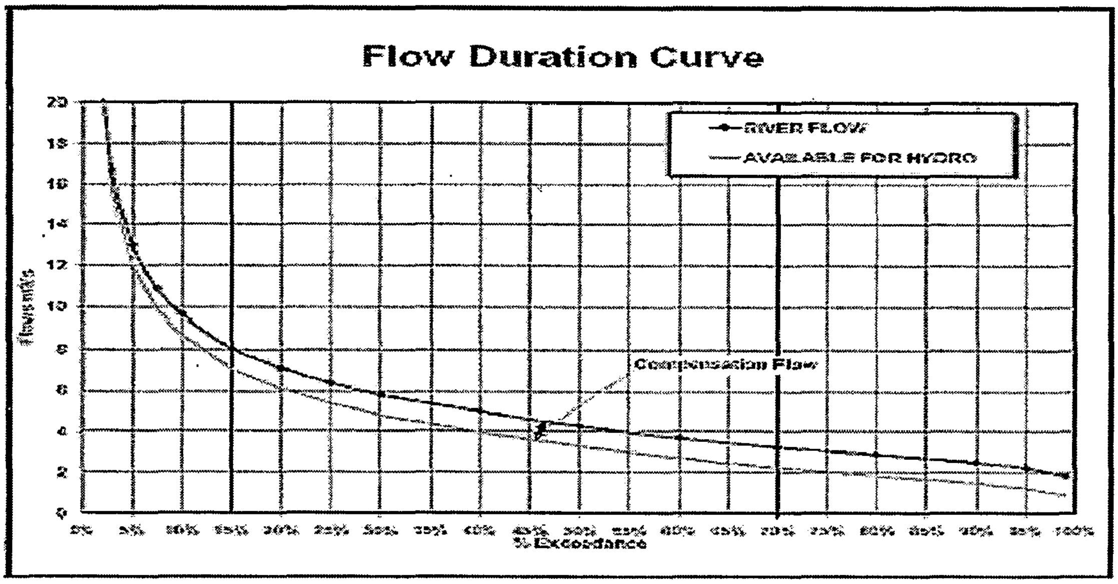


Fig. 2.3 Typical flow duration curve [19]

2.2.4 Efficiency

For a run-of-the river scheme, the head is assumed to be constant. The efficiency of the turbine varies with the variation of load or discharge. At part load, as well as for loads greater than that at most efficient rate, the efficiency will be less than the maximum. During the period of analysis the daily flow may not be meet the requirement corresponding to the maximum efficiency of the turbine. The actual flow will correspond to some percentage of the rated flow of the turbine. The number of days for which this flow will occur can be found out from the flow duration curve. From the knowledge of these data selection of the no of turbines with the specified operating limit can be done.

At the rated output, the unit efficiency (combined efficiency of turbine, generator and speed increaser if applicable) is generally considered from 85% to 90%, depending on the size of small hydro generating units. [1]

2.2.5 Energy Planning

Energy planning aspect in a run of the river scheme has been a debatable subject. The availability of flow data and its adequacy plays the most significant role in arriving at certain decisions. It is most significant to select the discharge which will ultimately govern the installed capacity of the proposed hydro electric power station and the annual energy generation.

Earlier a run-of-the river hydro electric scheme was planned for 90% dependable discharge which resulted in a very conservative value of estimated energy. Gradually this approach of planning has been upgraded and a higher value of plant discharge with dependability less than 90% has been selected. This trend is being adopted all over the world as well as in India. This approach has been developed with a view of deriving more and more energy from a run-of-the river scheme. Design discharge with an exceedance probability on flow duration curve (FDC) as low as 10 to 20% depending on the shape of FDC has been adopted in some of the run-of-the river hydro electric schemes in European countries [12]. This is decided on the basis of techno-economic analysis. Some authors have suggested range of design discharge with an exceedance probability between 34 to 50% (Q34 to Q50) for techno-economic analysis [11].

If the design discharge has been over estimated, the installed capacity of the turbine can not be utilized properly, hence financially it is uneconomical. On the other hand, if the design discharge has been estimated very conservatively, it is possible that the conservative estimate of available flow will prevent from the optimal power production. Therefore, correct estimate of available flow is very important to utilize available water power potential.

2.2.6 Plant Load Factor

Plant load factor is the ratio of estimated annual energy and annul energy generation with full installed capacity.

$$\text{Plant load factor (PLF)} = \frac{energy\ generated\ per\ year\ (KWh\ /\ year)}{installed\ capacity\ (KW) * 8760}$$

The peak power P can be estimated from the design flow Q_d and head H as follows:
$P(kW) = g \times \eta \times Q_d(m3/s) \times H(m)$
The annual energy output is then estimated using the plant load factor (PLF) as follows:
Energy (KWh/year) = P (KW) x PLF x 8760

There is clearly a balance to be struck between choosing a larger, more expensive turbine which takes a high flow but operates at a low plant load factor, and selecting a smaller turbine which will generate less energy over the year, but will be working flat out for more of the time i.e. a higher plant load factor. Plant load factor should be with in acceptable limit, the plant load factor for most mini-hydro schemes would normally fall within the range 50% to 70% in order to give a satisfactory return on the investment [17]. Small hydro run-of-the river scheme with out pondage is range 45% to 60% [9]. Capacity factor for a hydroelectric plant commonly varies from about 0.25 to 0.7 or more.[6]

2.2.7 Load Duration Curve

Load duration curve (LDC) is the plot of percentage exceedance probability in specified time to the load. The load is varying with the time. The load duration curve is also similar to the flow duration curve, but its extreme points shows maximum and minimum load. The area under the load curve represents the total energy production for that duration. The load factor is given by the ratio of the area under the curve to the area of the rectangle corresponding to the maximum demand occurring during that period.

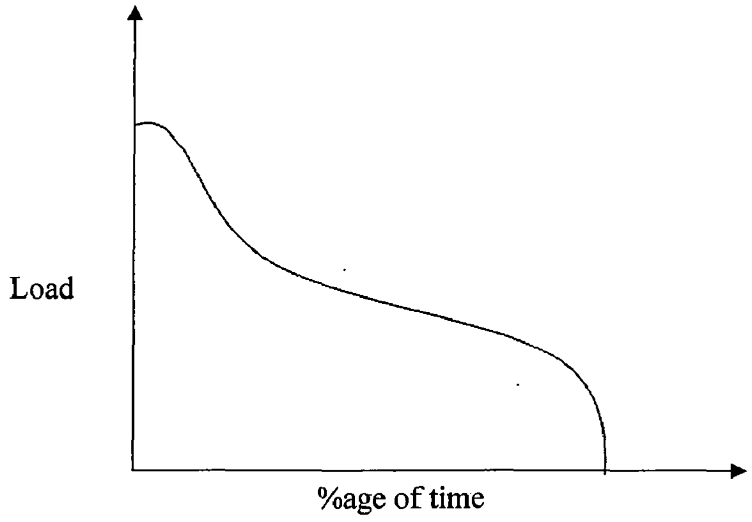


Fig. 2.4 Typical load duration curve

2.2.8 Firm Power

The firm or primary power is that power which is always available at any hour of a day. Such a power would correspond to the minimum stream flow and is available for most of the times, normally 90% of the time in hydropower. The firm power can be increased by creating pondage. The energy corresponds to that power is firm energy or primary energy. A run-of-river scheme has a low firm energy capacity. If a small hydro scheme has been developed as the single supply to an isolated area, the firm energy is extremely important. As failure to meet demand, could result in power shortages and blackouts.

The secondary energy is that energy which generated by the discharge available between minimum discharge and design discharge.

2.2.9 Optimal Installed Capacity

There are several logics to determining the optimal installation capacity of the hydroelectric project. One method is to use the available flow in any dependable year (normally 50% dependable year by arranging the flow for each 10-daily average). The amount of annual energy for any capacity can be calculated on the basis of available flow. A curve of different installed capacity verses annual energy for that capacity is drawn. From the slope of curve the optimal installed capacity can be decided.

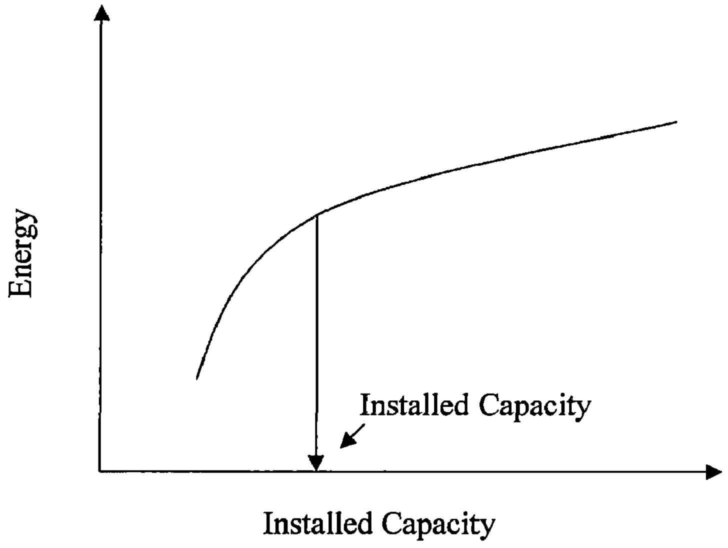


Fig. 2.5 Typical installed capacity vs energy graph

Similarly the installed capacity can be calculated by the help of graph of incremental installed capacity verses incremental energy. The optimal installed capacity is chosen at a point where the graph has sharp change.

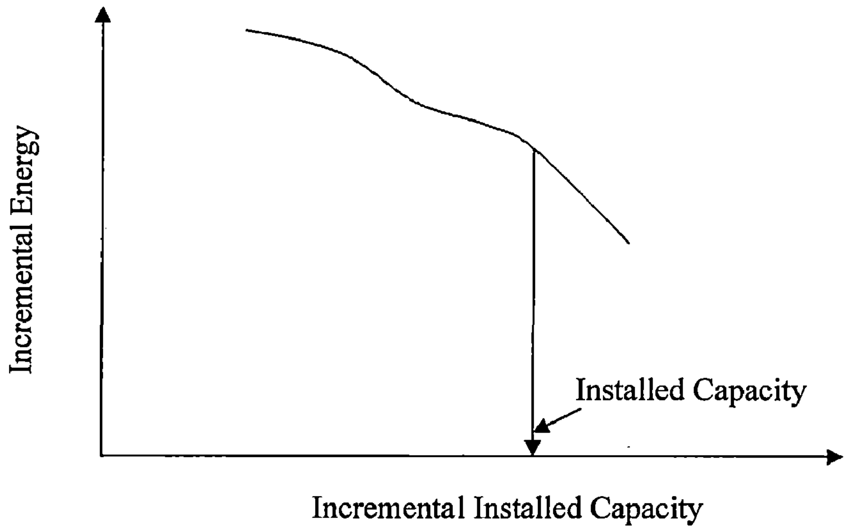


Fig. 2.6 Typical graph of incremental energy vs incremental installed capacity

The installed capacity may also be chosen on the basis of the minimum cost of generation or maximum benefit. The ideal practice is to plot a graph of the cost of unit generation against different installed capacities and the capacity which gives the minimum cost of generation per unit is chosen as the installed capacity.

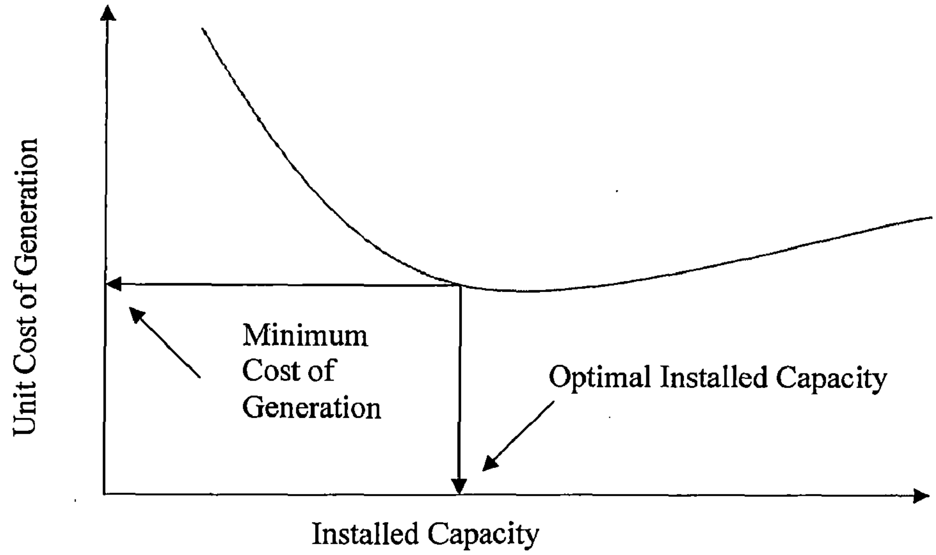


Fig. 2.7 Typical graph of installed capacity vs unit generation cost

To determine the optimal installation capacity of SHPPs all technical, economic and reliability indices are considered in a trade-off relation. Using this approach, the amount of annual energy is determined by using categorized statistics of the flow duration curve in different months. Then, after specifying the income and costs of the plant, the economic indices of different alternatives are extracted. The reliability indices are then calculated and ultimately, through comparison of the technical, economic and reliability indices a superior alternative can be selected, determining the optimal installation capacity. [9]

After determining the downstream water flow and environmental needs and rights, the energy calculation is done with respect to the water flow categorized data of the river. To estimate the generated energy, a range of flow rate is specified based on river discharge. Then, based on the daily and 10 days/or monthly statistics of the flow duration curve and the water flow with different probability percentages (e.g., 20%, 30%, 40%, 50%, 60% and70%), the monthly optimally generated energy is calculated. The amount of optimal annual energy generated is obtained by determining the sum of the monthly energies. Based on the peak, normal and low loads, the planner can choose different alternatives with the highest energy generation relative to the load. While coordinating between energy in peak and base states, the technical indices such as the plant factor of an SHPP should be within a reasonable and acceptable limit. [9]

2.3 ECONOMIC ANALYSIS

For the evaluation of income and costs and ultimately, the economic analysis of SHPPs, the costs of the project are divided into two categories: investment and annual costs. Investment costs include civil costs, electro-mechanical equipment, transmission line, and other indirect costs. Annual costs include the depreciation of equipment operating and maintenance, and replacement costs. The income of the project is based solely on the sale of electrical energy.

Civil costs consist of the construction and hydro structural costs of the project, including a diversion structure, conveyance of water system, the forebay, 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.

Electro mechanical equipment costs include turbines, generators, governors, gates, control systems, a power substation, electrical and mechanical auxiliary equipment, etc. Transmission line costs include a transmission line for delivering generated energy from power plant to power transmission network. The transmission line cost depends on the location, type of existing system (overhead line or cable system), and capacity of SHPP as well as length of transmission lines, which have a very high affect on project costs. Indirect costs include Engineering and Design (E&D), Supervision and administration (S&A) and inflation costs during the construction period.

E&D Costs: These costs are affected by many parameters, such as type, size and the 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.

S&A 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.

Inflation Costs During Construction: To precisely calculate the investment cost of a project, it is necessary to take into consideration 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. [9]

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

Depreciation of Equipment: In the economic analysis of the project, depreciation and other factors affecting the equipment should be considered. Generally, in the case of small hydropower depreciation is calculated very simply, using the straight- line method as follows:

$$\text{Depreciation} = \frac{\cos t - salvage\ value}{operational\ life}$$

O&M Costs: include salary/wages of personnel, labor, insurance, tax, duties, landscape, and consumable materials. These costs are increased by the annual price escalation coefficient. 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 to calculate investment costs, the interest rate during construction should also be considered. [9]

Replacement and Renovation Costs: The main parts of the SHPP, such as generator windings, turbine runners and other parts will eventually need replacement and renovation. With respect to the nature of the SHPPs, the costs of renovation and reconstruction of equipment at year 25 is taken to be approximately equal to the total value of equipment at time of purchase. [9]

Benefits: There are two benefits for the SHPPs: (1) tangible benefits and (2) intangible benefits. The tangible benefit is the sale of electrical energy. The intangible benefits cover the positive environmental effects, flood control , agriculture and irrigation, fish farm pools, camps and recreation centers, etc. which eventually turn into quantitative values. Generally, the intangible benefits are not included in the economic analysis of the project, but naturally a more desirable result will be obtained for the economic indices when taking these factors into account.

2.3.1 Methods of Economic Evaluation

While the payback period method is the easiest to calculate most accountants would prefer to look at the net present value and the internal rate of return. These methods take into consideration the greatest number of factors, and in particular, they are designed to allow for the time value of money.

When comparing the investments of different projects the easiest method is to compare the ratio of the total investment to the power installed or the ratio of the total investment to the annual energy produced for each project. This criteria does not determine the profitability of a given scheme because the revenue is not taken into account and is really an initial evaluation. [3]

3.3.1.1 Static Methods

Payback method

The payback method determines the number of years required for the invested capital to be offset by resulting benefits. The required number of years is termed the payback, recovery, or break-even period. The calculation is as follows:

$$\text{Payback Period} = \frac{Investment\ \cos t}{Net\ annual\ revenue}$$

The method usually neglects the opportunity cost of capital. The opportunity cost of capital is the return that could be earned by using resources for an alternative investment rather than for the purpose at hand. Investment costs are usually defined as first costs (civil works, electrical and hydro mechanical equipment) and benefits are the resulting net yearly revenues expected from selling the electricity produced, after deducting the operation and maintenance costs, at constant value money. The payback ratio should not exceed 7 years if the small hydro project is to be considered profitable.[3]

However, the payback does not compare the selection from different technical solutions for the same installation, or choosing among several projects that may be developed by the same promoter. In fact it does not consider cash flows beyond the payback period and thus does not measure the efficiency of the investment over its entire life.

Under the payback method of analysis, projects or purchases with shorter payback periods rank higher than those with longer paybacks do. The theory is that projects with shorter paybacks are more liquid, and thus represent less of a risk. [3]

For the investor, when using this method it is advisable to accept projects that recover the investment and if there is a choice, select the project, which pays back earliest. This method is simple to use but it is attractive if liquidity is an issue but does not explicitly allow for the "time value of money" for investors.

Return on Investment Method

The return on investment (ROI) calculates average annual benefits, net of yearly costs, such as depreciation, as a percentage of the original book value of the investment. The calculation is as follows:-

$$\text{ROI} = \frac{net\ annual\ revenue - depreciation}{investment\ \cos t} \text{x100}$$

Using ROI can give you a quick estimate of the project's net profits, and can provide a basis for comparing several different projects. Under this method of analysis, returns for the project's entire useful life are considered (unlike the payback period method, which considers only the period that it takes to recoup the original investment). However, the ROI method uses income data rather than cash flow and it completely ignores the time value of money. To get around this problem, the net present value of the project, as well as its internal rate of return should be considered.

3.3.1.2 Dynamic Methods

These methods of financial analysis take into account total costs and benefits over the life of the investment and the timing of cash flows.

Net Present Value (NPV) Method

NPV is a method of ranking investment proposals. The net present value is equal to the present value of future returns, discounted at the marginal cost of capital, minus the present value of the cost of the investment. The difference between revenues and expenses both discounted at a fixed, periodic interest rate, is the net present value (NPV) of the investment, and is summarized by the following steps: [3]

1. Calculation of expected free cash flows (often per year) that result out of the investment
2. Subtract /discount for the cost of capital (an interest rate to adjust for time and risk) giving the Present Value
3. Subtract the initial investments giving the Net Present Value (NPV

Therefore, net present value is an amount that expresses how much value an investment will result in, in today's monetary terms. Measuring all cash flows over time back towards the present time does this. A project should only be considered if the NPV results in a positive amount.

The formula for calculating NPV, assuming that the cash flows occur at equal time intervals and that the first cash flows occur at the end of the first period, and subsequent cash flow occurs at the ends of subsequent periods.

Benefit-Cost ratio

The benefit-cost method compares the present value of the plant benefits and investment on a ratio basis. It compares the revenue flows with the expenses flow. Projects with a ratio of less than 1 are generally discarded.

Internal Rate of Return method

The internal rate of return (IRR) method of analyzing a project allows the consideration of the time value of money. Basically, it determines the interest rate that is equivalent to the Euro returns expected from the project. Once the rate is known, it can be compared to the rates that could be earned by investing the money in other projects or investments. If the internal rate of return is less than the cost of borrowing used to fund your project, the project will clearly be a money-loser. However, usually a developer will insist that in order to be acceptable, a project must be expected to earn an IRR that is at least several percentage points higher than the cost of borrowing. This is to compensate for the risk, time and problems associated with the project.

To find the IRR a process of trial and error is used, whereby the net cash flow is computed for various discount rates until its value is reduced to zero. Electronic spreadsheets use a series of approximations to calculate the internal rate of return.

CHAPTER – 3

COMPONENTS OF SMALL HYDROPOWER STATIONS

3.1 INTRODUCTION

Hydropower systems use the energy in flowing water to produce mechanical energy, ultimately converted in to electrical energy. The water flows via water conductor system and penstock to the turbine where it strikes the buckets or blades of the turbine, causing the shaft of the turbine to rotate. When generating electricity, the rotating shaft, which is connected to an alternator or generator, converts the motion of the shaft into electrical energy. There are mainly two types of components (i) civil works or civil components (ii) electrical and mechanical equipment.

3.2 CIVIL WORKS

The Basic and common civil works of a small hydro plant of run-of river type are:

- Diversion and intake
- Desilting arrangement
- Water conductor system
- Forebay and balancing reservoir
- Surge tank
- Penstock
- Power house
- Tail race

The main objective of small hydro plants is to generate power economically and expeditiously using local men and material, hence the planning and design of works do not call for sophisticated analysis and design procedure as required for the large hydropower scheme.

3.2.1 Diversion and Intake

Diversion structures are design such a way that they should be able to divert all the lean flows and pass the floods with reasonable safety to the structure. These are generally two types (i) raised crest type made of boulders, stones, concrete, soil etc and (ii) trench weir type in which there is no structure above river bed.

The hilly streams generally carry big boulders during flood season which destroy the over ground structure constructed across the river and this aspect restricts the choice of adoption of over ground structure alternatives. Further if solid boulder type structure or conventional weir alternative is provided in non-rocky foundation maintenance and repair of damages due to scour may create problems.

The adoption of Trench Type weirs for diversion structure has solved this problem in significant extent. Where the river bed is not rocky (as is usually the case) and ground structures are not safe unless costly elaborate foundation arrangements are made, trench type weirs have been found to be successful. Trench weir is simple trapezoidal trough made up of masonry or concrete, covered with a trash rack. The trash rack itself is designed to withstand loads due to rolling boulders. The intake located at the end of a trench type weir is connected to the water conductor in a gated well structures constructed in R.C.C. or masonry. The intake gate should permit the release of water to the desired extent. A flushing sluice connected to a desilting pipe with gate control is provided to eject out the rolling bed material.

3.2.2 Desilting Arrangement

The water containing large quantities of coarse sediment causes erosion damages to turbine runners and other underwater parts. The extent of desilting requirement depends on sediment and flow characteristics as well as on the metallurgy of the runner etc. Hill streams generally carry large quantities of harmful sediment during monsoon and high head development on such streams experience serious abrasion damages. These damages call for frequent maintenance and repair efforts as well as loss of power generation. In view of the above, effort are made to exclude harmful sediment particles from the flow. Desilting basin / chamber is most effective and common device for removing sediment particles from the flow. Generally for small head <15 m, the particle size >0.5mm is to be excluded, for medium head 0.2 to 0.5mm and high head the particle size 0.1 to 0.2mm is to be excluded. [18]

The desilting basins are quite costly for the small hydro plants so some Vortex type devices have been developed which are less in cost, requires less flushing discharge.

3.2.3 Water Conductor System

Water conductor system is the life line of the system. It carries water from diversion structure to power house. It can be open channel or closed conduit or tunnel or a combination of two or more types depending on topography and geology of the area. The open channel may be lined or unlined and of rectangular or trapezoidal section depending on the strata. Generally the channels are lined to save seepage losses. The channel section is designed such that velocity is adequate to avoid silting and the head loss should also be minimum. Generally, to determine the bed width and water depth Manning's equation is used, which is as follows:

$$V = \frac{1}{n} R^{2/3} S^{1/2} \text{ and } Q = AV$$

Where,

V = Velocity in m/sec

n = Coefficient of rugosity

R = Hydraulic radius = $\frac{A}{P}$

P = Wetted perimeter

S = Longitudinal bed slope

Q = Discharge in Cumecs

A = Cross Sectional Area in m^2

3.2.4 Forebay and Balancing Reservoir

The forebay is provided at the end of the water conductor system. Its main functions are:

- Distribution of flow: It should be long enough to distribute flow smoothly and uniformly to the penstocks and should be wide enough to accommodate the intake.
- Regulation of flow: It should be able to regulate the flow during starting and closing of the turbine. It should have the capacity to supply water to the turbine for two minutes. It should have an automatic spilling arrangement to pass surplus water during sudden closing.

- Protection from silt and debris: It should have a sand sluice because sediment will deposit in it when the flow velocity is reduced to about 0.5 m/sec a trash rack is provided at the intake.

If the intake width accommodating all the penstock is B, then length and width of forebay should be

L (length) = (2.5 to 3) B_1, B_1 (width) = (1.2 to 105) B and D (depth) = 3 to 3.5m

Balancing reservoir is a pond to provide for storage of 1, 2 or 4 hours as may be possible justifying the economics and requirements for operation of power plant. The main purpose is to store up water during off peak hours to supply the same in peak hours and so meeting variable power demand. It is provided where flat terrace or natural depression is available. [18]

3.2.5 Surge Tanks

If the water conductor system is a conduit or tunnel running under pressure and is of long length (L > 5 times head), [18] a surge tank is provided at the down stream of the water conductor. Its main functions are:

- Flow regulations: Excess water at the time of closing the turbine is stored in surge tank and it supplies the same when the turbine again starts. This function is similar to the forebay.
- Water hammer relief: A free water surface becomes available near the power house by providing a surge tank. So it protects the head race tunnel or conduit from water hammer pressures.

The surge tank is required in a project involving the use of reaction turbine. In case of the impulse turbines, the pressure surge can be avoided with deflection of jet. This eliminates the need of surge tank, though there will be some wastage of water. Generally surge tanks are of three types (i) simple, (ii) restricted orifice and (iii) differential. In case of small hydropower plant a simple surge tank is best suited.

3.2.6 Penstock and Intake

Penstock is the carrier of water from surge tank or forebay to the power house. There are pipes made of either Hume pipes or steel. Hume pipes are used for small head. The diameter is decided on velocity considerations which are limited to about 5 m/sec. higher velocities may cause abrasion damage and higher head loss resulting in energy loss. Lower velocities increase diameter and the cost. The preliminary diameter may be worked out by the following empirical formula (P.J. Bier's Formula U.S.B.R.–1958) [18].

$$D = 0.176 \left(\frac{P}{H}\right)^{0.466}$$

Where,

D = Diameter in metre

P = Horse power of machine

H = Net head in metre

The thickness of steel pipe can be worked out by [18]

$$t = \frac{p * r * 1000}{q}$$

Where,

t = thickness of plate in mm

r = radius of penstock in m

p = internal pressure in t/m^2

q = allowable hoop stresses in t/m^2

There are two alternatives for the number of penstocks. One is to provide independent pipe for each unit in the power house and the other is to provide one penstock which is bifurcated or trifurcated near the power house to feed the units. The choice between the two alternatives depends on the transportation facilities, operational convenience and economy. The alignment of penstock should be, as far as possible, straight with minimum bends from head loss considerations. The minimum radius at bends should be 5 times the diameter. Before entering the power house the penstock should be straight in a reach of 10 times the diameter for uniform flow to the machine.

Penstock intake is provided at the forebay. Generally a bell mouth entry is provided to reduce head loss and to ensure smooth entry to the flow. The intake has a rectangular section, which is allowed by a transition length to change the rectangular section into circular where from the penstock liner is embedded. The intake is fitted with trash rack and control gate. Flow velocity through trash rack is kept 0.6m to 0.8m per minute so that head losses are not significant. Clogging to an extent of 50% of the trash rack area may be considered in the design. The trash racks are sloped with the vertical to facilitate cleaning of debris.

3.2.7 Power House

It is a structure to house generating equipment, auxiliary equipment and other machines with suitable outlet (draft tube) to discharge water into tail race. The generating equipment turbine and the generator are placed side by side connected through a horizontal or vertical shaft. Vertical shaft arrangement is used with big size units. The size and layout of the structure is depending on type of turbine and setting of equipment. The dimensions of the power house have been standardized in terms of runner diameter. Beside the area for generating equipment other area in a power house are required for maintenance, erection and for the control panels. The generating area is generally the central area and the other two areas are positioned around it. The controls may be either at one end or grouped around each unit. The erection area also may be located at either end. For small size machines it may be provided around the unit. The door and windows should be cover about 25% of wall area for ventilation and lighting. Depending on layout of power house, a sump for collecting all drainage water within the power house is constructed at the lowest elevation which is fitted with automatic sump pumps. These are also used for dewatering the penstock and draft tube.

3.2.8 Tail Race

The tail race channel is an open channel or a free flow cut and cover conduit carrying the discharge from power house into the river. The tail race channel should be designed for adequate capacity and sufficient slope to clear the discharges from the generating units. Generally the tail race water velocity is taken about 1.0 m/sec. The individual tailrace channel of each unit is connected to a common channel outside the power house building.

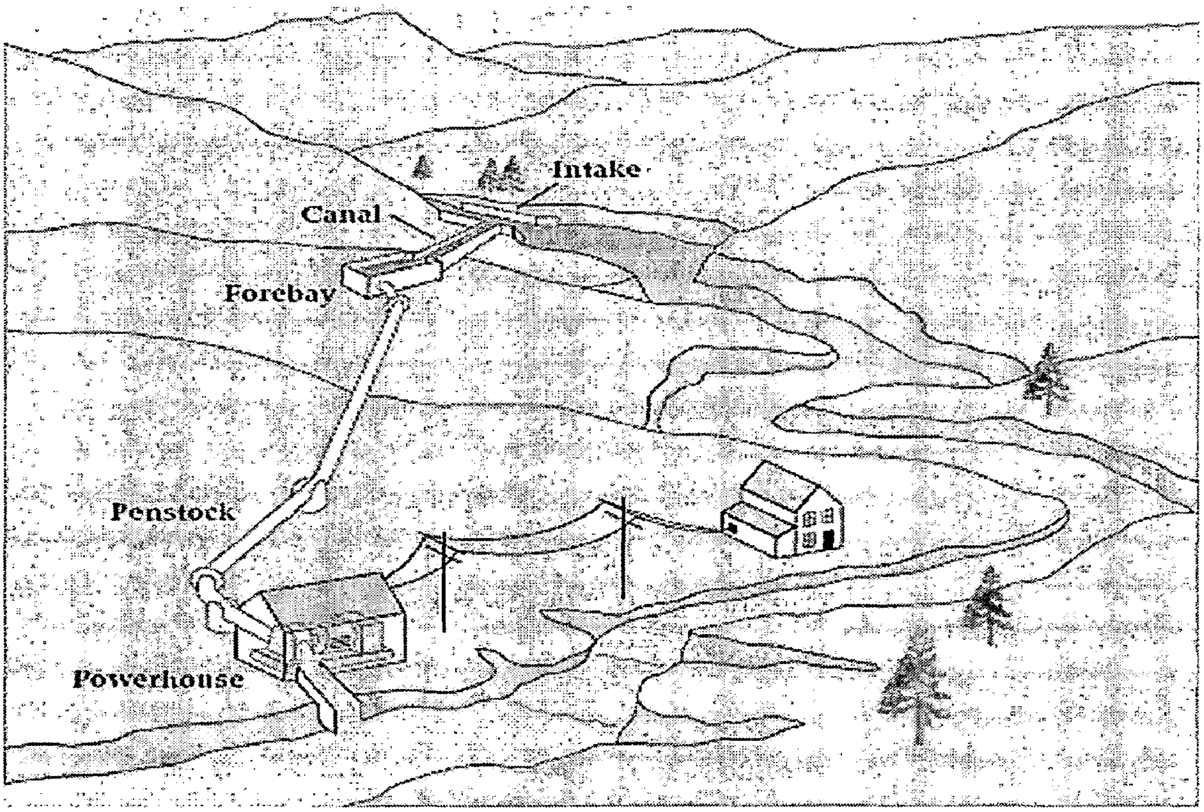


Fig. 3.1 Typical small hydropower scheme and components

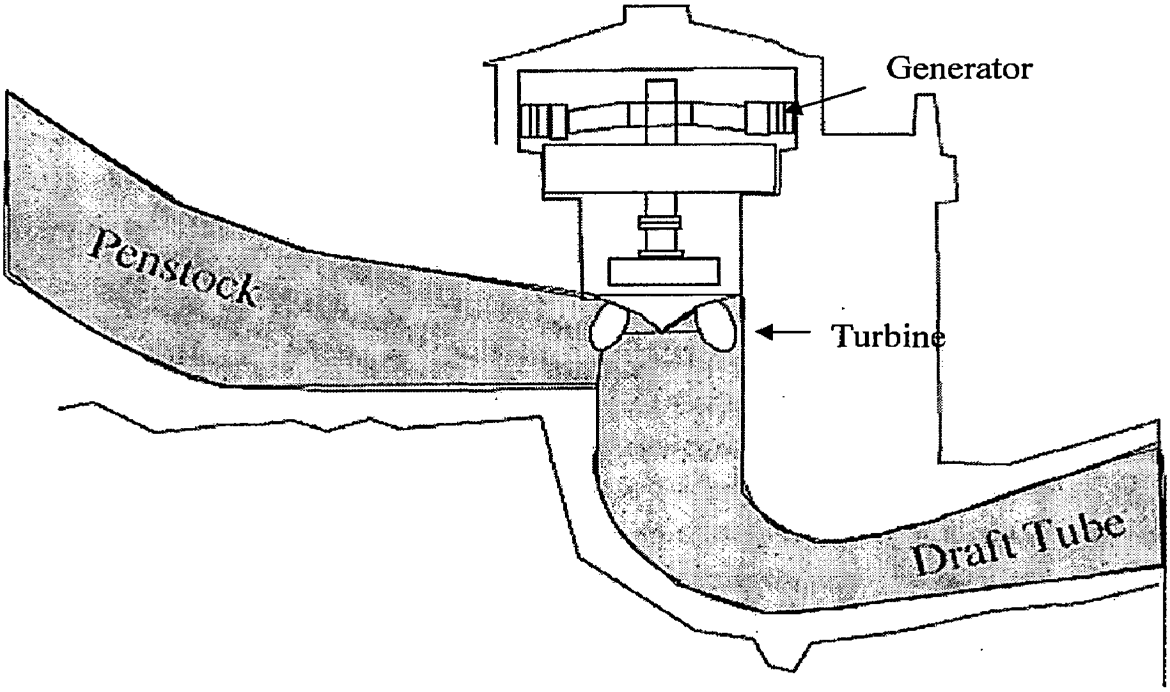


Fig. 3.2 Typical section of turbine and generator

3.3 ELECTRICAL AND MECHANICAL EQUIPMENTS

The primary electrical and mechanical components of a small hydro plant are the turbine(s) and generator(s).

3.3.1 Hydraulic Turbines

`Hydraulic turbines convert the potential energy of water into shaft work, which in turn, rotates the electric generator coupled to it in producing electric power. Different types of turbines are used in small hydropower plants. Classifications of the hydraulic turbines are as follows:

(I) According to energy conversion technique
  - (a) Reaction turbine
  - (b) Impulse turbine

(II) According to head
  - (a) High head turbine
  - (b) Medium head turbine (Francis)
  - (c) Low head turbine (Axial)

(III) According to the direction of flow of water over runner
  - (a) Tangential flow (Pelton, Turgo, Cross flow)
  - (b) Radial flow (Old Francis, Girad)
  - (c) Mixed flow (Modern Francis)
  - (d) Axial flow (Propeller, Kaplan)
  - (e) Diagonal flow (Deriaz)

(IV) According to alignment of shaft
  - (a) Horizontal
  - (b) Vertical

(V) Based on Specific Speed

The specific speed of turbine N_s, is the speed of a geometrically similar turbine which produces 1 KW power under 1 m head. It is given by [10]

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

Where, N = Normal working speed in rpm

P = Output of turbine in KW

H = Net head in m

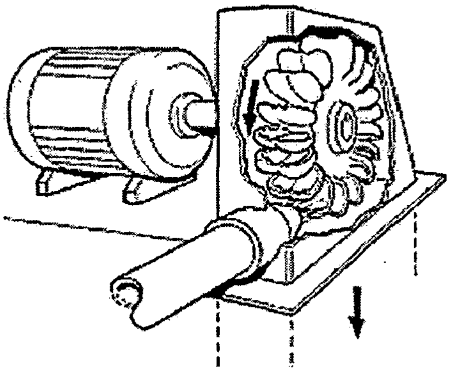
Table 3.1 Specific speeds of turbines

Turbine	Specific Speed
Pelton	13-30
Turgo	20-70
Cross Flow	20-80
Francis	80-400
Axial	340-1000

3.3.1.1 Pelton Turbine

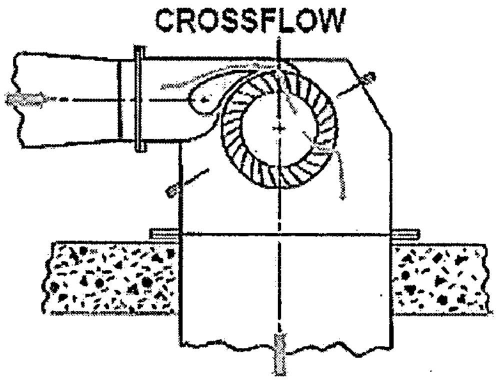
The Pelton turbine is basically a impulse turbine where all available energy of water (Potential Energy) is converted into Kinetic Energy by means of a nozzle before sending it in to the turbine runner and the turbine runner which is a movable part of the turbine rotates due to impulse of water jet emerging from the nozzle. This turbine is considered as an open turbine where water remains at atmospheric pressure inside the turbine. They are extensively used for high head installation. The runner consists of large circular disc on the periphery of which a number of buckets are mounted. The number of nozzle varies from 1 to 6.

PELTON



3.3.1.2 Cross - Flow Turbine

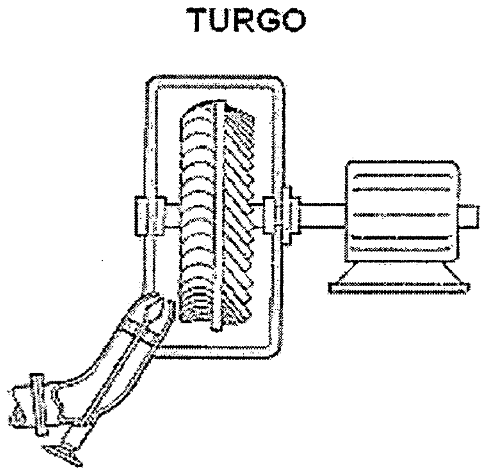
Cross-flow turbine is an impulse type turbine, which is called a Banki turbine. Water jet strikes tangentially over the periphery of the runner and transfers a part of energy to runner, water having remaining component of energy from blade crosses the shaft, so it is called cross-flow turbine. This type of turbine is very easy to fabricate and can be used under a wide range of operating parameters, but the efficiency is low as compare to other type of turbines.



3.3.1.3 Turgo Impulse Turbine

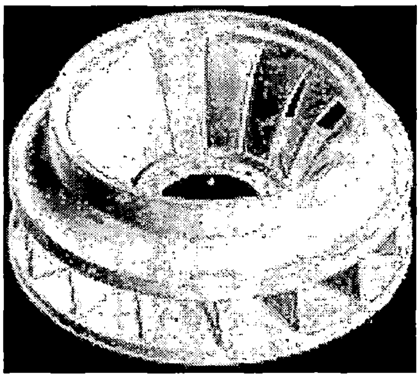
Turgo impulse turbine was developed by Mr. Gilbert in U.K., which is suitable for more power development under medium head in comparison of Pelton turbine. The limitation of discharge with Pelton turbine can be over come by this turbine up to certain extent. So this turbine operates between Pelton turbine and Francis turbine. Basically this is a free jet impulse turbine where the jet strikes at one end of the bucket and exits at the other end. Following are the main feature, which distinguish it from Pelton turbines:

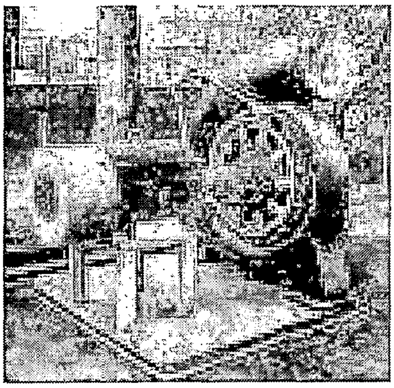
- Water jet strike over a number of buckets, normally over 3 buckets at a time.
- Water enters at one end of bucket and exit to another.
- Jet or nozzle does not remain in the plain of the runner but it is deviated by a small angle of 20° from plane of the bucket.
- It has single cup almost hemispherical bucket.



3.3.1.4 Francis Turbine

Francis turbines are very versatile. These are reaction turbines, i.e. during energy transfer from water to runner there is a drop in static pressure as well as a drop in velocity head. In order to get higher value of speed ratio under a medium head first turbine was developed was inward radial flow type. Now a days, this value of speed ratio is turbine enhanced by modifying of to radial flow to mix radial flow type. Water from penstock enters a spiral or scroll casing, which surrounds the runner. The cross-section of the spiral diminishes uniformly along the circumference to keep the water velocity constant along its path. The water then enters the guide vanes which are pivoted and can be turned suitably to regulate the flow and output. The runner has a number of curved vanes.

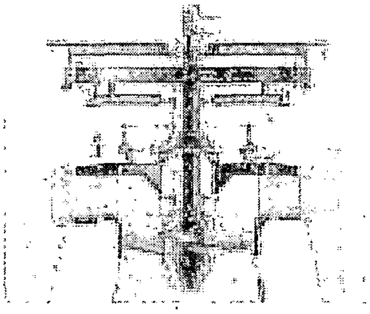


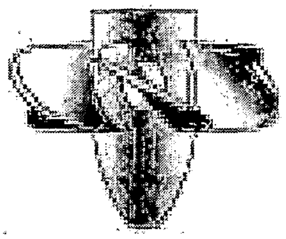


3.3.1.5 Axial Turbine

Axial turbines are basically reaction type turbine. Basic difference between Francis and Axial turbine is that it is purely axial flow type turbine. It facilitates handling of large quantity of discharge through turbines are similar to Francis turbine, however the guide vanes are generally called wicket gates and runner vanes are called runner blades. The following are the types of the Axial Turbine:

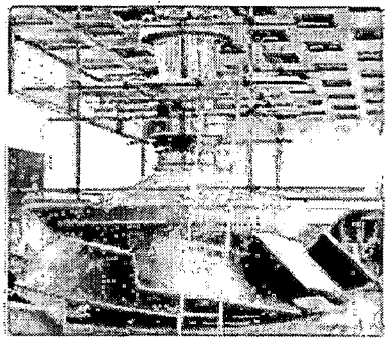
1. Axial flow type – Runner blade fixed and wicket gate fixed.
2. Propeller type – Runner blade fixed and wicket gate movable.
3. Semi-Kaplan – Runner blade movable and wicket gate fixed.
4. Kaplan – Runner blade and wicket gate are both movable.





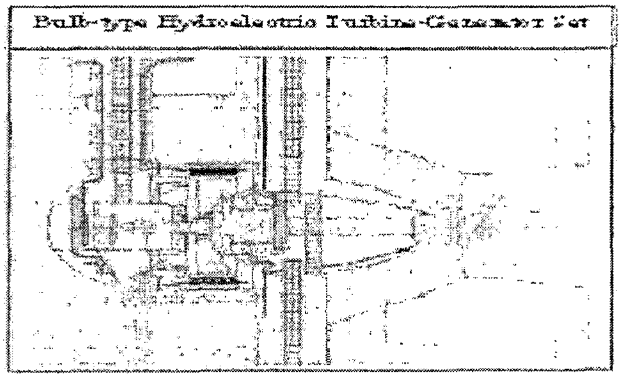
3.3.1.6 Deriaz Turbine

The Deriaz turbine is also known as 'diagonal turbine'. The flow over the runner is at an angle of 45^0 to the axis. It has adjustable blades like Kaplan turbine. At the same time its flow is diagonal or mixed as in Francis turbine. It can be described as a cross between the two turbines. The number of blades varies from 10 to 20. It is suitable for reversible flow conditions over turbine also have to work as a pump as on pumped storage power plant.



3.3.1.7 Bulb Turbine

Tubular or bulb turbines are small fixed axial flow propeller turbine operating under low head. The turbo-generator is housed in an enclosed bulb shaped casing, which is installed right in the middle of the flow passage. The bulb and the propeller forms an integral unit flowed by straight conical flaring draft tube. Bulb turbines are suitable for tidal power plant.



3.3.2 Use of Turbines According to Head

Table 3.2 Use of turbine according to head

Head Class	Head Range	Potential Technologies	Best Fit Technologies
Very Low	< 3m	Propeller, Crossflow, Kaplan	Propeller, Kaplan
Low	3m to 15m	Propeller, Crossflow, Kaplan, (possibly) Francis	Propeller, Kaplan
Medium	15m to 100m	Crossflow, Kaplan, Francis, (possibly) Turgo	Francis
High	> 100m	Crossflow, Francis, Turgo; Impulse & Pelton	Francis/Impulse

3.3.3 Use of Turbines According to Head and Discharge

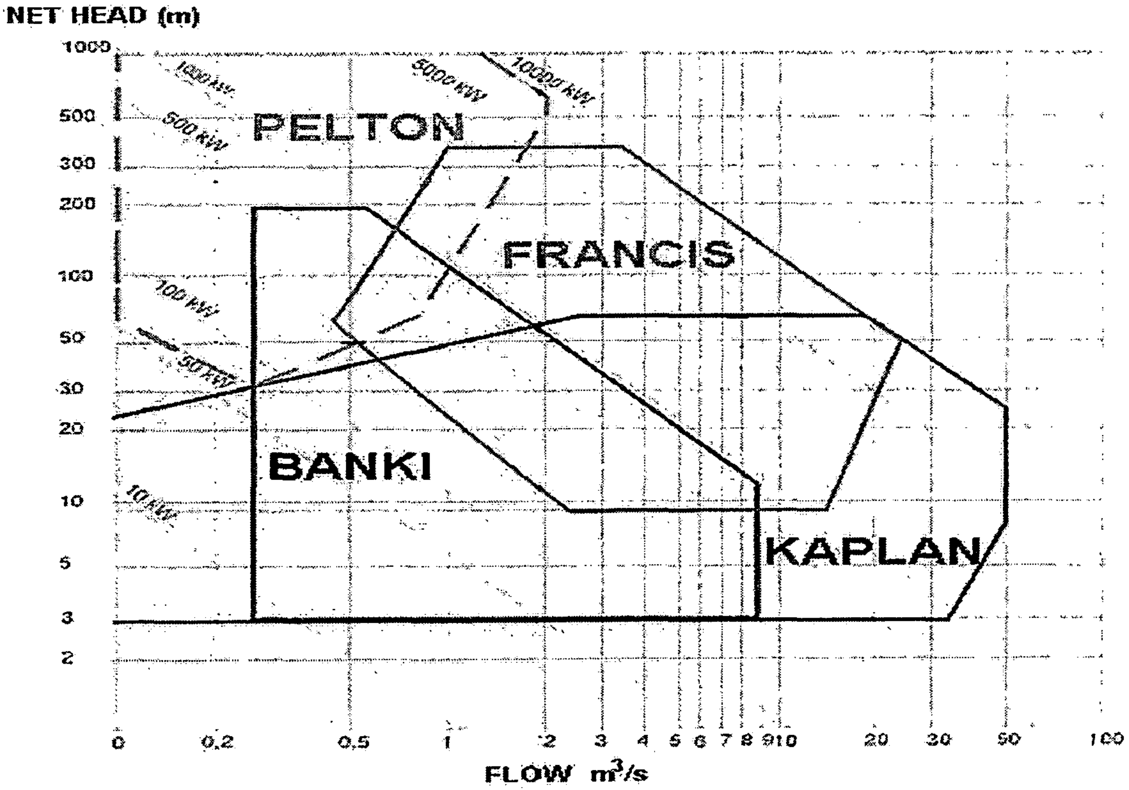


Fig. 3.3 Use of turbine according to head and discharge

3.3.4 Cavitation

When the hydrodynamic pressure in a liquid flow falls below the vapour pressure of the liquid, there is a formation of the vapour phase. This phenomenon induces the formation of small individual bubbles that are carried out of the low-pressure region by the flow and collapse in regions of higher pressure. The formation of these bubbles and their subsequent collapse gives rise to what is called cavitation. Experience shows that these collapsing bubbles create very high impulse pressures accompanied by substantial noise (in fact a turbine undergoing cavitation sounds as though gravel is passing through it). The repetitive action of such collapse in a reaction turbine close to the runner blades or hub for instance results in pitting of the material. With time this pitting degenerates into cracks formed between the pits, and the metal is snatched from the surface. In a relatively short time the turbine is severely damaged. To minimize this problem setting of reaction turbine is needed.

Setting of reaction turbine with reference to minimum tail water is dictated by requirement from cavitational considerations. In general cavitation co-efficient for Francis turbines is much lesser than that for propeller turbines necessitating relatively lesser submergence and excavations for Francis turbine. Impulse turbine are installed above maximum tail water level thus cavitation free and requiring minimum excavation costs. The recommended allowable turbine setting above tail water, i.e., draft head (depth of centre line of runner of runner below minimum level of tail water) is given as: [10]

$$Z = Ha - Hv - \sigma H$$

Where,

Ha = atmospheric pressure head in metre at plant elevation

Hv = vapour pressure in metre at plant location temperature

σ = plant sigma or cavitation coefficient for the turbine specific speed

H = Head on turbine, metres

The value of σ may be found from the expression which is as follows: [10]

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

Where,

Ns = specific speed of the turbine

3.3.5 Generator

To convert the mechanical energy output of the turbine into electrical energy alternators or generators are required .There are two basic types of generators used in small hydro plants synchronous and induction (asynchronous). Economics and considerations will determine which type should be used for specific site. Most installations utilize synchronous generators. Induction generators are only used when system conditions economics permit. A synchronous generator can be operated in isolation while an induction generator must normally be operated in conjunction with other synchronous generators. Induction generators with capacities less than about 500 kW are generally best suited for mini hydro plants providing energy to a large existing electricity grid.

Synchronous generators of small hydroelectric units are of generally salient pole type since speeds higher than 1500 rpm have not been used, in practice speeds are generally kept limited to 1000 rpm. However, in case of small hydro units, use of speed increasing gear box is now normally adopted for low head, low speed turbines. Small hydro generators thus now be expected to have speeds of 500,750 or 1000 rpm and exceptionally of 1500 rpm, other speed may be involved only rarely.

3.3.5.1 Synchronous Generator

The use of synchronous generators with separate excitation in small hydropower plant has a long tradition too. Especially for off-grid installation, the SG is still the technology of choice. Due to the high complexity of this type of machine compared to the ASG for excitation and voltage control. For lower capacity the specific cost is higher but in higher capacity the specific cost is lower than the ASG. The SG can maintain a given power factor and can easily be operated without a grid by using rotating permanent magnets for a pilot exciter which supplies the main exciter coils with the necessary magnetic field. The principal advantage of a synchronous generator for small hydropower plant applications is its capability to operate with either a leading a lagging power factor, by control of its excitation.

They should have a power factor rating required by the local load, or the connecting utility power system, or both, which commonly ranges from 0.9 to 0.95. Some applications may require a machine with an even lower power factor. Another advantage of the SG 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 and voltage and reactive power control. SG requires direct current field excitation. Excitation for smaller, higher speed units is generally provided by the direct-driven brushless exciters. Larger, slower speed generators generally utilize static exciters with solid-state equipment that converts alternating current to direct current. AVR compare measured generator voltage with a reference value, and adjust the exciter output accordingly to reduce the difference to zero. The device used o adjust the reference value is motor operated, allowing control from a remote location.

3.3.5.2 Induction Generator

This type of generator has a simple and robust design and combines high efficiency and low specific cost. The excitation of the generator is performed via the grid through the rotor. The asynchronous generator is directly connected to the grid with a normal switch, as soon as synchronous speed is achieved. No synchronization is needed.

The advantages of the induction generators 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 voltage control or to be used as an isolated power source, as well as its lower efficiency throughout the operating range.

3.3.5.3 Voltage Regulation and Synchronization

Asynchronous Generators

An asynchronous generator needs to absorb reactive power from the three-phase mains supply to ensure its magnetization is even. The mains supply defines the frequency of the stator rotating flux and hence the synchronous speed above which the rotor shaft must be driven.

On start-up, the turbine is accelerated to a speed slightly above the synchronous speed of the generator, when a velocity relay closes the main line switch. From this hyper-synchronized state the generator speed will be reduced to synchronous speed by feeding current into the grid. Speed deviations from synchronous speed will generate a driving or resisting torque that balances in the area of stable operation.

Synchronous Generators

The synchronous generator is started before connecting it to the mains by the turbine rotation. By gradually accelerating the turbine, the generator must be synchronized with the mains, regulating the voltage, frequency, phase angle and rotating sense. When all these values are controlled correctly, the generator can be switched to the grid. In the case of an isolated or off grid operation, the voltage controller maintains a predefined constant voltage, independent of the load. In case of the mains supply, the controller maintains the predefined power factor or reactive power.

3.3.6 Exciters

The exciting current for the synchronous generator can be supplied by a small DC generator, known as the exciter, driven from the main shaft. The power absorbed by this DC generator amounts to 0.5% - 1.0% of the total generator power. Nowadays a static exciter usually replaces the DC generator, but there are still many rotating exciters in operation.

Rotating exciters

The field coils of both the main generator and the exciter generator are usually mounted on the main shaft. In larger generators a pilot exciter with permanent magnet excitation is also used. It supplies the exciting current to the main exciter, which in turn supplies the exciting current for the rotor of the generator.

Brushless exciters

A small generator has its field coils on the stator and generates AC current in the rotor windings. A solid state rectifier rotates with the shaft, converting the AC output from the small generator into the DC, which is supplied to the rotating field coils of the main generator without the need for brushes. The voltage regulation is achieved by controlling the current in the field coils of the small generator.

Static exciters

A static exciter is a grid connected rectifier that provides DC current to the generator field coils instead of the rotating exciter. The voltage and power factor control works in the same way as with the rotating device. Static exciters are robust, easy to maintain and have a high efficiency. The response to the generator voltage oscillations is very good.

3.3.7 Speed Governors

A governor is a combination of devices and mechanisms, which detect speed deviation and convert it into a change in servomotor position. A speed-sensing element detects the deviation from the set point; this deviation signal is converted and amplified to excite an actuator, hydraulic or electric, that controls the water flow to the turbine. In a Francis turbine, where there is a reduction in water flow need to rotate the wicket-gates. For this, a powerful governor is required to overcome the hydraulic and frictional forces and to maintain the wicket-gates in a partially closed position or to close them completely.

Several types of governors are available varying from old fashioned purely mechanical to mechanical-hydraulic to electrical-hydraulic and mechanical-electrical. The purely mechanical governor is used with fairly small turbines, because its control valve is easy to operate and does not require a big effort. These governors use a flyball mass mechanism driven by the turbine shaft. The output from this device - the flyball axis descends or ascends according to the turbine speed - directly drives the valve located at the entrance to the turbine.

In a modern electrical-hydraulic governor a sensor located on the generator shaft continuously senses the turbine speed. The input is fed into a summing junction, where it is compared to a speed reference. If the speed sensor signal differs from the reference signal, it emits an error signal (positive or negative) that, once amplified, is sent to the servomotor so this can act in the required sense. In general the actuator is powered by a hydraulic power unit consisting of a sump for oil storage, an electric motor operated pump to supply high pressure oil to the system, an accumulator where the oil under pressure is stored, oil control valves and a hydraulic cylinder. All these regulation systems, as have been described, operate by continuously adjusting the wicket-gates position back and forth. To provide quick and stable adjustment of the wicket-gates, and/or of the runner blades, with the least amount of over or under speed deviations during system changes a further device is needed. In electrical-hydraulic governors the degree of sophistication is much greater, so that the adjustment can be proportional, integral and derivative (PID) giving a minimum variation in the controlling process.

An asynchronous generator connected to a stable electric grid, does not need any controller, because its frequency is controlled by the mains. Not withstanding this, when the generator is disconnected from the mains the turbine accelerates up to runaway speed of the turbine. Generator and speed increaser have to be designed to withstand this speed long enough until the water flow is closed by the controlling system (guide vanes or valve).

To ensure the control of the turbine speed by regulating the water flow, certain inertia of the rotating components is required. Additional inertia can be provided by a flywheel, on the turbine, or the generator shaft. When the main switch disconnects the generator, the power excess accelerates the flywheel; later, when the switch reconnects the load, the deceleration of this inertia flywheel supplies additional power that helps to minimize speed variation.

To achieve good regulation, it is necessary that Tm/Tw > 4. Realistic water starting times do not exceed 2.5 sec [3]. If it is larger, modification of the water conduits must be considered - either by decreasing the velocity or by installing a surge tank. The possibility of adding a flywheel to the generator to increase the inertia rotating parts can also be considered. It should be noted that an increase in the inertia of the rotating parts would improve the water hammer effect and decrease the runaway speed.

3.3.8 Switchgear Equipment

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. Therefore various associated electrical devices are required inside the powerhouse 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 generator breaker, either air, magnetic or vacuum operated, is used to connect or disconnect the generator from the power grid. Instrument transformers, both potential transformers (PTs) and current transformers (CTs) are used to transform high voltages and currents down to more manageable levels for metering. The generator control equipment is used to control the generator voltage, power factor and circuit breakers.

The asynchronous generator protection must include, among other devices: a reverse-power relay giving protection against motoring; differential current relays against internal faults in the generator stator winding; a ground-fault relay providing system backup as well as generator ground-fault protection, etc. The power transformer protection includes an instantaneous over-current relay and a timed over-current relay to protect the main transformer when a fault is detected in the bus system or an internal fault in the main power transformer occurs.

Metering equipment must be installed at the point of supply to record measurements according to the requirements of the electric utility.

In the high voltage side there is a line circuit breaker and a line disconnection switch - combined with a grounding switch - to disconnect the power generating unit and main transformer from the transmission line. Metering is achieved through the corresponding P.T and C.T. A generator circuit breaker is included as an extra protection for the generator unit. A transformer provides energy for the operation of intake gates, shutoff valves, servomotors, oil compressors etc. in the station service.

Greater complexity may be expected in multiunit stations where flexibility and continuity of service are important.

3.9 OTHER MECHANICAL AND ELECTRICAL COMPONENTS OF A SMALL HYDRO PLANT INCLUDE:

- Speed increaser to match the ideal rotational speed of the turbine to that of the generator (if required).
- Water shut-off valve(s) for the turbine(s).
- River by-pass gate and controls (if required).
- Hydraulic control system for the turbine(s) and valve(s).
- Electrical protection and control system.
- Transformers for station service and power transmission.
- Station service including lighting and heating and power to run control systems and switchgear.
- Water cooling and lubricating system (if required).

- Dewatering system.
- Cranes for installation and maintenance
- Ventilation system.
- Backup power supply.
- Telecommunication system.
- Fire and security alarm systems (if required).
- Utility interconnection or transmission and distribution system.

COMPARATIVE STUDY OF WATER CONDUCTOR SYSTEM

4.1 INTRODUCTION

A water conductor of a small hydropower plant is a major component of civil works involving large chunk of land, cost and time – span for installation. Due to its length it is also important in respect of stability and geophysical conditions of site, felling of trees, safety of houses, fields, orchards and roads, maintenance and repair cost, ecological and environmental considerations. Therefore it is important that a most economical, sound and optimally suitable system is adopted for the water conductor system.

Various types of systems like kutcha canals, lined channels, RCC open or box channels, tunnels, RCC Hume pipes, HDPE pipes, M. S Pipe etc. have been used for conducting water from the source to the Forebay. But so far there is lack of a proper analysis regarding the most suitable system. It carries water from diversion structure to power house. It can be open channel or closed conduit or tunnel or a combination of two or more types depending on topography and geology of the area.

4.2 OPEN CHANNEL

The open channel may be lined or unlined and of rectangular or trapezoidal section depending on the strata. Generally the channels are lined to save seepage losses. The channel section is designed such that velocity is adequate to avoid silting and should also be minimize the head loss. Commonly used following two equations give the bed width and water depth.

$$V = \frac{1}{n} R^{2/3} S^{1/2} \text{ and } Q = AV$$

Where,

V = Velocity in m/sec

n = Coefficient of rugosity

R = Hydraulic radius = $\frac{A}{P}$

P = Wetted perimeter

S = Longitudinal bed slope

Q = Discharge in Cumecs

A = Cross Sectional Area in m^2

4.3 HUME PIPES OR STEEL PIPES

Hume pipes or steel pipes are best suited in the regions with steep hill slopes. These are buried in a cut and cover trench without disturbing the hill slopes and drainages. These may be designed as running full under pressure or partially.

4.4 TUNNEL

Tunnels are defined as under-ground passages made without removing the overlying rock or soil. The tunnels for carrying water are known as hydraulic tunnels. In the field of hydropower tunnels are commonly used for the conveyance of the water.

4.4.1 Classifications of Tunnels

The hydraulic tunnels used for hydropower are classified as follows:

(i) Head race tunnels or pressure tunnels
(ii) Free flow tunnels
(iii) Free flowing cum pressure tunnels

Depending on their shape, tunnels may be classified as:

(i) D-Shaped
(ii) Horse-shoe shaped
(iii) circular shaped

Depending upon the liner, they are:

(i) Lined tunnels
(ii) Unlined tunnels

Tunnels may also be classified on the basis of the supporting arrangement:

(i) Unsupported tunnels
(ii) Steel ribs supported tunnels
(iii) Rock bolts supported tunnels
(iv) Shotcrete supported tunnels
(v) Tunnels supported by a combination of above (ii, iii, iv)

4.4.2 Planning and Designing of Tunnels

The first step for the planning and designing of a tunnel include the selection of its alignment and geological investigations along the alignment selected for tunnels. The layout of tunnel should be straight as far as possible and should pass through rock of good quality. After the finalization of alignment of tunnel, next step is to choose an appropriate geometric section of the tunnel. The choice of a section is mainly based on the prevailing site conditions. Commonly used sections or shapes are D-shaped, Horse-shoe section and Circular section. D-shaped section is found to be suitable in tunnels located in good quality, intact sedimentary rocks and massive external igneous, hard, compacted, metamorphic rocks where the external pressures due to rock and water are not very large and where the lining is not designed to carry any external or internal pressure. The Horse- shoe section is a compromise between circular and D-shaped sections. Where a moderately good rock is available and the tunnel has to resist internal pressures also, these sections are found to be most suitable. The circular section is most suitable from structural considerations. It is also hydraulically more efficient section. However, circular section is difficult for excavation particularly where the cross-sectional area is small.

After finalizing the alignment and geometry shape of the tunnel, the next step is to work out the economical diameter of the tunnels. The factors like discharge, velocity, facility for construction, maintenance, gates etc should be considered while working out the diameter. The economical diameter of tunnels for the small hydropower is becomes small due to the small discharge, to construct small diameter tunnel is practically difficult thus minimum size feasible for vehicles and working personnel movement is selected. After deciding the diameter hydraulic and structural design of tunnel is done.

The tunnels which run partially are designed as open channel. The under pressure conduits and tunnels are designed on velocity consideration. The construction cost of tunnel is much higher than open channel in the case of small hydropower plants. However, in the open channel difficult and costly maintenance & repairs leading to longer shut down of power plant, thus the present thinking towards the selection of tunnel as water conductor system for SHPs. For the long run of project tunnels may be cheaper than open channel, comparing with maintenance and loss of generation of these systems in the whole life.

4.5 CASE STUDIES

To study about the water conductor system for the existing SHPs five cases are studied. The study focused on to find out the best type of water conductor system from the economical aspect for the long run of the system. The four cases are taken from the Dharchula area of the Pithoragarh District and one case from the Uttarkashi district of Uttaranchal State of India. In all cases water conductor system is open channel.

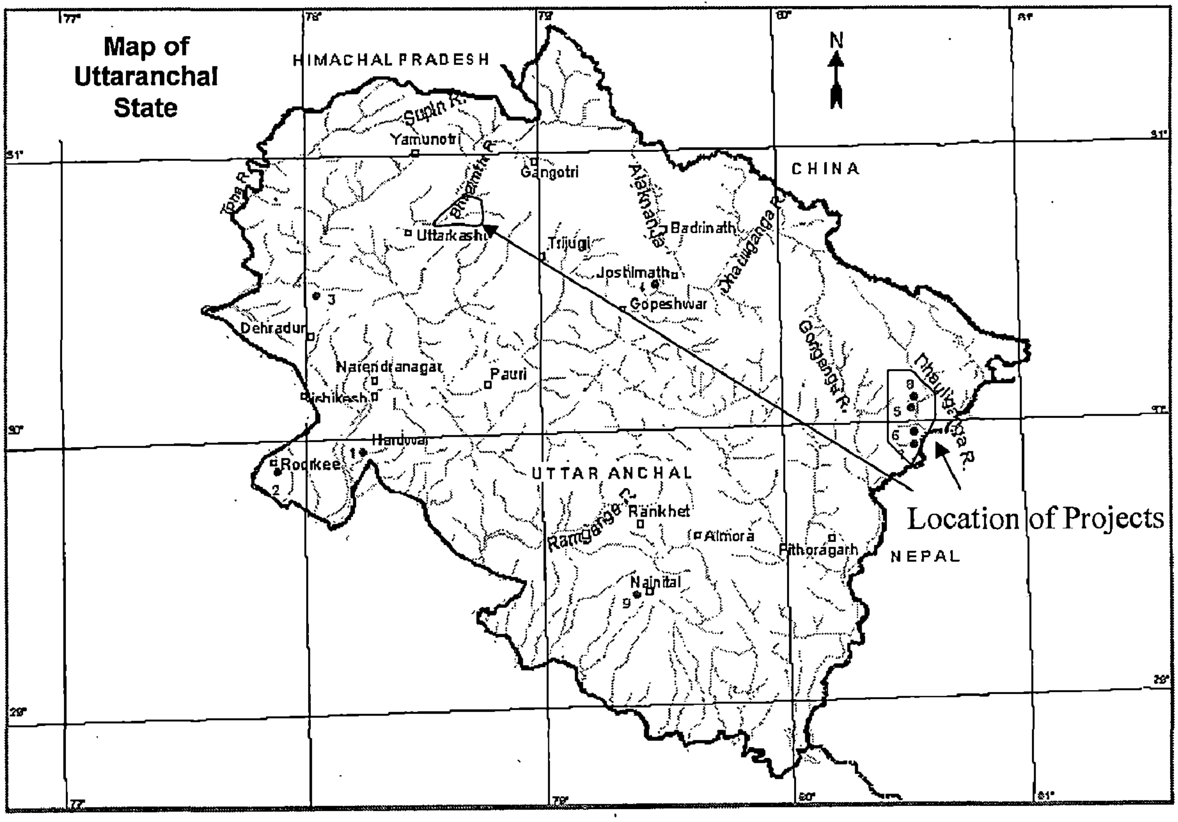


Fig. 4.1 Location map of case study projects

4.5.1 Kanchauti SHP

The Kanchauti SHP is situated at a distance of about 30 km from the Dharchula on the road to Sobla and Dar. The project of 2000 KW envisages the utilization of 0.616 cumecs discharge of the stream Kanchauti Gad, a tributary of the river Dhauliganga.

Salient Features of the Project

Table 4.1 Salient feature of Kanchauti SHP

1	Name of Project	:	Kanchauti SHP
2	Date of Commissioning	:	25.08.1993
3	Location	:	Tehsil Dharchula, Distt. Pithoragarh
4	Name of Stream	:	Kanchauti Gad
5	Geographical Coordinates	:	
	Longitude	:	80^0 35' 30" East
	Latitude	:	30^0 North
6	Total installed Capacity	:	2000 KW
7	Number of Units	:	2 X 1000 KW
8	Plant Load Factor	:	60 %
9	Annual Energy	:	8.934 MU
10	Turbine	:	Pelton Wheel
11	Generator	:	Synchronous
12	Head	:	400m
13	Discharge	:	0.616 cumecs
14	Intake	:	Trench Weir Type
15	Water Conductor System	:	Open Channel
	Length	:	330m
	Cross-section	:	1.2m X 0.85m
16	Power House	:	Surface Type
17	Project Cost	:	508.30 Lacs

Table 4.2 Annual outage details of Kanchauti SHP

Causes	**Hours Per Year**					**Average Hours**	**% of Outage**
	2002/2003	**2003/2004**	**2004/2005**	**2005/2006**	**2006/2007**		
Grid Fail	772	416	685	513	478	572.80	25.63
Shutdown due to problem in water conveyance system and maintenance of civil works	318	177	305	227	357	276.80	12.39
E/M Problem	653	798	1146	717	846	832.00	37.23
Others	527	611	519	479	629	553.00	24.75
Total	2270	2002	2655	1936	2310	2234.60	100.00

Source: Collected from outage resister of the station

Table 4.3 Energy loss calculated data of the Kanchauti SHP

Planed annual generation (MU)	8.93
Actual average annual generation (MU)	10.00
Percentage of average annual outage	25.50
Average annual outage hours due to problem in WCS (Hrs)	277.00
% of outage due to problem in WCS	3.16
Energy loss due to problem in WCS (MU)	0.388
Average loss amount per year at the rate of Rs 2.50/KWh (Lacs)	9.7
Present value of average loss amount for 30 year at the rate of Rs 2.50/KWh taking 10% discount rate	91.42

4.5.2 Chhirkila SHP

The Chhirkila SHP is situated at a distance of about 25 km from the Dharchula on the road to Sobla and Dar. The project of 1500 KW envisages the utilization of 0.68 cumecs discharge of the stream Duggu Gad, a tributary of the river Dhauliganga.

Salient Features of the Project

Table 4.4 Salient feature of Chhirkila SHP

1	Name of Project	:	Chhirkila SHP
2	Date of Commissioning	:	01.05.1997
3	Location	:	Tehsil Dharchula, Distt. Pithoragarh
4	Name of Stream	:	Duggu Gad
5	Geographical Coordinates	:	
	Longitude	:	80^{0} 36’ East
	Latitude	:	29^{0} 55’ North
6	Total installed Capacity	:	1500 KW
7	Number of Units	:	1 X 1000 KW and 1 X 500 KW
8	Plant Load Factor	:	60 %
9	Annual Energy	:	7.767 MU
10	Turbine	:	Pelton Wheel Double Jet
11	Generator	:	Synchronous
12	Head	:	275m
13	Discharge	:	0.68 cumecs
14	Intake	:	Trench Weir Type
15	Water Conductor System	:	Open Channel
	Length	:	2266m
	Cross-section	:	1.2m X 0.85m
16	Power House	:	Surface Type
17	Project Cost	:	450.90 Lacs

Table 4.5 Annual outage details of Chhirkila SHP

Causes	**Hours Per Year**					**Average Hours**	**% of Outage**
	2002/2003	**2003/2004**	**2004/2005**	**2005/2006**	**2006/2007**		
Grid Fail	678	488	654	575	533	585.60	12.26
Shutdown due to problem in water conveyance system and maintenance of civil works	273	378	403	475	355	376.80	7.89
E/M Problem	1500	3200	3020	4500	2910	3026.00	63.36
Others	853	904	775	802	603	787.40	16.49
Total	3304	4970	4852	6352	4401	4775.80	100.00

Source: Collected from outage resister of the station

Table 4.6 Energy loss calculation of the Chhirkila SHP

Planed annual generation (MU)	7.767
Actual average annual generation (MU)	4.67
Percentage of average annual outage	54.52
Average annual outage hours due to problem in WCS (Hrs)	377
Percentage of outage due to problem in WCS	4.30
Energy loss due to problem in WCS (MU)	0.396
Average loss amount per year at the rate of Rs 2.50/KWh (Lacs)	9.90
Present value of average loss amount for 30 year at the rate of Rs 2.50/KWh taking 10% discount rate (Lacs)	93.32

4.5.3 Kulagad SHP

The Kulagad SHP is situated at a distance of about 12 km from the Dharchula on the road to Tawaghat. The project of 1200 KW envisages the utilization of 0.79 cumecs discharge of the stream Kulagad, a tributary of the river Mahakali.

Salient Features of the Project

Table 4.7 Salient feature of Kulagad SHP

1	Name of Project	:	Kulagad SHP
2	Date of Commissioning	:	01.09.1995
3	Location	:	Tehsil Dharchula, Distt. Pithoragarh
4	Name of Stream	:	Kulagad
5	Geographical Coordinates	:	
	Longitude	:	79^{0} 36’ East
	Latitude	:	29^{0} 28” North
6	Total installed Capacity	:	1200 KW
7	Number of Units	:	2 X 600 KW
8	Plant Load Factor	:	60 %
9	Annual Energy	:	5.362 MU
10	Turbine	:	Horizontal Turgo Impulse
11	Generator	:	Synchronous
12	Head	:	200m
13	Discharge	:	0.79 cumecs
14	Intake	:	Trench Weir Type
15	Water Conductor System	:	Open Channel
	Length	:	730m
	Cross-section	:	1.2m X 0.85m
16	Power House	:	Surface Type
17	Project Cost	:	378.78 Lacs

Table 4.8 Annual outage details of Kulagad SHP

Causes	Hours Per Year					Average Hours	% of Outage
	2002/2003	2003/2004	2004/2005	2005/2006	2006/2007		
Grid Fail	782	493	664	557	547	608.60	14.43
Shutdown due to problem in water conveyance system and maintenance of civil works	566	497	513	635	357	513.60	12.18
E/M Problem	903	2825	907	1214	1155	1400.80	33.21
Others	1573	1747	2057	1904	1192	1694.60	40.18
Total	3824	5562	4141	4310	3251	4217.60	100.00

Source: Collected from outage resister of the station

Table 4.9 Energy loss calculation of the Kulagad SHP

Planed annual generation (MU)	5.36
Actual average annual generation (MU)	3.04
Percentage of average annual outage	48.15
Average annual outage hours due to problem in WCS (Hrs)	514
Percentage of outage due to problem in WCS	5.87
Energy loss due to problem in WCS (MU)	0.432
Average loss amount per year at the rate of Rs 2.50/KWh (Lacs)	10.79
Present value of average loss amount for 30 year at the rate of Rs 2.50/KWh taking 10% discount rate (Lacs)	101.79

4.5.4 Relagad SHP

The Relagad SHP is situated at a distance of about 14 km from the Dharchula on the road to Tawaghat. The project of 3000 KW envisages the utilization of 1.42 cumecs discharge of the stream Relagad, a tributary of the river Mahakali.

Salient Features of the Project

Table 4.10 Salient feature of Relagad SHP

1	Name of Project	:	Relagad SHP
2	Date of Commissioning	:	17.02.2004
3	Location	:	Tehsil Dharchula, Distt. Pithoragarh
4	Name of Stream	:	Relagad
5	Geographical Coordinates	:	
	Longitude	:	80^0 33' East
	Latitude	:	29^0 55' 49" North
6	Total installed Capacity	:	3000 KW
7	Number of Units	:	2 X 1500 KW
8	Plant Load Factor	:	60 %
9	Annual Energy	:	12.49 MU
10	Turbine	:	Turgo Impulse
11	Generator	:	Synchronous
12	Head	:	275m
13	Discharge	:	1.42 cumecs
14	Intake	:	Trench Weir Type
15	Water Conductor System	:	Open Channel
	Length	:	2475m
	Cross-section	:	1.5m X 1.1m
16	Power House	:	Surface Type
17	Project Cost	:	1088.29 Lacs

Table 4.11 Annual outage details of Relagad SHP

Causes	Hours Per Year					Average Hours	% of Outage
	2002/2003	2003/2004	2004/2005	2005/2006	2006/2007		
Grid Fail	Started on 17th Feb		150	725	125	333.33	5.92
Shutdown due to problem in water conveyance system and maintenance of civil works			6616.5	1214	6347	4725.83	83.90
E/M Problem			96	528	47	223.67	3.97
Others			250	700	100	350.00	6.213569
Total			7112.5	3167	6619	5632.83	100.00

Source: Collected from outage resister of the station

Table 4.12 Energy loss calculation of the Relagad SHP

Planed annual generation (MU)	12.49
Actual average annual generation (MU)	5.1
Percentage of average annual outage	64.31
Average annual outage hours due to problem in WCS (Hrs)	4726
Percentage of outage due to problem in WCS	53.94
Energy loss due to problem in WCS (MU)	9.922
Average loss amount per year at the rate of Rs 2.50/KWh (Lacs)	248.06
Present value of average loss amount for 30 year at the rate of Rs 2.50/KWh taking 10% discount rate (Lacs)	2349.23

4.5.5 Pilangad SHP

The Pilangad SHP is situated at a distance of about 25 km from the Uttarkashi on the road to Gangotri. The project of 2250 KW envisages the utilization of 2.75 cumecs discharge of the stream Pilangad, a tributary of the river Bhagirathi.

Salient Features of the Project

Table 4.13 Salient feature of Pilangad SHP

1	Name of Project	:	Pilangad SHP
2	Date of Commissioning	:	01.04.2004
3	Location	:	Bhatwani block, Malla village, Distt. Uttarkashi
4	Name of Stream	:	Pilangad
5	Geographical Coordinates	:	
	Longitude	:	78^0 37' 09.54" East
	Latitude	:	30^0 47' 04" North
6	Total installed Capacity	:	2250 KW
7	Number of Units	:	2 X 1125 KW
8	Plant Load Factor	:	NA
9	Annual Energy	:	12.00 MU
10	Turbine	:	Francis horizontal
11	Generator	:	Synchronous
12	Head	:	102m
13	Discharge	:	2.75 cumecs
14	Intake	:	Trench Weir Type
15	Water Conductor System	:	Open Channel
	Length	:	1300m
	Cross-section	:	1.8 m X 1.2m
16	Power House	:	Surface Type
17	Project Cost	:	900 Lacs

Table 4.14 Annual outage details of Pilangad SHP

Causes	Hours Per Year					Average Hours	% of Outage
	2002/2003	2003/2004	2004/2005	2005/2006	2006/2007		
Grid Fail	Started on 1st April		429.75	402.8	541.25	457.93	16.67
Shutdown due to problem in water conveyance system and maintenance of civil works			1654	1444.65	368.25	1155.63	42.06
E/M Problem			1426.25	862.15	1114	1134.13	41.28
Others			0.00	0.00	0.00	0.00	0.00
Total			3510	2709.6	2023.5	2747.70	100.00

Source: Collected from outage resister of the station

Table 4.15 Energy loss calculation of the Pilangad SHP

Planed annual generation (MU)	12.00
Actual average annual generation (MU)	12.43
Percentage of average annual outage	31.37
Average annual outage hours due to problem in WCS (Hrs)	1155.63
Percentage of outage due to problem in WCS	13.19
Energy loss due to problem in WCS (MU)	1.820
Average loss amount per year at the rate of Rs 2.50/KWh (Lacs)	45.50
Present value of average loss amount for 30 year at the rate of Rs 2.50/KWh taking 10% discount rate (Lacs)	429.50

Table 4.16 Summary of total unit wise annual outage details of all projects

SHP	Unit	2002/2003		2003/2004		2004/2005		2005/2006		2006/2007		Average hours	%age time of year
		unit wise	Average	unit wise	Average	Unit wise	Average	unit wise	Average	unit wise	Average		
Kanchauti	I	3213.5	2270.4	3205.3	2001.8	3072.1	2655.5	1511.7	1980.9	983.3	2310.7	2243.8	25.61
	II	1327.2		798.3		2238.8		2450.0		3638.0			
Chhirkila	I	2131.3	3305.3	1180.1	4970.1	1626.4	4852.6	3945.0	6352.5	1461.4	4402.7	4776.6	54.53
		4479.3		8760.0		8078.8		8760.0		7344.0			
Kulagad	I	4824.0	3824.6	7554.8	5562.5	5025.6	4141.7	4697.1	4310.5	3561.4	3249.5	4217.7	48.15
	II	2825.2		3570.1		3257.8		3923.9		2937.5			
Relagad	I	0.0	0.0	0.0	0.0	7956.5	7112.8	3943.7	3167.5	6697.2	6619.2	5633.1	64.31
	II	0.0		0.0		6269.2		2391.3		6541.2			
Pilangad	I	0.0	0.0	0.0	0.0	2556.8	3510.0	3010.8	2709.6	2120.8	2023.5	2747.7	31.37
	II	0.0		0.0		4463.2		2408.4		1926.3			

4.5.6 Loss of Energy Due to the Problem in Open Channel

From the above five studied SHPPs minimum of 3.16% to maximum 53.94% time in a year plants remains closed due to the problem in water conductor system. In the case of Relagad SHP repair & maintenance of damaged portion of channel taking more time may be due to the poor management or else, thus it is counted as exceptional case. The average outage of rest four power plants is 6.71% time of the year due to the problem in the water conductor system, the details are shown in the appendix. The problem in the power channel occurred generally during in the rainy season when the full discharge is available thus the loss of generation will be 0.0671*KW*8760 units, but the maintenance period is found longer, therefore in general calculation average annual energy loss will be 0.0671*KW*8760*PLF units

Where, KW is the installed capacity in kilowatt.

PLF is the planned plant load factor.

For example if the installed capacity is 3000 KW and PLF is 60% then the power loss will be 0.0671*3000*8760*.6 = 1190484 units = 1.06 MU per year. Its annual planned generation will be 15.77 MU, thus annual percentage loss of energy will be 6.71%.

Table 4.17 Summary of energy loss calculation of the all above operational SHPs

Project Name	Cost of project (Lacs)	Planed Annual Generation (MU)	Actual average annual generation (MU)	%age of average annual outage	Average annual outage hours due to problem in WCS (Hrs)	%age of outage due to problem in WCS	Energy loss due to problem in WCS [Taking 70% PLF] (MU)	Average loss amount per year at the rate of Rs 2.50 / KWh (Lacs)	Present value of average loss amount for 30 years at the rate of Rs 2.50 / KWh taking 10% discount rate (Lacs)
Kanchauti	508.29	8.934	10.00	25.50	277.0	3.16	0.388	9.70	91.42
Chhirkila	450.9	7.767	4.67	54.52	377.0	4.30	0.396	9.90	93.32
Kulagad	375.85	5.362	3.04	48.15	514.0	5.87	0.432	10.79	101.79
Relagad	1088.3	12.49	5.10	64.31	4725.0	53.94	9.922	248.06	2339.23
Pilangad	900	12.00	12.43	31.37	1182.0	13.19	1.820	45.50	429.50

4.5.7 Construction Cost of Water Conductor System

The construction cost of the water conductor system for same dimension is varies project to project due to the geology topology and other factors. Due to the unavailability of the actual data the average data of the various projects is used for the calculation purpose.

Cost Calculation for Tunnel

In the above all five cases if the tunnel was used as a water conductor system then the size of the tunnel should be minimum size due the small discharge (maximum 2.75cumec in Pilangad SHP). The unit cost of tunnels of minimum sized is calculated on the basis of the different projects data shown in table 4.18

Table 4.18 Calculation for per unit length cost of tunnel

Name of Project	Design Discharge for Turbine (Cumecs)	Length of Tunnel (m)	Size and Type of tunnel	Estimated Cost of Tunnel in 2005 (Lacs)	Unit Cost of Tunnel (Rs/m)
Kaliganga II	4.8	1500	2.1m*3.05m D-shaped	587.00	39133.00
Sarju Stage I	3.411	3740	2m*2.5m D-shaped	1300.00	34760.00

From the above table the minimum size of the tunnel is 2m*2.5m, from the following formula we can calculate the maximum discharge for free flow:

$$V = \frac{1}{n} R^{2/3} S^{1/2} \text{ and } Q = AV$$

Where,

V = Velocity in m/sec

n = Coefficient of rugosity

R = Hydraulic radius = $\frac{A}{P}$

P = Wetted perimeter

S = Longitudinal bed slope

Q = Discharge in Cumecs

A = Cross Sectional Area in m^2

Taking longitudinal bed slop is 1 in 500 and rugosity coefficient 0.018, Velocity of flow becomes 1.76 m/sec which is less than 2 m/sec and the discharge becomes 5.3 cumecs. In the study projects Pilangad SHP has design discharge for turbine is 2.75 cumecs and it is largest in all five projects which is less than the above discharge. The required sizes for the study projects will be smaller than this but due to the construction difficulty small sizes can not be feasible and Surju stage I project have almost similar topology and geology as the case study projects, thus the unit cost of tunnel of this project can be used for the calculation of the tunnel cost of the case study projects.

Table 4.19 Calculation for tunnel cost of case study project

Name of Project	Design Discharge	Length of Open Channel in meter (L)	Proposed Length of Tunnel in meter (Taking 2L/π)	Cost of Proposed Tunnel in 2005 as per above rate in Lacs	Cost of Proposed Tunnel in Completion Year Taking 5% Price Escalation in Lacs
Kanchauti	0.616	330	210.19	73.06	40.68
Chhirkila	0.680	2266	1443.31	501.70	339.57
Kulagad	0.790	730	464.97	161.62	99.22
Relagad	1.420	2475	1576.43	547.97	521.87
Pilangad	2.750	1300	828.03	287.82	274.12

Cost of Open Channel

Table 4.20 Cost of open channel of the case study projects

Name of Project	Completion Year	Length of Open Channel (m)	Cost of Channel (Lacs)	Cost of Open Channel in 2005 Taking 5% Price Escalation
Kanchauti	1993	330	23.89	42.9
Chhirkila	1997	2266	168.71	249.26
Kulagad	1995	730	58.26	94.9
Relagad	2004	2475	330.00	346.5
Pilangad	2004	1300	210.48	221

4.5.8 Cost Comparison for Tunnel and Open Channel

Table 4.21 Cost comparison of tunnel and channel

Name of Project	Cost of Project in Lacs		Difference in Construction Cost in Lacs	%age Increase in Cost Using Tunnel	%age Average Increase in Cost Using Tunnel
	For Tunnel as WCS	For Open Channel as WCS			
Kanchauti	525.09	508.29	16.80	3.30	15.36
Chhirkila	621.76	450.9	170.86	37.89	
Kulagad	416.81	375.85	40.96	10.90	
Relagad	1280.16	1088.29	191.87	17.63	
Pilangad	963.64	900	63.64	7.07	

Table 4.22 Comparison of increased cost of project due to tunnel with energy loss amount using open channel

Name of Project	Actual Project Cost	Increased Cost of Project Using Tunnel	Percentage Increase in Project Cost Using Tunnel in Lacs	Energy Loss Amount Using Channel for 30 Year Life after Converting into First Year of operation in Lacs	Energy Loss Amount Using Channel in Percentage of Project Cost
Kanchauti	508.29	30.43	3.30	91.42	17.99
Chhirkila	450.9	284.66	37.89	93.32	20.70
Kulagad	375.85	74.21	10.90	101.79	27.08
Relagad	1088.3	366.77	17.63	2339.23	214.95
Pilangad	900	155.50	7.07	438.88	48.76

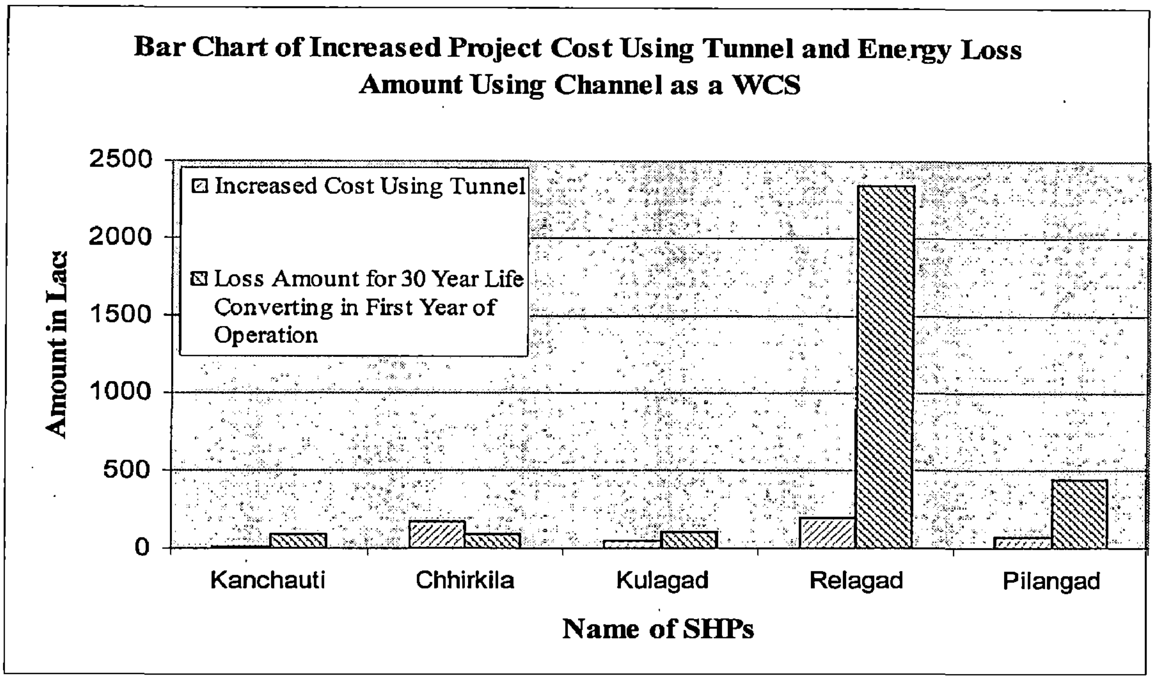


Fig. 4.2 Comparative bar chart of increased project cost using tunnel and energy losses amount using channel as a WCS

In average the cost of project is increased by 15.36% using tunnel as a water conductor system, except Chhirkila SHP it becomes 9.73%. Similarly in average energy loss amount except Relagad SHP it becomes 28.63% of the project cost in 30 year life time, the Relagad SHP is exceptional case it is not working from long time after commissioning thus it is not included. From the above all calculation it is found that the tunnel is economical and reliable than the open channel in the case of small hydro also.

4.6 DEMERITS OF OPEN CHANNEL OR RCC BOX WATER CONDUCTOR SYSTEM FOR SMALL SHPs

1. Ultimately costlier than the tunnel for whole life considering economic & reliability aspects.
2. Needs more land and felling of more number of trees
3. Prone to flooding, overflowing and seepage problems.
4. Loss of water leading to reduced power generation.
5. Increased risk of slips and slides of hill slopes.
6. Difficult and costly maintenance and repairs leading to longer shut down of power plant.

7. Likely to be chocked due to slides and rolling debris & stones.
8. Quality of water likely to be deteriorated.
9. Ecologically unfriendly. Risk to wild life.
10. Opposed by villagers, land and house owners.
11. Pilferage of water and sabotage possible.
12. Weakens the geophysical conditions due to seepage, leakage and flooding.
13. Likely to suffer serious damage due to earthquake.

4.7 MERITS OF TUNNEL FOR SMALL HYDRO ELECTRIC POWER PROJECTS

1. Needs lesser land and feeling of fewer numbers of trees.
2. Less repair and maintenance required.
3. Less head loss due to the shorter length with compared to open channel leads higher power.
4. No water pilferage and risk of sabotage.
5. No possibility of chocking due to blockage therefore leading to higher power generation.
6. Water quality not prone to deterioration.
7. Ecologically friendly. No risk to wild life.
8. Not opposed by locals because no risk to their fields and houses due saturation, failure and flooding.
9. Overall reduced shutdown period and generation of more power.
10. Reduced risk due to earthquakes slips and slides.

CHAPTER-5

OPTIMIZATION OF INSTALLED CAPACITY OF SHP

5.1 GENERAL

One of the most important issues in planning Small Hydro-Power Plants of the ''run-off river'' type is to determine the optimal installation capacity of the SHPP and estimate its optimal annual energy value. Generally, in the hilly area the SHPPs are in the ''run of the river'' category because their generated capacity is based on the deviated water flow of river runoff. After determining the downstream water flow and environmental needs and rights, the energy calculation is done with respect to the water flow categorized data of the river. To estimate the generated energy, a range of flow rate is specified based on river discharge. Then, based on the daily and 10 days/or monthly statistics of the flow duration curve and the water flow optimally generated energy is calculated.

To determine the optimal installation capacity of SHPPs developed model of unit capacity cost is used for different installed capacity and economic analysis is done. At which capacity the unit generation cost is minimum is selected as an optimal or most economical installed capacity.

5.2 OPTIMIZATION

Optimization means to make as perfect as possible. The realization of this definition depends on how well the mathematical relationships among all the important variables defined the situation. The procedures for defining the variables and relationships with subsequent methods for finding the best solution are in the subject matter associated with the study of operation research. The most prominent operation research technique is linear programming. It is designed for models with strict linear objective and constraints functions. Other techniques include integer programming (in which the variables assume integer values), dynamic programming (in which the original model can be decomposed into smaller sub-networks), network programming (in which the problem can be modeled as a network), and nonlinear programming (in which the functions of the model are nonlinear). There are basically five major phases: [16]

i. Formulation of the problem
ii. Construction of the model
iii. Deriving a solution from the model
iv. Validation of the model
v. Implementation of the solution

5.2.1 Formulation of Problem

Formulation of problem involves defining the scope of the problem under investigation. The end result of the investigation is to identify three principal elements of the decision problem namely: (1) description of the decision alternatives, (2) determination of the alternatives of the study, and (3) specification of the limitations under which the modeled system operates. [16]

In general, the first crucial step in any such model is the definition of the alternatives or the decision variables of the problem. Next, the decision variables are used to construct the objective function and the constraints of the model. The model is usually organized in the following general format:

Maximized or minimized objective function

Subject to

Constraints

An objective function is a mathematical expression of the specific measures for the objective. The objective function can be written in terms of volume, cost, benefits, and so on. The mathematical expression includes at least one objective function, which is either maximized or minimized. Any number of the decision variable can be included in the objective function; the overall measure must be the same. The unit of measurement cannot be mixed. There are some limitations, which are expressed in the mathematical equations and are called constraints.

5.2.2 Construction of a Model

A model will be defined here as a mathematical abstraction of reality that preserves and uses characteristics of the problem. The mathematical abstraction is expressed in terms of mathematical symbols and expressions. These symbols are classified as variables and constants of the model. If there are n decisions to be made, they are represented by the decision variables (say X_1, X_2......X_n) whose values to be determined.

The values for the decision variables are evaluated by the objective function, which is a quantifiable measure of the objectives of the study. The values of the decision variables are limited by the constraints of the problem. The constraints are expressed mathematically by means of inequalities and/or equations. An interpretation of the model is to choose the values of the decision variables that optimize the objective function subject to the constraints set. Optimization is done on these lines. Solving the equations is referred to as maximization or minimization of the objective function.

5.2.3 Deriving a Solution

After the model is constructed, a mathematical technique is then used to obtain a solution. The choice of the technique depends on the mathematical formulation of the model, desired solutions, and the resources available for solving the model. A peculiarity of most operation research techniques is that solutions are not generally obtained in closed forms. Instead, they are determined by algorithms. An algorithm provides fixed computational rules that are applied repetitively to the problem with each repetition (called iteration) moving the solution closer to the optimum. Because the computations associated with each iteration are typically tedious and voluminous, it is imperative that these algorithms be executed on the computer. If accuracy is not highly desired and the little time and money exist for analysis, then approximation or heuristic procedures can be used. Heuristic procedures use intuition and judgment but do not guarantee an optimal solution.

Some times the solution to the model is not the best because the model does not represent real-world conditions. However, the responsiveness of the model to various actions can be examined by the use of sensitivity analysis. Sensitivity analysis refers to varying the parameters of the model and the recording of the results. The analysis determines which parameters of the model results are most sensitive to input data changes, so that more attention can be focused on accurate determination of input data. Also, variability of the results can be recorded for reasonable changes in the input parameters.

5.2.4 Validation of the Model

The validation of the model involves checking and testing of the model output for the acceptable limit. A common method for checking the validity of the model is to compare its output with historical output data.

5.2.5 Implementation of the Solution

Implementation of the solution of a validated model involves the translation of the results into operating instructions issued in understandable form to the individuals who will administer the recommended system.

5.3 COST ANALYSIS OF SHP

5.3.1 General

Cost-effectiveness is defined as a ratio of net favorable consequences to the cost of the practice. The net favorable consequences should be measured by a consistent set of the monetary units of the government. The cost of the practice over a period of time should reflect all the cost, both initial and operational. The practice must be defined as a best management practice to be eligible for cost-effective analysis.

The cost of any management system can generally be classified into three basic categories: capital, operating and risks. Capital cost includes the cost of planning, design, construction, land, surveys, and all others for startup. Operating cost includes those for operation (labor and expenses), replacement, and repairs necessary to operate over the economic life of the project. These costs are abbreviated as O&M costs. Risk can be measured by damages or restoration costs.

One of the criteria used to help determine the best alternate is cost-effectiveness or the maximum operational effectiveness for each rupee invested. The procedure for cost-effectiveness analysis is a systematic comparison of alternatives of selects the one that minimizes cost while reliably satisfying technical limitations and preferences over the expected time for operation.

Under this chapter, cost effective approach for further development of SHPPs in Uttaranchal state of India and similar other areas has been presented on the basis of collected data of some SHPPs.

5.3.2 Methodology

Costs are site specific; there are various factors which affects the project cost. An empirical relationship of head, capacity and cost is developed to find out the approximate project cost and optimal benefited installed capacity can be optimized. To make this model following steps are taken:

i Data collection and processing

ii Model development

iii Regression analysis

5.3.2.1 Data Collection and Processing

Data for the project, total cost of project, head and installed capacity are collected from different project site office. To check the consistency of data, the standard deviation for each data series are calculated. The total cost of project is converted to same base year by assuming 5% price escalation by following formula.

$P = Q^* (1.05)^n$

Where,

P is present cost

Q is project cost

n is years

Table 5.1 Collected data of SHPPs

Project Name	Project Completion year	Capacity (KW)	Head (m)	Cost of Project (Lacs)
Kulagad	1995	1200	200.0	375.850
Chhirkila	1997	1500	275.0	450.900
Kanchauti	1993	2000	400.0	508.290
Pilangad	2004	2250	102.0	900.000
Relagad	2004	3000	265.0	1088.290

Table 5.2 Present cost and unit capacity cost of SHPPs

Project Name	Project Completion year	Capacity (KW)	Head (m)	Cost of Project (Lacs)	Project Cost in 2007, Taking 5% Price Escalation	Cost per KW (Rs)
Kulagad	1995	1200	200.0	375.850	674.973	56247.72

Chhirkila	1997	1500	275.0	450.900	734.469	48964.57
Kanchauti	1993	2000	400.0	508.290	1006.379	50318.97
Pilangad	2004	2250	102.0	900.000	1041.863	46305.00
Relagad	2004	3000	265.0	1088.290	1259.832	41994.39

Table 5.3 Log transformed values of capacity, head and unit capacity cost of SHPPs.

Project Name	**Log of Capacity (KW)**	**Log of Head (m)**	**Log of Cost of 1 KW (Rs)**
Kulagad	3.079	2.301	4.750
Chhirkila	3.176	2.439	4.690
Kanchauti	3.301	2.602	4.702
Pilangad	3.352	2.009	4.666
Relagad	3.477	2.423	4.623

5.3.2.2 Model Development

After converting the collected data in log series, a model was developed in power form taking the log (cost per unit capacity) as dependent variable and log (head), log(capacity) as independent variable by using SPSS (software package for statistical sciences). A linear regression analysis is done using the software. The model was tested and validated for the collected data.

5.3.2.3 Regression Analysis

Regression analysis is a statistical procedure that minimizes the variability in estimating a variable, which is dependent on other independent variables. It may be the choice for extreme estimation when a general equation is required for an area. For this study linear regression analysis is used to construct a model. Output of the regression analysis using SPSS software as follows:

Dependent Variable: Cost

Independent Variable: Capacity and Head

Predictors: (Constant), Capacity, Head

	Coefficients
Constant	5.575
Head	.012
Capacity	-.280

$R^2 = 0.862$

Log (per unit Cost) = 5.575 - 0.280 Log (Capacity) + 0.012 Log (Head)

Taking Antilog on both sides following relation is developed.

Per unit cost = 375837.4* Capacity $^{-0.280}$ * Head $^{0.012}$ in Rupees

Per unit KW cost = 3.758 * Capacity $^{-0.280}$ * Head $^{0.012}$ in Lacs

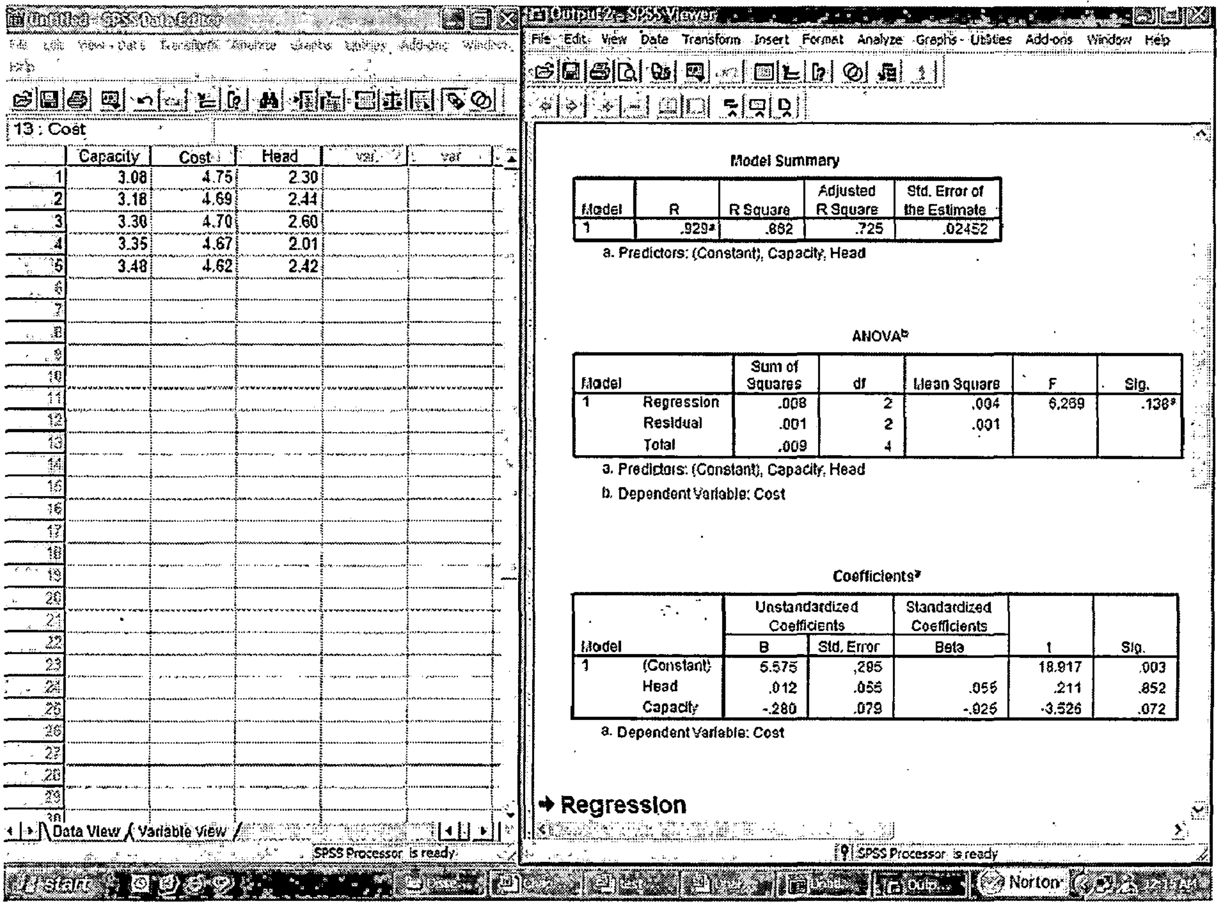
The above relation is developed on the basis of 2007 cost data and it can be used only for that year. The generalized relation for any year will be as follows:

Per unit KW cost = 3.758 * Capacity $^{-0.280}$ * Head $^{0.012}$ *$(1+r/100)^{2007-n}$ in Lacs

Where,

r = percentage price escalation rate

n = required year



13 : Cost

	Capacity	Cost	Head	var	var
1	3.08	4.75	2.30		
2	3.18	4.69	2.44		
3	3.30	4.70	2.60		
4	3.35	4.67	2.01		
5	3.48	4.62	2.42		

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.929[a]	.862	.725	.02452

a. Predictors: (Constant), Capacity, Head

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.008	2	.004	6.269	.138[a]
	Residual	.001	2	.001		
	Total	.009	4			

a. Predictors: (Constant), Capacity, Head

b. Dependent Variable: Cost

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.575	.295		18.917	.003
	Head	.012	.055	.055	.211	.852
	Capacity	-.280	.079	-.925	-3.526	.072

a. Dependent Variable: Cost

Regression

SPSS Processor is ready

Fig 5.1: Input output window screen of SPSS

Table 5.4 Comparison of model output data with actual data

Project Name	Actual Per Unit KW Cost (Lacs)	Calculated Per Unit Cost (Lacs)	Actual Cost (Lacs)	Computed Cost (Lacs)	Variation in Cost (%) #
Kulagad	0.562	0.528	674.97	660.05	-2.21
Chhirkila	0.490	0.502	734.47	778.06	+5.94
Kanchauti	0.503	0.474	1006.38	961.44	-4.47
Pilangad	0.463	0.572	1041.86	1029.51	-1.19
Relagad	0.420	0.498	1259.83	1281.04	+1.68

#Positive sign indicates computed value is more and negative sign indicates less

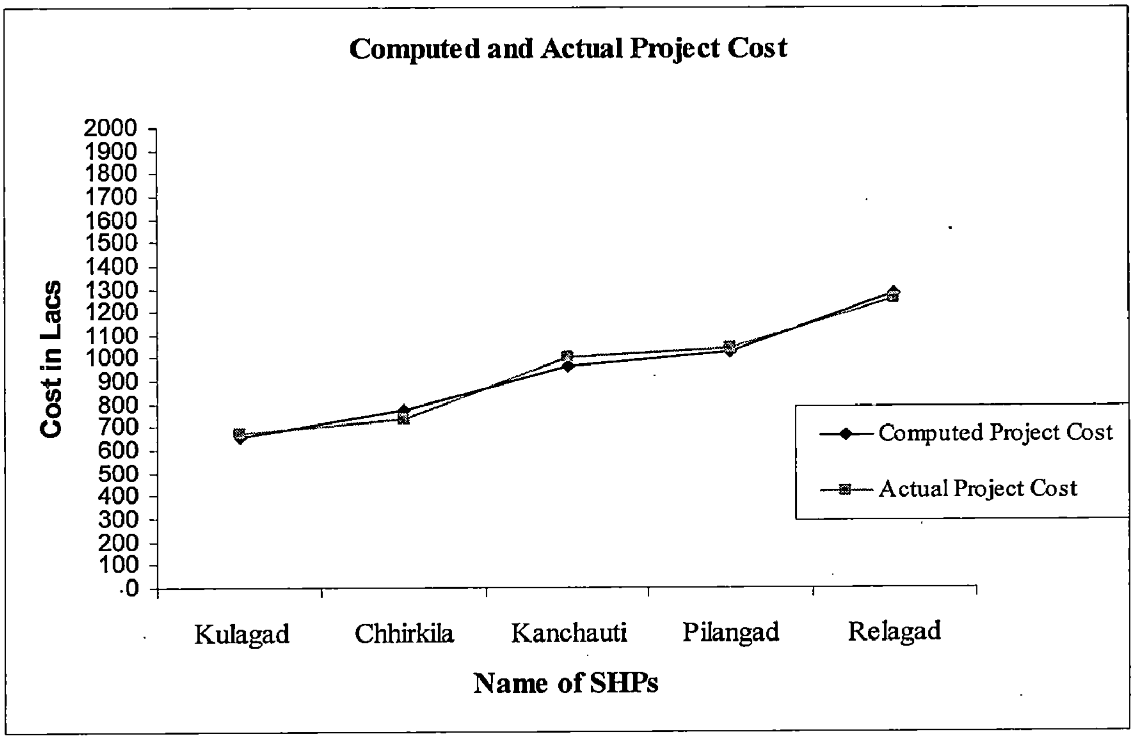


Fig 5.2: Graphical representation of actual and computed values of project cost

5.4 OPTIMIZATION OF CAPACITY

General Flow Chart

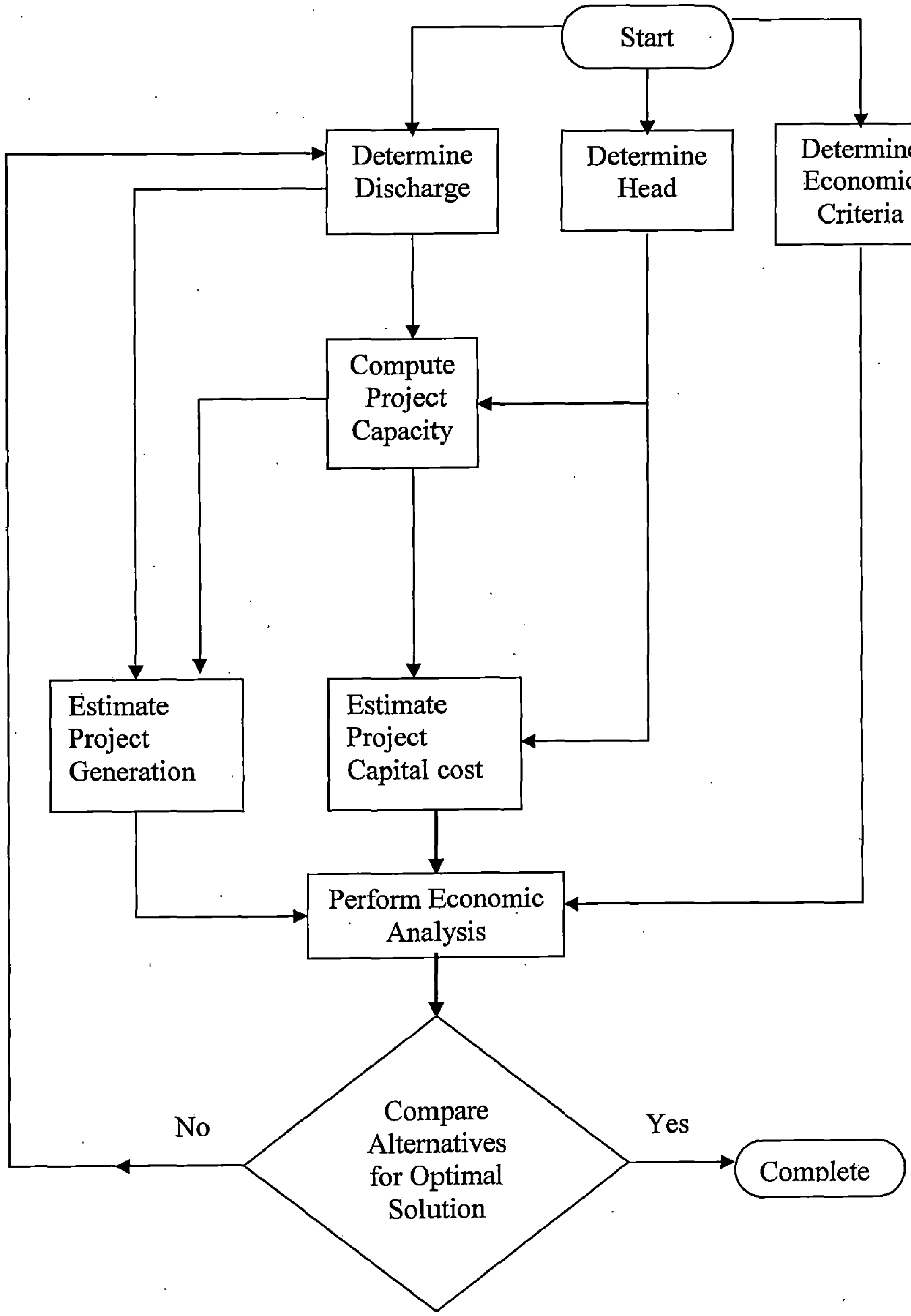


Fig 5.3 Capacity Optimization General Flow Chart

Cost of Generation for First Year

The following assumptions are considered for the computation of unit generation cost of first year of operation.

Loan equity ratio 70:30

Interest on loan 10%

Depreciation 3%, using straight line method taking 10% salvage value and 30 year life of project

O&M cost 3% with 5% annual price escalation

Return on equity (ROE) 14%

Income taxes are not included

Cost of first year = Interest on loan + depreciation + O&M cost + ROE

$$= C*0.7*0.1 + C*0.03 + C*0.03 + C*0.3*0.14$$

$$= 0.172\,C$$

Where, C is the total project cost

The cost of first year of operation is computed 17.2% of the total project cost.

Estimation of Annual Generation

From the discharge data sheet gross annual generation can be calculated using following formula:

$$KWh = 9.81*Q*H*\eta*t$$

Where,

Q discharge in cumecs

H net head in meter

η Efficiency of the unit

t time in hours

After deducting the environmental flow and arranging these average ten daily data in descending order and assuming 96% generator & 90% turbine efficiencies, the following relation can be obtained:

$$\text{Annual gross generation} = 2040*H*\left[n*Q_n + \sum_{i=n+1}^{36} Q_i\right] \quad \text{(KWh)}$$

Where,

H = Net head in meter

i = Serial number of descending average ten daily data of discharge

Q_i = Discharge at ith serial number in cumecs

n = Serial number of discharge table corresponding to the design discharge

Q_n = Design discharge in cumecs

Assuming 10% forced outage

Annual net estimated generation = $1836*H*\left[n*Q_n+\sum_{i=n+1}^{36}Q_i\right]$ (KWh)

Assuming transmission loss 1%, transformation loss 0.5% and losses due to auxiliary consumption 0.5%

Annual saleable generation = 98% of Annual net estimated generation

$$=0.98*1834*H*\left[n*Q_n+\sum_{i=n+1}^{36}Q_i\right] \quad \text{(KWh)}$$

$$=1800*H*\left[n*Q_n+\sum_{i=n+1}^{36}Q_i\right] \quad \text{(KWh)}$$

The unit generation cost for first year = $\dfrac{0.172\,C}{1800*H*\left[n*Q_n+\sum_{i=n+1}^{36}Q_i\right]}$ (Rs/KWh)

Where,

C = Total project cost in Rupees

Estimation of Profit for First Year of Operation

The profit can be determined for the first year of operation assuming the following factors:

Loan equity ratio 70:30

Period of loan repayment 10 years

Interest on loan 10%

Depreciation 3%, using straight line method taking 10% salvage value and 30 year life of project

O&M cost 3% with 5% annual price escalation

Thus, Annual cost = 0.7*0.1*C+0.7*0.1*C+0.03*C+0.03*C = 0.2*C

Where,

C is the total project cost

Profit = (Annual Energy)*(Price) – Annual Cost

Profit in percentage of project cost = $\dfrac{Profit}{Total\ Project\ cost} X\ 100$

5.4.1 Determination of Optimal Economic Installed Capacity of High Head SHPs (Case Study)

High head small hydropower plants are considered above 70 m net head, thus above all five cases are considered high head SHPPs. The economical installed capacity is determined on the basis of minimum unit generation cost. The unit generation cost is the ratio of the expenditure made to the total generation on a year. The total expenditure of first year of operation is calculated using the above derived formula cost = 0.172*C. The C (project cost) is computed from the unit cost model developed above. From the above derived formula annual generation is computed for the computation of unit generation cost and plant load factor.

5.4.1.1 Kanchauti SHP

Table 5.5 Unit generation cost calculation of Kanchauti SHP

10 Daily Average Discharge (Cumecs)	Head (m)	Capacity (KW)	Generation of Ten Days (KWh)	Total Annual Generation (KWh)	Per KW Cost (Lacs) #	Unit Cost for First Year of Generation (Rs/KWh
≥0.72	400	2448	517018	13607616	0.454	1.40
≥0.72	400	2448	517018	13607616	0.454	1.40
≥0.72	400	2448	517018	13607616	0.454	1.40
≥0.72	400	2448	517018	13607616	0.454	1.40
≥0.72	400	2448	517018	13607616	0.454	1.40
≥0.72	400	2448	517018	13607616	0.454	1.40
≥0.72	400	2448	517018	13607616	0.454	1.40
≥0.72	400	2448	517018	13607616	0.454	1.40
≥0.72	400	2448	517018	13607616	0.454	1.40
≥0.72	400	2448	517018	13607616	0.454	1.40
0.70	400	2380	502656	13464000	0.457	1.39
0.66	400	2244	473933	13148045	0.465	1.36
0.63	400	2142	452390	12889536	0.471	1.35
0.62	400	2108	445210	12796186	0.473	1.34
0.62	400	2108	445210	12796186	0.473	1.34
0.61	400	2074	438029	12688474	0.475	1.34
0.60	400	2040	430848	12573581	0.478	1.33
0.60	400	2040	430848	12573581	0.478	1.33
0.59	400	2006	423667	12444326	0.480	1.33
0.55	**400**	**1870**	**394944**	**11898586**	**0.489**	**1.32****
0.55	400	1870	394944	11898586	0.489	1.32
0.50	400	1700	359040	11144602	0.503	1.32
0.50	400	1700	359040	11144602	0.503	1.32
0.50	400	1700	359040	11144602	0.503	1.32

0.45	400	1530	323136	10282906	0.518	1.32
0.40	400	1360	287232	9385306	0.535	1.33
0.32	400	1088	229786	7891699	0.569	1.35
0.32	400	1088	229786	7891699	0.569	1.35
0.28	400	952	201062	7087450	0.591	1.37
0.27	400	918	193882	6879206	0.597	1.37
0.26	400	884	186701	6663782	0.604	1.38
0.26	400	884	186701	6663782	0.604	1.38
0.25	400	850	179520	6433997	0.610	1.39
0.24	400	816	172339	6197030	0.617	1.40
0.24	400	816	172339	6197030	0.617	1.40
0.23	400	782	165158	5945702	0.625	1.41

Unit Cost Model =3.754*(Capacity)$^{-0.28}$*(Head)$^{0.012}$

** Minimum generation unit cost for first year of operation

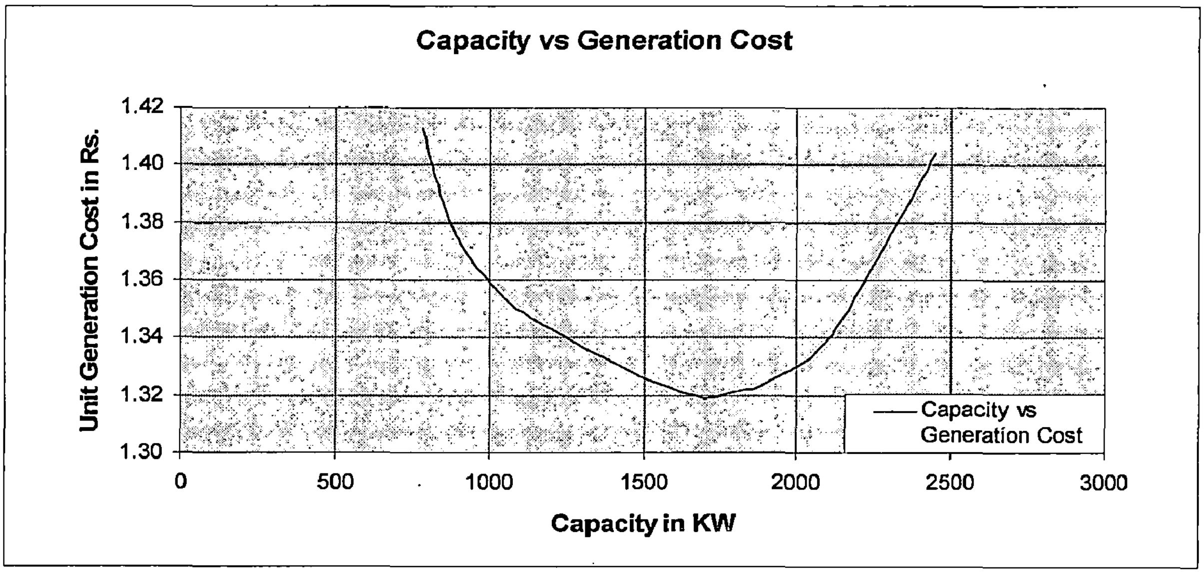


Fig. 5.4 Graph of capacity vs unit generation cost of Kanchauti SHP

From the above table 5.5 optimal economic installed capacity becomes 1870 KW and actual installed capacity 2000 KW is above & near to optimal capacity. For the execution of any projects we have to select nearer suitable and available capacity to reduce the extra cost for design of new capacity machines. For the optimal economic capacity the design discharge available for 55.55% of time of the year the plant load factor becomes 72.64%. The percentage profit becomes maximum at minimum unit generation cost and it is 12.51% at Rs 2.50 energy sale price.

5.4.1.2 Relagad SHP

Table 5.6 Unit generation cost calculation of Relagad SHP

10 Daily Average Discharge (Cumecs)	Head (m)	Capacity (KW)	Generation of Ten Days (KWh)	Total Annual Generation (KWh)	Per KW Cost (Lacs)	Unit Cost for First Year of Generation (Rs/KWh
≥1.76	265	3964	837281	22592323	0.395	1.19
≥1.76	265	3964	837281	22592323	0.395	1.19
≥1.76	265	3964	837281	22592323	0.395	1.19
≥1.76	265	3964	837281	22592323	0.395	1.19
≥1.76	265	3964	837281	22592323	0.395	1.19
≥1.76	265	3964	837281	22592323	0.395	1.19
≥1.76	265	3964	837281	22592323	0.395	1.19
≥1.76	265	3964	837281	22592323	0.395	1.19
≥1.76	265	3964	837281	22592323	0.395	1.19
≥1.76	265	3964	837281	22592323	0.395	1.19
≥1.76	265	3964	837281	22592323	0.395	1.19
1.69	265	3807	803980	22226012	0.399	1.18
1.69	265	3807	803980	22226012	0.399	1.18
1.69	265	3807	803980	22226012	0.399	1.18
1.56	265	3514	742136	21360187	0.408	1.15
1.40	265	3154	666019	20218440	0.421	1.13
1.38	265	3108	656505	20066207	0.422	1.13
1.36	**265**	**3063**	**646990**	**19904460**	**0.424**	**1.12**
1.36	265	3063	646990	19904460	0.424	1.12
1.35	265	3041	642233	19814071	0.425	1.12
1.34	265	3018	637476	19718926	0.426	1.12
1.30	265	2928	618446	19319314	0.429	1.12
1.20	265	2703	570874	18272712	0.439	1.12
1.10	265	2478	523301	17178538	0.450	1.12
1.05	265	2365	499514	16607664	0.456	1.12
1.00	265	2253	475728	16013004	0.462	1.12
0.91	265	2027	428155	14776112	0.476	1.12
0.90	265	1982	418641	14519219	0.479	1.12
0.88	265	1915	404369	14119607	0.484	1.13
0.85	265	1689	356796	12739996	0.501	1.14
0.75	265	1644	347281	12454559	0.505	1.15
0.73	265	1644	347281	12454559	0.505	1.15
0.73	265	1622	342524	12302326	0.507	1.15
0.73	265	1622	342524	12302326	0.507	1.15
0.73	265	1599	337767	12140579	0.509	1.15
0.67	265	1509	318738	11474559	0.517	1.17

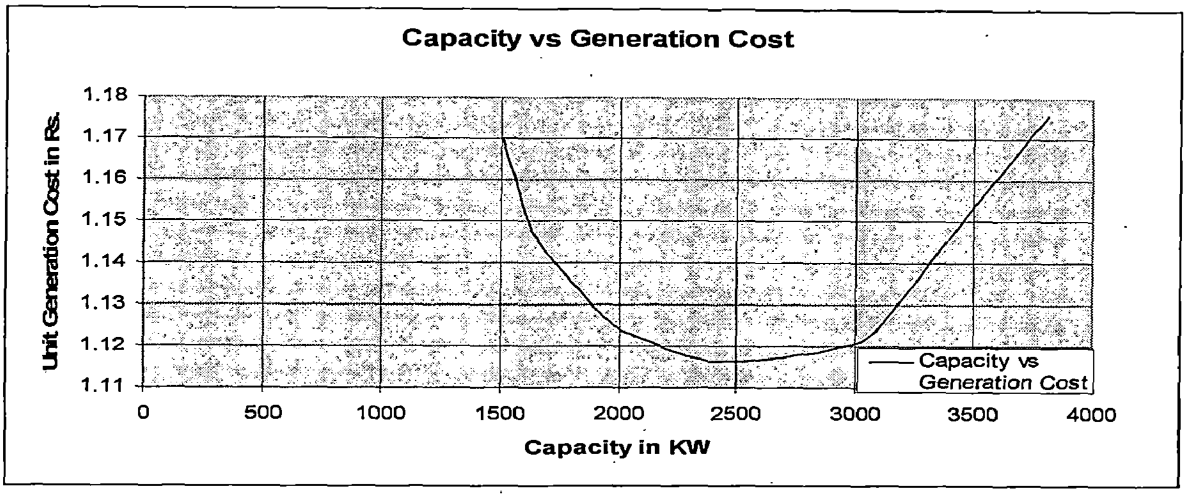


Fig. 5.5 Graph of capacity vs unit generation cost of Relagad SHP

From the above table optimal economic installed capacity becomes 3063 KW and actual installed capacity 3000 KW is very near to optimal capacity. For the execution of any projects we have to select nearer suitable and available capacity to reduce the extra cost for design of new capacity machines. For the optimal economic capacity the design discharge available for 50% of time of the year the plant load factor becomes 74.17%. The percentage profit becomes maximum at minimum unit generation cost and it is 18.30% at Rs 2.50 energy sale price.

5.4.1.3 Pilangad SHP

Table 5.7 Unit generation cost calculation of Pilangad SHP

10 Daily Average Discharge (Cumecs)	Head (m)	Capacity (KW)	Generation of Ten Days (KWh)	Total Annual Generation (KWh)	Per KW Cost (Lacs)	Unit Cost for First Year of Generation (Rs/KWh
≥5.44	102	4716	996121	22678223	0.372	1.33
≥5.44	102	4716	996121	22678223	0.372	1.33
≥5.44	102	4716	996121	22678223	0.372	1.33
≥5.44	102	4716	996121	22678223	0.372	1.33
≥5.44	102	4716	996121	22678223	0.372	1.33
≥5.44	102	4716	996121	22678223	0.372	1.33
≥5.44	102	4716	996121	22678223	0.372	1.33
≥5.44	102	4716	996121	22678223	0.372	1.33
4.42	102	3832	809348	21184042	0.394	1.23
4.30	102	3728	787375	20986283	0.397	1.21
3.87	102	3355	708637	20198908	0.409	1.17
3.77	102	3269	690326	19997487	0.412	1.16
3.75	102	3251	686664	19953540	0.412	1.16
3.60	102	3121	659197	19596475	0.417	1.14

3.51	102	3043	642718	19365756	0.420	1.14
3.44	102	2982	629900	19173490	0.422	1.13
3.43	102	2974	628069	19144192	0.423	1.13
3.28	102	2844	600602	18677261	0.428	1.12
3.27	102	2835	598771	18644301	0.428	1.12
3.15	102	2731	576798	18226809	0.433	1.12
3.00	102	2601	549331	17677478	0.439	1.11
2.81	102	2436	514540	16946868	0.447	1.11
2.77	**102**	**2402**	**507216**	**16785730**	**0.449**	**1.10**
2.66	102	2306	487074	16322461	0.454	1.10
2.53	102	2194	463269	15751157	0.460	1.10
2.45	102	2124	448620	15384936	0.464	1.10
2.29	102	1985	419323	14623197	0.473	1.11
2.23	102	1933	408336	14326558	0.477	1.11
2.19	102	1899	401012	14121474	0.479	1.11
2.07	102	1795	379039	13484250	0.487	1.11
2.07	102	1795	379039	13484250	0.487	1.11
1.96	102	1699	358896	12859843	0.494	1.12
1.93	102	1673	353403	12684057	0.497	1.13
1.91	102	1656	349741	12563205	0.498	1.13
1.84	102	1595	336923	12127402	0.503	1.14
1.83	102	1587	335092	12063313	0.504	1.14

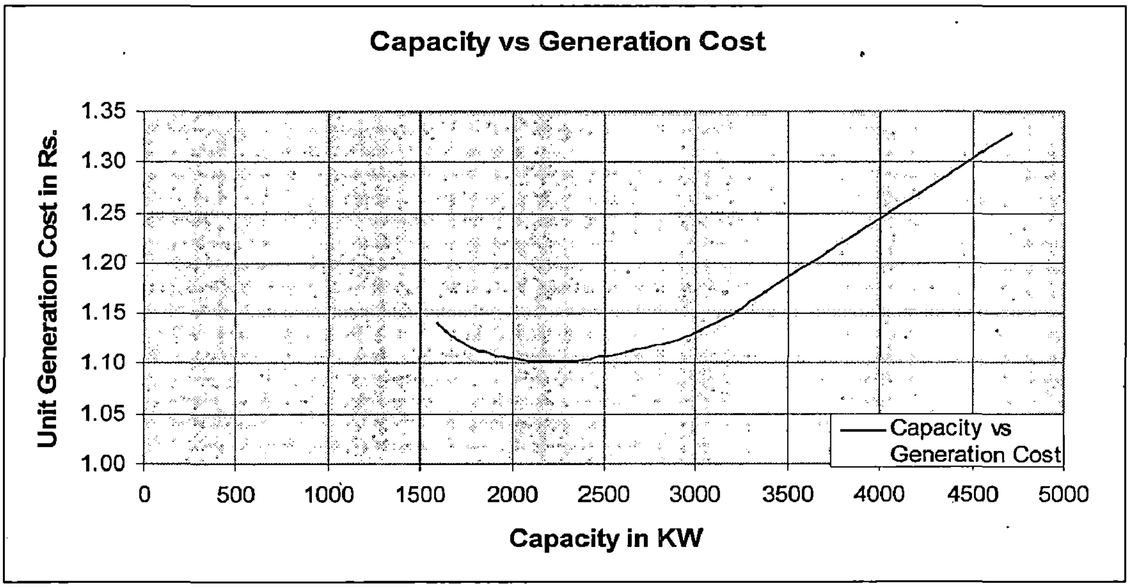


Fig. 5.6 Graph of capacity vs unit generation cost of Pilangad SHP

From the above table optimal economic installed capacity becomes 2402 KW and actual installed capacity 2250 KW is near to optimal capacity but upper suitable value of 2500 KW should be best choice. For the optimal economic capacity the design discharge available for 63.88% of time of the year and the plant load factor becomes 79.79%. The percentage profit becomes maximum at minimum unit generation cost and it is 18.9% at Rs 2.50 energy sale price.

5.4.1.4 Kulagad SHP

Table 5.8 Unit generation cost calculation of Kulagad SHP

10 Daily Average Discharge (Cumecs)	Head (m)	Capacity (KW)	Generation of Ten Days (KWh)	Total Annual Generation (KWh)	Per KW Cost (Lacs)	Unit Cost for First Year of Generation (Rs/KWh
≥0.81	200	1377	290822	5657752	0.529	2.21
≥0.81	200	1377	290822	5657752	0.529	2.21
≥0.81	200	1377	290822	5657752	0.529	2.21
≥0.81	200	1377	290822	5657752	0.529	2.21
≥0.81	200	1377	290822	5657752	0.529	2.21
≥0.81	200	1377	290822	5657752	0.529	2.21
≥0.81	200	1377	290822	5657752	0.529	2.21
≥0.81	200	1377	290822	5657752	0.529	2.21
≥0.81	200	1377	290822	5657752	0.529	2.21
0.70	200	1190	251328	5302303	0.551	2.13
0.65	200	1105	233376	5122783	0.562	2.09
0.62	200	1054	222605	5004300	0.570	2.06
0.57	200	969	204653	4788876	0.583	2.03
0.55	200	935	197472	4695525	0.589	2.02
0.51	200	867	183110	4494463	0.602	2.00
0.46	200	782	165158	4225183	0.619	1.97
0.44	200	748	157978	4110290	0.627	1.96
0.39	200	663	140026	3805106	0.649	1.94
0.36	**200**	**612**	**129254**	**3611224**	**0.663**	**1.93**
0.35	200	595	125664	3543007	0.669	1.93
0.33	200	561	118483	3399391	0.680	1.93
0.31	200	527	111302	3248594	0.692	1.93
0.29	200	493	104122	3090616	0.705	1.93
0.24	200	408	86170	2677720	0.743	1.95
0.22	200	374	78989	2505381	0.762	1.96
0.20	200	340	71808	2325861	0.782	1.97
0.19	200	323	68218	2232511	0.793	1.97
0.17	200	289	61037	2038629	0.819	2.00
0.16	200	272	57446	1938098	0.833	2.01
0.13	200	221	46675	1625733	0.882	2.06
0.13	200	221	46675	1625733	0.882	2.06
0.11	200	187	39494	1403128	0.925	2.12
0.10	200	170	35904	1288236	0.950	2.16
0.10	200	170	35904	1288236	0.950	2.16
0.098	200	167	35186	1263821	0.955	2.17
0.09	200	153	32314	1163290	0.978	2.21

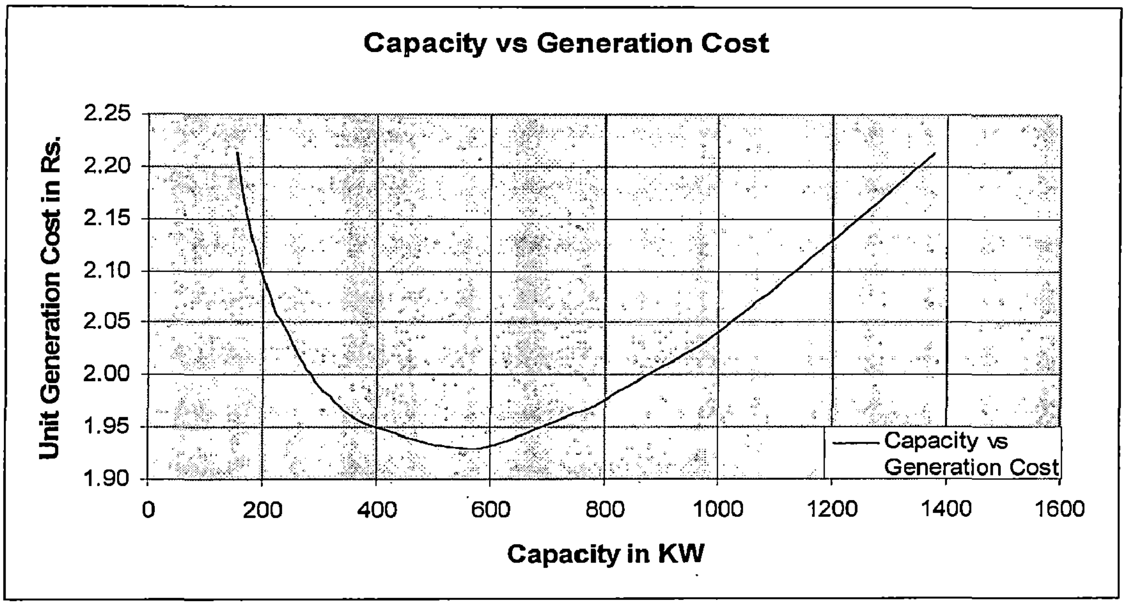


Fig. 5.7 Graph of capacity vs unit generation cost of Kulagad SHP

From the above table optimal economic installed capacity becomes 612 KW and actual installed capacity 1200 KW is much more than optimal capacity. For the optimal economic capacity the design discharge available for 52.77% of time of the year and the plant load factor becomes 67.36%. The percentage profit becomes maximum at minimum unit generation cost and it is 2.23% at Rs 2.50 energy sale price.

5.4.1.5 Chhirkila SHP

Table 5.9 Unit generation cost calculation of Chhirkila SHP

10 Daily Average Discharge (Cumecs)	**Head (m)**	**Capacity (KW)**	**Generation of Ten Days (KWh)**	**Total Annual Generation (KWh)**	**Per KW Cost (Lacs)**	**Unit Cost for First Year of Generation (Rs/KWh**
≥0.90	275	2104	444312	10843681	0.471	1.57
≥0.90	275	2104	444312	10843681	0.471	1.57
≥0.90	275	2104	444312	10843681	0.471	1.57
≥0.90	275	2104	444312	10843681	0.471	1.57
≥0.90	275	2104	444312	10843681	0.471	1.57
≥0.90	275	2104	444312	10843681	0.471	1.57
≥0.90	275	2104	444312	10843681	0.471	1.57
≥0.90	275	2104	444312	10843681	0.471	1.57
≥0.90	275	2104	444312	10843681	0.471	1.57
≥0.90	275	2104	444312	10843681	0.471	1.57
0.88	275	2057	434438	10744945	0.474	1.56
0.76	275	1777	375197	10093288	0.494	1.50
0.70	275	1636	345576	9737838	0.506	1.46

0.61	275	1426	301145	9160232	0.526	1.41
0.61	275	1426	301145	9160232	0.526	1.41
0.6	275	1403	296208	9086180	0.528	1.40
0.59	275	1379	291271	9007192	0.530	1.40
0.56	275	1309	276461	8755415	0.538	1.38
0.56	275	1309	276461	8755415	0.538	1.38
0.55	275	1286	271524	8661616	0.541	1.38
0.53	275	1239	261650	8464144	0.547	1.38
0.52	**275**	**1216**	**256714**	**8360471**	**0.550**	**1.37**
0.50	275	1169	246840	8143252	0.556	1.37
0.50	275	1169	246840	8143252	0.556	1.37
0.48	275	1122	236966	7906285	0.562	1.37
0.46	275	1075	227093	7659445	0.569	1.37
0.43	275	993	209814	7210196	0.582	1.38
0.40	275	935	197472	6876962	0.591	1.38
0.38	275	888	187598	6600502	0.600	1.39
0.37	275	865	182662	6457334	0.605	1.39
0.35	275	818	172788	6161126	0.614	1.40
0.34	275	795	167851	6008086	0.619	1.41
0.34	275	795	167851	6008086	0.619	1.41
0.32	275	748	157978	5682257	0.630	1.43
0.32	275	748	157978	5682257	0.630	1.43
0.31	275	725	153041	5509469	0.635	1.44

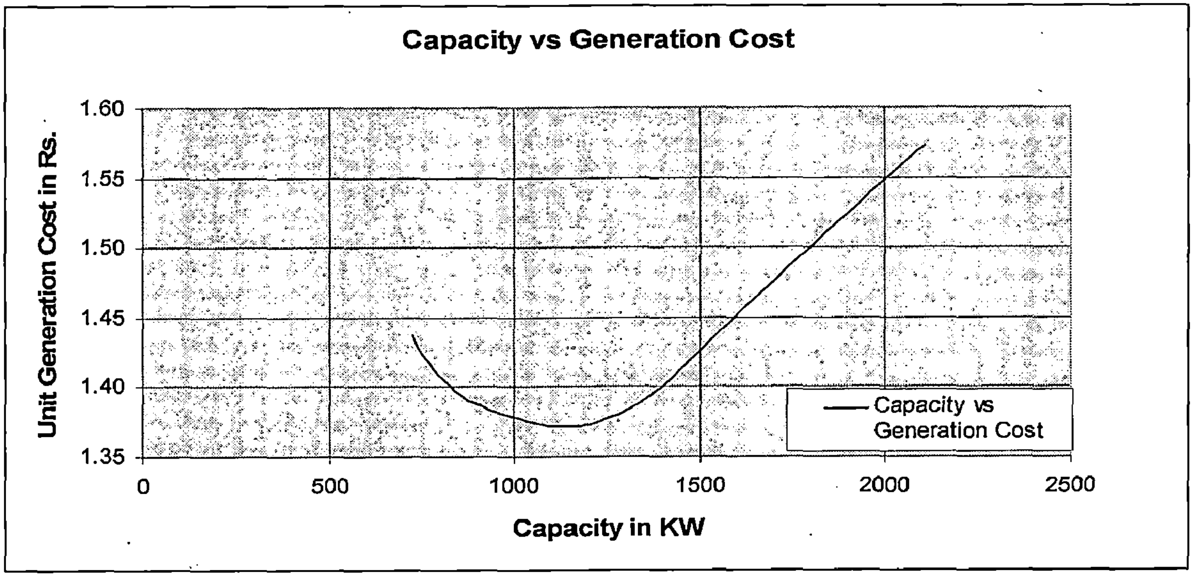


Fig. 5.8 Graph of capacity vs unit generation cost of Chhirkila SHP

From the above table optimal economic installed capacity becomes 1216 KW and actual installed capacity 1500 KW is slightly more than optimal capacity. For the optimal economic capacity the design discharge available for 61.11% of time of the year and the plant load factor becomes 78.52%. The percentage profit becomes maximum at minimum unit generation cost and it is 11.29% at Rs 2.50 energy sale price.

Table 5.10 Summary of the all five cases

Name of SHP	Actual Capacity (KW)	Planed Annual Generation (MU)	Actual Annual Generation (MU)	Computed Optimal Economic Capacity (KW)	Annual Generation for Optimal Capacity (MU)	PLF for Optimal Capacity (%)	Optimal Design Discharge (Cumecs)	Availability of Computed Discharge (%)
Kanchauti	2000	8.93	10.00	1870	11.90	72.64	0.55	55.55
Relagad	3000	12.49	5.09	3226	20.82	73.67	1.38	47.22
Pilangad	2250	12.00	12.43	2402	16.79	79.79	2.77	63.88
Kulagad	1200	5.36	3.04	612	3.61	67.34	0.36	52.77
Chhirkila	1500	7.77	4.67	1216	8.36	78.55	0.52	61.11

5.4.2 Determination of Optimal Economic Installed Capacity and Dam Height for West and East Nayar SHPs

These two case studies are taken from the Pauri Garwal district of the Uttaranchal State of India. The case study projects are under the planning stage in the Nayar River which is the tributary of river Ganga. The Nayar is perennial and snow fed river. These projects are planning for run-of-river type and power house located at the dam toe.

The selection of optimal economical height of dam and installed capacity is done after selecting different alternates and comparing themselves on the basis of minimum generation cost. To compute the unit generation cost, total cost of scheme, capacity and annual generation is needed. The cost of the project is divided into three major category, these are cost of dam, cost of electromechanical equipment, and cost of other works. The cost of dam for any height is computed from the trend power/exponential equation of cost vs height which is developed from the calculated cost of dam using Excel Software for its different height. For the cost of electromechanical equipment, present cost trend is followed. The cost of other works for any height and discharge is computed from the trend power equation which is developed from the calculated cost of various cases using SPSS Software for linear regression analysis. The annual energy is calculated from the available river discharge data and capacity.

5.4.2.1 East Nayar Dam SHP

The proposed dam site is near the village Biyali and the scheme has the power house located at the dam toe.

Computation of Cost of Dam

The cost of dam for different height is calculated from the available cross-section of the river at dam site assuming per unit cost of concrete Rs. 4500.00. The trend of the dam cost for any height can be computed from the following data:

Table 5.11 Calculated data of cost of dam for computing trend equation of East Nayar Dam SHP

S. No.	Height of Dam (m)	Cost of Dam (Lacs
1	3	133.06
2	6	171.06
3	8	213.43
4	10	264.60
5	12	323.22
6	14	391.42
7	16	468.20
8	18	558.27
9	20	663.06
10	25	923.46
11	30	1254.72
12	35	1657.30
13	40	2149.52
14	45	2740.56
15	50	3443.32

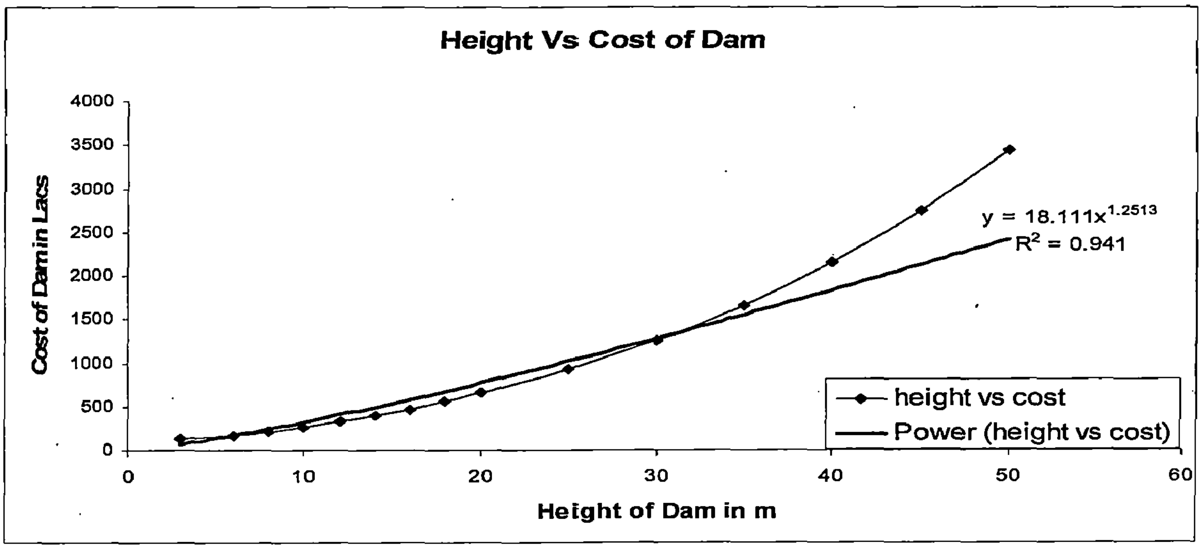


Fig. 5.9 Graph of height vs cost of dam of East Nayar Dam SHP

From the above figure,

The cost of the dam = $18.11*H^{1.25}$

Where, H is the height of the dam

$R^2 = 0.987$

Cost of Other Works

Table 5.12 Calculated data for computing trend equation of cost of other works

Head (m)	Discharge (Cumecs)	Cost (Lacs)	Log of Head	Log of Discharge	Log of Cost
30	16	470	1.477	1.204	2.672
40	16	500	1.602	1.204	2.699
50	16	525	1.699	1.204	2.720
20	16	450	1.301	1.204	2.653
35	10	325	1.544	1.000	2.512
40	10	345	1.602	1.000	2.538
60	10	400	1.778	1.000	2.602
70	13	550	1.845	1.114	2.740
50	13	500	1.699	1.114	2.699
45	12	450	1.653	1.079	2.653
65	15	565	1.813	1.176	2.752

The general trend of cost of other works developed from the linear regression analysis by SPSS software is as follows:

	Coefficients
Constant	1.249
Head	.3
Discharge	.82

$R^2 = 0.93$

Log (Cost) = 1.249 + 0.82 Log (Discharge) + 0.3 Log (Head)

$C = 17.74*Q^{0.82}*h^{0.3}$

Where, Q = Design Discharge in Cumecs

h = Net Head in Meter

C = Cost of Other Works in Lacs

Determination of Economical Optimal Installed Capacity

Optimal economical installed capacity and corresponding height of dam is computed after doing various trials in various alternatives in Excel Software, the following is the final table.

Table 5.13 Calculated data for the optimization of unit generation cost of East Nayar Dam SHP

Height of Dam (m)	Discharge (Cumecs)	Power (KW)	Annual Energy (MU)	Cost of Dam	Cost of E/M Equipments	Other Cost	Total Cost (Lacs)	Unit Cost (Rs)
35	103.52	32063.07	42.1	1541.71	5450.72	2314.65	9307.08	3.80
35	63.40	19636.09	39.1	1541.71	3338.13	1548.34	6428.19	2.83
35	60.09	18613.15	38.6	1541.71	3164.24	1481.88	6187.83	2.75
35	48.96	15164.92	36.2	1541.71	2578.04	1252.71	5372.46	2.56
35	42.39	13131.20	34.2	1541.71	2232.30	1113.19	4887.21	2.46
35	23.03	7133.22	27.0	1541.71	1212.65	674.92	3429.28	2.18
35	20.42	6325.80	25.8	1541.71	1075.39	611.61	3228.71	2.15
35	15.11	4680.61	23.1	1541.71	795.70	477.76	2815.17	2.10
35	**14.48**	**4484.82**	**22.7**	**1541.71**	**762.42**	**461.31**	**2765.44**	**2.09**
35	13.23	4099.33	21.9	1541.71	696.89	428.53	2667.13	2.10
35	12.03	3727.49	21.0	1541.71	633.67	396.39	2571.78	2.11
35	10.73	3322.26	19.9	1541.71	564.78	360.69	2467.19	2.13
35	10.32	3197.81	19.6	1541.71	543.63	349.57	2434.91	2.14
35	8.80	2725.80	18.1	1541.71	463.39	306.67	2311.77	2.20
35	8.64	2675.72	17.9	1541.71	454.87	302.04	2298.62	2.21
35	8.36	2590.73	17.6	1541.71	440.42	294.15	2276.28	2.22
35	8.18	2533.05	17.4	1541.71	430.62	288.77	2261.10	2.24
35	8.10	2508.77	17.3	1541.71	426.49	286.50	2254.70	2.24
35	7.44	2303.88	16.4	1541.71	391.66	267.16	2200.54	2.31
35	7.43	2300.84	16.4	1541.71	391.14	266.88	2199.73	2.31
35	6.24	1932.04	14.6	1541.71	328.45	231.26	2101.42	2.47
35	5.86	1815.18	14.0	1541.71	308.58	219.72	2070.02	2.54
35	5.64	1745.36	13.7	1541.71	296.71	212.77	2051.19	2.58
35	5.31	1645.19	13.1	1541.71	279.68	202.70	2024.10	2.66
35	5.10	1579.93	12.7	1541.71	268.59	196.09	2006.39	2.71
35	5.04	1561.72	12.6	1541.71	265.49	194.23	2001.43	2.73
35	4.72	1461.55	12.0	1541.71	248.46	183.95	1974.13	2.83
35	4.56	1412.98	11.7	1541.71	240.21	178.93	1960.85	2.89
35	4.41	1364.42	11.4	1541.71	231.95	173.87	1947.53	2.95
35	4.22	1308.26	11.0	1541.71	222.40	167.98	1932.09	3.03
35	3.91	1211.13	10.3	1541.71	205.89	157.68	1905.29	3.19
35	3.70	1147.39	9.8	1541.71	195.06	150.84	1887.61	3.32
35	3.69	1144.35	9.8	1541.71	194.54	150.51	1886.77	3.32

35	3.25	1006.24	8.7	1541.71	171.06	135.45	1848.22	3.67
35	3.16	978.92	8.4	1541.71	166.42	132.43	1840.56	3.75
35	3.03	937.94	8.1	1541.71	159.45	127.86	1829.03	3.88

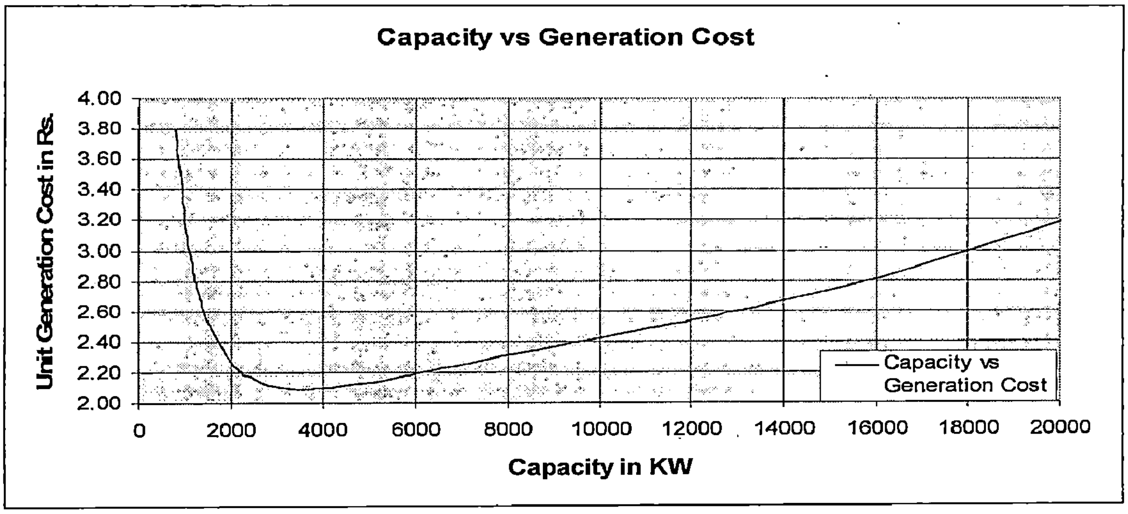


Fig.5.10 Graph of capacity vs unit generation cost of East Nayar Dam SHP

The table 5.10 is final table of analysis and Rs. 2.09 can be considered optimal minimum unit generation cost. The optimal economic installed capacity becomes 4484.82 KW at minimum unit generation cost of 2.09 but this capacity is not practicable, thus we have to choose nearest suitable capacity, the installed capacity of 4500 KW can be chosen for execution of project. If we increase dam height to 36 m the minimum cost becomes Rs. 2.10 and it is more than Rs. 2.09. Similarly if we decrease the dam height up to 22 m the minimum unit generation cost becomes Rs 2.09 and it is equal to Rs. 2.09 but we loose energy per year in every step. From the available data 90% dependable year's 90% flow is 3.4 cumecs, considering 2 sets of generating units and 50% load variation maximum design discharge should be 13.6 cumecs. For the installed capacity of 4500 KW design discharge becomes 14.5 cumecs which is slightly more than 13.6 cumecs but it can be accepted for Kaplan turbine (Kaplan can be used up to 40% load). Thus, dam for 35 m net head and 4500 KW installed capacity will be economically optimal. At the optimal economical installed capacity computed value of PLF is 57.78%, percentage profit at Rs 2.50 energy sale price is 0.53% and percentage annual available design discharge is 25.00%.

5.4.2.2 West Nayar Dam SHP

The proposed dam site is near the village Santoodhar and the scheme has the power house located at the dam toe.

Computation of Cost of Dam

The cost of dam for different height is calculated from the available cross-section of the river at dam site assuming per unit cost of concrete Rs. 4500.00. The trend of the dam cost for any height can be computed from the following data:

Table 5.14 Calculated data of cost of dam for computing trend equation of West Nayar Dam SHP

S. No.	Height of Dam (m)	Cost of Dam (Lacs)
1	3	122.44
2	6	146.93
3	8	172.20
4	10	212.55
5	12	260.30
6	14	315.22
7	16	379.61
8.	18	455.81
9	20	543.44
10	25	778.11
11	30	1085.80
12	35	1479.10
13	40	1967.60
14	45	2558.31
15	50	3266.88

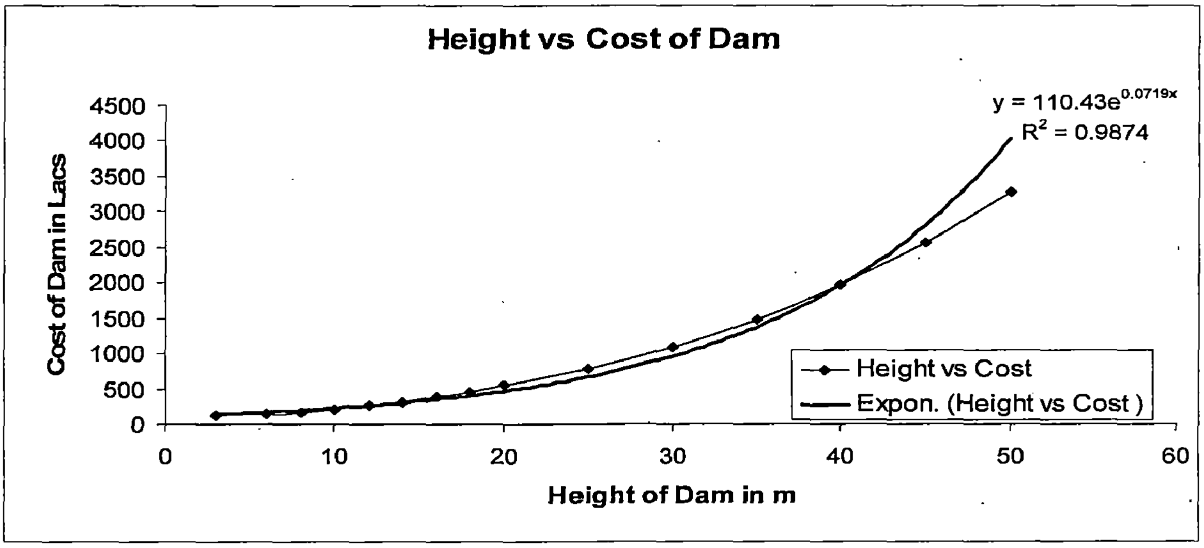


Fig. 5.11 Graph of height vs cost of dam of West Nayar Dam SHP

From the above figure,

The cost of the dam = $110.43*e^{(0.0719*H)}$

Where, H is the height of the dam and e = 2.72

$R^2 = 0.987$

Cost of Other Works

The general trend of cost of other works developed from the linear regression analysis by SPSS software for East Nayar SHP can be used for this project also. The relation is as follows:

$Cost = 17.74*Q^{0.82}*h^{0.3}$

Where, Q = Design Discharge in Cumecs

h = Net Head in Meter

Determination of Economical Optimal Installed Capacity

Optimal economical installed capacity and height of dam is computed after doing various trials in various alternatives using Excel Software. The following is the final computed table in which the minimum unit generation cost obtained.

Table 5.15 Calculated data for the optimization of unit generation cost of West Nayar Dam SHP

Height of Dam (m)	Discharge (Cumecs)	Power (KW)	Annual Energy (MU)	Cost of Dam	Cost of E/M Equipments	Other Cost	Total Cost (Lacs)	Unit Cost (Rs)
19	63.38	10656.53	14.0	433.26	1811.61	1288.75	3533.63	4.34
19	38.81	6526.28	13.0	433.26	1109.47	862.09	2404.82	3.18
19	36.79	6186.30	12.8	433.26	1051.67	825.08	2310.02	3.09
19	29.98	5040.24	12.0	433.26	856.84	697.48	1987.59	2.84
19	25.96	4364.30	11.4	433.26	741.93	619.80	1795.00	2.72
19	14.10	2370.81	9.0	433.26	403.04	375.78	1212.09	2.32
19	12.50	2102.45	8.6	433.26	357.42	340.53	1131.21	2.27
19	9.25	1555.65	7.7	433.26	264.46	266.01	963.73	2.16
19	8.87	1490.58	7.5	433.26	253.40	256.85	943.51	2.15
19	8.10	1362.46	7.3	433.26	231.62	238.60	903.48	2.14
19	**7.37**	**1238.87**	**7.0**	**433.26**	**210.61**	**220.70**	**864.57**	**2.13**
19	6.57	1104.19	6.6	433.26	187.71	200.83	821.80	2.14
19	6.32	1062.83	6.5	433.26	180.68	194.64	808.58	2.14
19	5.39	905.95	6.0	433.26	154.01	170.75	758.02	2.17

19	5.29	889.31	6.0	433.26	151.18	168.17	752.61	2.17
19	5.12	861.06	5.9	433.26	146.38	163.78	743.42	2.19
19	5.01	841.89	5.8	433.26	143.12	160.78	737.16	2.19
19	4.96	833.82	5.7	433.26	141.75	159.52	734.53	2.20
19	4.55	765.72	5.5	433.26	130.17	148.75	712.19	2.25
19	4.55	764.71	5.4	433.26	130.00	148.59	711.86	2.25
19	3.82	642.14	4.9	433.26	109.16	128.76	671.19	2.38
19	3.59	603.29	4.7	433.26	102.56	122.34	658.16	2.43
19	3.45	580.09	4.5	433.26	98.62	118.47	650.34	2.46
19	3.25	546.80	4.4	433.26	92.96	112.86	639.08	2.52
19	3.12	525.11	4.2	433.26	89.27	109.18	631.71	2.57
19	3.09	519.06	4.2	433.26	88.24	108.14	629.65	2.58
19	2.89	485.76	4.0	433.26	82.58	102.42	618.26	2.67
19	2.79	469.62	3.9	433.26	79.84	99.62	612.72	2.72
19	2.70	453.48	3.8	433.26	77.09	96.81	607.16	2.77
19	2.59	434.82	3.6	433.26	73.92	93.53	600.71	2.84
19	2.39	402.53	3.4	433.26	68.43	87.79	589.49	2.97
19	2.27	381.35	3.3	433.26	64.83	83.99	582.08	3.08
19	2.26	380.34	3.2	433.26	64.66	83.80	581.72	3.08
19	1.99	334.44	2.9	433.26	56.85	75.42	565.53	3.38
19	1.94	325.36	2.8	433.26	55.31	73.73	562.31	3.44
19	1.85	311.74	2.7	433.26	53.00	71.19	557.45	3.56

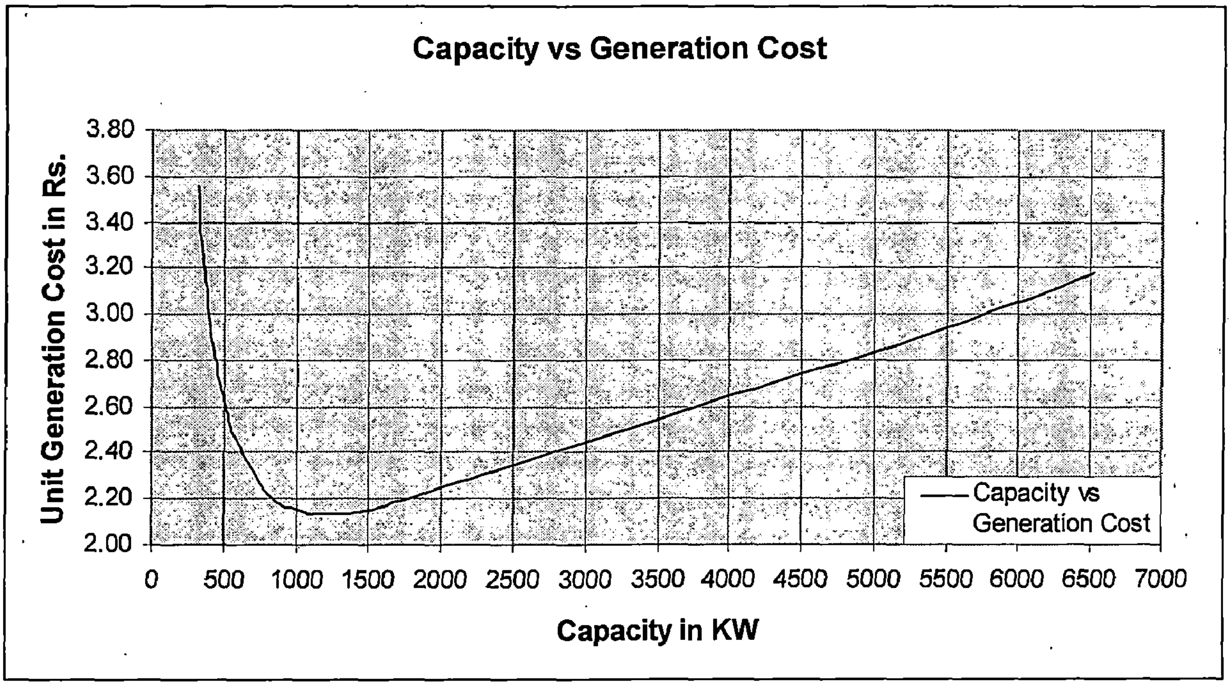


Fig. 5.12 Graph of capacity vs unit generation cost of West Nayar Dam SHP

The table 5.12 is final table of analysis and Rs. 2.13 can be considered optimal minimum unit generation cost. The optimal economic installed capacity becomes 1237.83 KW at minimum unit generation cost of 2.13 but this capacity is not practicable, thus we have to choose nearest suitable capacity, the installed capacity of 1250 KW can be chosen for execution of project. If we increase dam height to 20 m the minimum cost becomes Rs. 2.14 and it is more than Rs. 2.13. Similarly if we decrease the dam height to 18 m the minimum unit generation cost becomes Rs 2.13 and it is equal to Rs. 2.13 but we loose 0.24 MU/year. From the available data 90% dependable year's 90% flow is 2.04 cumecs, considering 2 sets of generating units and 50% load variation maximum design discharge should be 8.16 cumecs. For the installed capacity of 1250 KW design discharge becomes 8.0 cumecs which is less than 8.14 cumecs. Thus, 19 m dam height and 1250 KW installed capacity will be economically optimal. At the optimal economical installed capacity computed value of PLF is 64.5%, percentage profit at Rs 2.50 energy sale price is 0.16% and percentage annual available design discharge is 30.55%.

CONCLUSION AND RECOMMENDATION

The hydro power is renewable source of energy and widely used in the world. Mainly the small hydro is renewable, non-polluting and environmentally benign source of energy. The study focused on the run-of-river small hydropower schemes for the best selection of water conductor system and optimal economic selection of installed capacity. The study is done in the basis of existing operational small hydropower plants data of the Uttaranchal state of the India.

A. Conclusion and recommendation from the study of the water conductor system

From this study following conclusion can be drawn:

1 A water conductor of a small hydropower plant is a major component of civil works involving large chunk of land, cost and time – span for installation. Water conductor system is the life line of the system.

2 The construction cost is more for tunnel than the open channel and in average it is about 2.55 times, but in hilly area lot of problems occurred in the open channel after operation of the schemes results large amount of energy loss.

3 From the comparative study of the water conductor system in Chapter – 4, out of five cases in four cases the increased cost using tunnel as a water conductor system is found less than the energy losses amount due to the problem in open channel system considering 30 years life of the project. In the Chhirkila SHP the increased cost of project is more than the loss amount due to the problem in open Channel.

4 In Chapter – 4 the cost of projects is increased by 15.36% using tunnel as a water conductor system. Similarly in average energy loss amount becomes 28.63% of the project cost in 30 year life time taking 10% discount rate.

5 It is found that the tunnel is economical and reliable than the open channel in the case of run-of-river small hydropower plants for long run of projects, even the case of small design discharge.

6 In the planning and designing stage very careful concern towards the selection and design of major components is required, three out of five studied projects there are massive damage in intake structure and in each projects problem in open channel is common, in one SHP there is frequent problem in penstock pipe.

B. Conclusion and recommendation from the study of the optimal installed capacity

The installed capacity of the plant is depends on the discharge and the head, the optimal economical installed capacity is the maximum capacity at minimum generation cost. The cost of the SHPs governs by the various factor but main two variables are capacity and head.

From this study following conclusion can be drawn:

1 For the prediction of cost per unit capacity a relation between cost per unit capacity, capacity and head is developed from the collected data of the study projects by the regression analysis using SPSS software.

2 The developed relation is as:

Per unit capacity cost = $3.758 * \text{Capacity}^{-0.280} * \text{Head}^{0.012} * (1+r/100)^{2007-n}$ in Lacs

The relation is found to be suitable with the acceptable R^2 value of 0.862.

3 The cost of project for first year of operation is becomes 17.2% of the total project cost and the annual generation can be calculated from the relation $1800 * H * \left[n * Q_n + \sum_{i=n+1}^{36} Q_i \right]$ in KWh, and the first year unit generation cost is calculated from the relation $\dfrac{0.172\,C}{1800 * H * \left[n * Q_n + \sum_{i=n+1}^{36} Q_i \right]}$ in Rs/KWh

4 From the calculation of case study projects in Chapter – 5, for the optimal installed capacity plant load factor (PLF) varies from 57.78% to 78.55% and annual availability of the design discharge varies from 25.00% to 63.88%.

5 The generation cost of SHP power house located at dam toe is more than the SHP power house located at remotely.

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