OPTIMISATION OF LOW HEAD SMALL HYDRO POWER INSTALLATIONS

A THESIS

Submitted in partial fulfilment of the
requirements for the award of the degree
of
DOCTOR OF PHILOSOPHY

by

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DECEMBER, 2008

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"OPTIMISATION OF LOW HEAD SMALL HYDRO POWER INSTALLATIONS"** in partial fulfillment of the requirement for the award of degree of **Doctor of Philosophy** and submitted in **Alternate Hydro Energy Centre** of the Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during the period from August, 2002 to December, 2008 under the supervision of **Dr. R.P. Saini**, Associate Professor, Alternate Hydro Energy Centre and **Dr. C.S. Raghuvanshi**, Former Professor, Water Resources Development & Management Department.

The matter presented in this thesis has not been submitted by me anywhere for the award of any other degree of this or any other institute.

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ABSTRACT

Energy is one of the most important inputs in the process of development for a nation. With the growth of industrialization, there is increase in the demand of energy for trade and commerce on the one hand and demand of transport sector for energy on the other. As regards the primary sector of Indian economy i.e. agriculture and allied sectors are concerned, the demand for electricity and Diesel consumption have also increased on account of increased intensive activities. The domestic energy demand for meeting fuel and lighting requirements has also increased during the past three decades on account of rapid increase in population and improvement in the living standard of the people. After independence large hydro power projects have been executed in India, some of them are still under construction and some have been planned for future. Hydro power stations have inherent ability for instantaneous starting, stopping and load variations and also help in improving reliability of power system.

However, economic and environmental factors seriously restrict the exploitation of hydro power through conventional large capacity projects. Due to these constraints renewable energy resources such as solar, wind, biomass and small hydro power (SHP), which India has in abundance are being considered to meet the energy demand in environmentally benign manner. Among all the renewable energy sources, small hydro power which is defined by plant capacity up to 25 MW is considered as one of the most promising source. In India, it has been estimated that a potential of 15,000 MW exists in small hydro out of which only 2,045 MW has been installed so far.

Large potential of untapped hydro energy is available in flowing streams, river slopes, canal falls, drainage works and irrigation and water supply dams. Most of these hydro power sites come under low head range i.e. from 3 to 20 m. High head and medium head small hydro power schemes, are mainly run of river schemes. These

schemes are site specific and their installation cost is governed by the cost of civil works. However, low head schemes are mainly canal based schemes. Run of river in low terrains and dam toe schemes also considered under low head schemes.

Literature survey reveals that a number of studies have been carried out to optimise various components of small hydro power specifically. In low head SHP schemes relatively large discharges are handled, thus size of machines become bigger. The cost of such projects depend on both civil works as well as electro-mechanical equipment. It is therefore, there is a scope for cost optimisation for such schemes. However, no study was reported so far, for cost optimisation of low head small hydro power installations.

Keeping this in view the present study is carried out covering the following aspects ;

(i) Study of various components of low head small hydro power schemes.

(ii) Carry out the sizing of various components under civil works and selection of electro-mechanical equipment for different schemes.

(iii) Computation of cost of different components, based on determined sizes for low head small hydro power schemes.

(iv) Development of correlations for cost of various components for different schemes under different conditions in order to determine the total installation cost.

(v) Financial analysis for cost optimisation of different schemes based on developed correlations for cost.

In order to achieve the above objectives, a detailed study of different SHP schemes and their components has been carried out. There are three types of schemes under low head hydro power i.e. (i) canal based (ii) run of river and (iii) dam toe. These schemes have two basic components i.e. civil works and electro-mechanical equipment.

Most of the components are similar in different type of schemes. Out of these, hydro turbines play an important role which can be said as a heart of small hydro power station. The type and specification of other components of low head SHP installations depend upon the type of hydro turbines as it affects civil works on one side and electrical equipment on other side.

In the present study, an attempt has been made to develop a methodology for assessment of cost of the project for determination of its techno-economical viability before undertaking detailed investigations, so that only feasible projects are undertaken for detailed investigations and implementation. The cost of SHP schemes is site specific, based on type of scheme, type of components, land and infrastructrual facilities required for execution. The components considered under civil works, were intake, channel, desilting tank, forebay, penstock and powerhouse building. Various alternatives under different schemes such as location of power house, type of soil, type of turbine and generator and number of generating units have been considered for cost analysis

The sizes of civil works have been determined based on discharge carrying capacity which is based on head and capacity of the scheme. The head range is considered from 3 to 20 m and the unit size from 1 MW to 5 MW with total installed capacity upto 25 MW for electro-mechanical equipment, turbine and generator are considered as major equipment. Axial flow turbines i.e. tubular, vertical and bulb type and type of generator as synchronous and induction have been considered under the present study. Runner diameter and speed of the turbine have also been determined based on head and capacity of the scheme.

Based on the correlations developed, installation cost (total project cost) has been computed for different low head SHP schemes. The total project cost includes cost of civil works, cost of electro-mechanical equipment, cost of miscellaneous items and other indirect costs. Establishment related cost including designs, audit and account, indirect charges, tools and plants, communication expenses, preliminary expenses on report preparation, survey and investigations and cost of land were considered under miscellaneous and indirect costs. In order to validate the correlation developed for installation cost a comparison has been made with the actual cost data of recently developed plants obtained from the developers. Maximum deviation in cost has been found as ±12% for canal based schemes, ±12.5 % in case of run of river schemes and ±11% for dam toe schemes. The deviation in the costs is considered within reasonable limits.

It has been found that the electro-mechanical equipment constitute major part in the cost of low head SHP schemes in canal based schemes. As a typical example, cost of electro-mechanical equipment is found to be 54.5% for a plant having installed capacity of 2,000 kW at 3 m head and 50.3% at 20 m head. The similar trend has been observed in case of dam toe schemes. However, in case of run of river scheme, cost of civil works constitutes major part in total installation cost in higher range of head.

Financial analysis has been carried to determine the optimum layout under different type of schemes based on type of turbines, type of generators and plant load factor. Different layouts were evaluated for cost optimisation based on installation cost, generation cost, benefits cost (B-C) ratio, net present value (NPV) and financial internal rate of return (FIRR).

It is found that these financial parameters follow the same trend for the optimum layout, leading International financial institutions (World Bank, Asian development bank) evaluate development projects based on FIRR. Thus FIRR has been considered as financial parameter to determine the optimum layout.

For a typical canal based scheme of 2,000 kW capacity at 3 m head, tubular turbine with propeller runner and coupled with induction generator is found optimum layout as it has minimum installation cost and maximum FIRR value at 90% load factor. However, for load factors 60%, 70% and 80%, tubular turbine having semi Kaplan runner coupled with induction generator results in the maximum FIRR values which is considered as optimum layout. At load factor 50%, bulb turbine with Kaplan runner coupled with induction generator is found to be the optimum layout as it has maximum FIRR. It has been found that low head SHP layouts under run of river and dam toe schemes also follow the similar trend for optimum layouts.

Methodology for determination of optimum installation based on financial parameters has been employed to compare different alternatives, which can be used by developers to plan investment in low head SHP schemes. The financers may also use these cost correlations for appraisal of such schemes for financing.

ACKNOWELEDGEMENTS

It is indeed a great privilege to express my sincere thanks and gratitude to my superviors **Dr. R.P. Saini**, Associate Professor, Alternate Hydro Energy Centre and **Dr. C.S. Raghuvanshi**, Former Professor, Water Resources Development and Management Department, Indian Institute of Technology Roorkee, Roorkee for their tireless academic and moral support to carry out the present work. Their expert guidance, timely help, constructive criticism and encouragement brought the thesis in the present form.

I express my sincere thanks to Prof. J.D. Sharma, Chairman, Centre Research Committee, Prof. M.K. Mittal and Prof. N.M. Bhandari of Civil Engineering Department and Dr. M.P. Sharma of Alternate Hydro Energy Centre for being members of my research committee in time to time reviewing the work and providing valuable suggestions.

Author is highly thankful to Dr. Arun Kumar, Head, Alternate Hydro Energy Centre, IIT Roorkee for his continuous encouragement, motivation and providing all necessary facilities in the centre.

I wish to express my sincere thanks to Prof. Bharat Singh, Former Vice Chancellor, University of Roorkee (now IIT Roorkee), Prof. O.D. Thapar, Foremer Director, Alternate Hydro Energy Centre and Shri D.K. Agarwal, Foremer Engineer in Chief, U.P. Irrigation for their valuable suggestions and blessings.

I express my heartful thanks to the family of my supervisors Dr. R.P. Saini and Dr. C.S. Raghuvanshi for their kind cooperation and moral support.

I am also thankful to my all collegues for their coopration all through the work. Special thanks are due to Shri Deepak Kapil, Shri Ram Baran, Shri R.K. Joshi, Shri Sushil Kumar, Shri Amit Sharma for extending assistant in drawing work and typing the manuscript of this study.

A great sense of gratitude is due to my father Shri Sadhu Ram and mother Mrs. Kusum Lata for their continueous encouragement and blessings.

I express my special thanks and great appreciations to my wife Sunita and son Mohit for bearing all sorts of incovenience and hardships during my involvement in this work.

Above all author bestows himself to Almighty God and falls short of words to express thanks for blessings with an opportunity to carry out the present work.

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NOMENCLATURE

A	Area of cross section, m^2
A.C.	Alternating current, Ampere
A_s	Dimension, m (Ref. Fig.3.11)
a_1-a_{15}	Coefficients (Ref. Eq. 5.3-5.
B	Dimension, m (Ref. Fig.3.18)
B-C	Benefit-cost
B_d	Dimension, m (Ref. Fig.3.12)
B_e	Water way width of weir, m
B_f	Width of forebay, m
B_s	Dimension, m (Ref. Fig.3.11)
C	Total cost per kW, Rs.
C_a	Annual cost, Rs.
C_d	Depreciation cost, Rs.
C_g	Generation cost, Rs.
C_i	Interest cost, Rs.
C_s	Dimension, m (Ref. Fig.3.11)
C_1	Cost per kW of diversion channel, Rs.
C_2	Cost per kW of spillway, Rs.
C_3, C_9	Cost per kW of power house building, Rs.
C_4	Cost per kW of diversion weir, Rs.
C_5	Cost per kW of power channel, Rs.
C_6	Cost per kW of desilting tank, Rs.
C_7	Cost per kW of forebay, Rs.
C_8	Cost per kW of penstock, Rs.
C_{10}	Cost per kW of tail race channel, Rs.
C_{11}	Cost per kW of intake, Rs.

C_{12}	Cost per kW of turbines with governing system, Rs.
C_{13}	Cost per kW of generator with excitation system, Rs.
C_{14}	Cost per kW of electrical and mechanical auxiliary, Rs.
C_{15}	Cost per kW of transformer & switchyard equipment, Rs.
C_c	Cost per kW of civil works, Rs.
$C_{e\&m}$	Cost per kW of electro-mechanical equipment, Rs.
C_{mc}	Cost per kW of Miscellaneous items, Rs.
C_{tc}, C_{tr}, C_{td}	Installation cost per kW, Rs.
CFi	Cash flow in ith year starting with initial investment
d	Discount rate
d	Dimension, m (Ref. Eq. 3.11 and Fig.3.19)
d_T	Water depth of desilting tank, m
D	Runner diameter, m
D.C.	Direct current, Ampere
D_s	Dimension, m (Ref. Fig.3.11)
E	Annual energy generation in kWh
E_s	Dimension, m (Ref. Fig.3.11)
e	Joint efficiency
FIRR	Financial internal rate of return, %
F_1	Froude number
F_s	Dimension, m (Ref. Fig.3.11)
f	Frequency in Hz
f_e	Stress in steel, N/mm^2
f_s	Allowable stress in steel, N/mm^2
G_s	Dimension, m (Ref. Fig.3.11)
GW	Gigawatt
g	Acceleration due to gravity (m/s^2)
H	Rated net head in meter
H_1	Dimension, m (Ref. Fig.3.18)

H_a	Atmospheric pressure head, m
H_θ	Vapour pressure, m
H_c	Head over spillway crest, m
H_d	Dimension, m (Ref. Fig.3.12)
H_f	Dimension, m (Ref. Fig.3.18)
H_s	Dimension, m (Ref. Fig.3.11)
h	Water depth in channel, m
kW	Kilowatt
kWh	Kilowatt hour
L	Length of spillway crest, m
L_l	Length of basin, m
L_d	Dimension, m (Ref. Fig.3.12)
L_f	Length of forebay, m
L_T	Length of desilting tank
M_s	Dimension, m (Ref. Fig.3.11)
MW	Megawatt
m	Meter
NPV	Net present value, Rs.
n	Last year of cash flow
n_g	Slip speed
N	Rotational speed of turbine in revolution per minute
N_s	Specific speed
O&M	Operation and maintenance
P	Rated output power, kW
PCC	Plain cement concrete
P_u	Unit output power, kW
p	Number of poles
P_L	Load factor
PV	Present value

Q	Discharge, m^3/s
Q_f	Flood discharge, m^3/s
Q_s	Design discharge for desilting tank, m^3/s
q	Discharge intensity, m^2/s
R	Hydraulic radius, m
RCC	Reinforced cement concrete
Rs	Indian rupees
Rs/kWh	Rupees per kilowatt hour
S	Slip
S_n	Salvage value
S_l	Longitudinal slope of channel, degree
s	Side slope of channel
SHP	Small hydropower
TWh	Terawatt hour
t	Penstock thickness, mm
V	Velocity, m/s
V_1	Free fall velocity, m/s
V_f	Fall velocity, m/s
V_h	Horizontal velocity, m/s
$x_1 \ldots x_{15}$	Coefficients (Ref. Eq. 5.3-5.17)
$y_1 \ldots y_{15}$	Coefficients (Ref. Eq. 5.3-5.17)
Z	Objective function (Ref. Eq.6.6)
$z_1 \ldots z_6$	Variable parameters (Ref. Eq.6.6)

Greek letters

θ_3	Velocity ratio at discharge diameter of runner
η_g	Efficiency of generator
η_T	Efficiency of turbine
σ	Thoma coefficient

CHAPTER-1

INTRODUCTION AND LITERATURE REVIEW

1.1 GENERAL

The development of infrastructure is an important factor to sustain economic growth and power sector is one of the most important constituents of infrastructure. The achievement of energy security necessitates diversification of the energy resources and the sources of their supply, as well as measures for conservation of energy. Energy is one of the most important inputs in the process of development for a nation. With the growth of industrialization there is an increase in the demand of energy for trade and commerce on the one hand and demand of transport sector for energy on the other. The modern modes of transportation are, however, more energy consuming. As regards the primary sector of Indian economy i.e. agriculture and allied sectors, are concerned, the demand for electricity and Diesel consumption have also increased on account of increased intensive activities. The domestic energy demand for meeting fuel and lighting requirement has also increased during the past three decades on account of rapid increase in population and improvement in the living standard of the people.

The oil embargo of 1972 triggered the world attention to looking for alternative energy sources. So far conventional sources of energy like thermal, hydro (large hydro) and nuclear were considered the main sources of energy generation. Fortunately, India is blessed with the third largest coal supplies in the world, although not of the best quality, but it can not be used indefinitely. The impact of the energy crisis is particularly felt in developing countries like India, where an ever-increasing percentage of national budgets earmarked for development are diverted for the purchase of petroleum products. After independence, large hydro power projects have been executed, some of them are still under construction and some have been planned for future. The ideal hydro thermal mix should be in the ratio of 40:60 [19]. Because of the imbalance in the hydel thermal mix in India, many thermal power stations are required to close down during off peak hours. Hydro power stations have inherent ability for instantaneous starting, stopping, load variations etc. and help in improving reliability of power system.

1.2 HYDRO POWER – GLOBAL SCENARIO

Hydro power is a mature technology throughout the world and currently contributes about 6% of total world energy production and 16% of total world electricity generation. Global Population is projected to grow by 1% per year on an average from an estimated 6.5 billion in 2006 to 8.2 billion in 2030. Combing population and economy growth, there is an average increase in per capita income of 2.4% per annum, from US$ 9253 in 2004 to US$ 17,196 in 2030 (projected). Global primary energy demand is projected to increase by 45% between 2006 and 2030 at an average rate of 1.6% per year. Over 70% of this increase comes from developing countries [1]. The world's remaining economically exploitable energy sources are adequate to meet the projected demand. Hydro power continues to expand mostly in developing countries. Globally less than a third of economic potential has been exploited [2]. Worldwide total hydro power capacity in operation is 848 GW with annual generation of 3045 TWh/year. The contribution of small hydro power (SHP) in total hydro power installed capacity is about 5% with 34,000 MW. Presently, hydro power is contributing more than 50 percent of electricity supply in about 50 countries. There is about 157 GW of hydro power installation under construction in 106 countries [3].

As per the World Atlas, 2008 [3] hydro power, large and small has been important source of energy in all European countries possessing water potentials With the invention of sophisticated turbines in the twentieth century, small hydro power plants have become the main source of electrical energy. This development continued till about 1960 when the national grid was extended. The grid supply was cheaper than the operation and maintenance of isolated small hydro power plants. The situation was changed after the 1974 oil stock. Due to the oil crisis as well as protest against nuclear power, European Union outlined the strategy and action plan to promote renewable energy sources in Europe in 1997. They targeted 12% share of renewable energy in the total energy by the year 2010 against 6% in 1996. Small hydro power accounts for approximately 7% of total hydro power in Europe. Presently total installed capacity in 30 European countries is 12,600 MW, generating 50,000 GWh under small hydro power. The leading countries are Italy, Germany, Spain, Sweden, Norway, Austria and Switzerland, which combine 86% of SHP production [4].

There has been a small but steady increase in hydro power capacity in South America. Brazil is the leading hydro power generating country in South America. Canada is the leading country in hydro power generation in North America emerging as "energy super power". Canada is producing 60 percent electricity from hydro power.

In Australia 140 MW Bogong hydro power project is likely to complete in 2009. New Zealand is planning 240 MW Lower Waitilki hydro power project.

China has commissioned three Gorges hydro power plant largest in the world with capacity 18,200 MW. It is the world's largest source of commercially traded renewable energy. Status of world hydro power potential and development is given in Table 1.1 [3].

Table 1.1 World hydro potential and development [3]

S. No.	Continent/Country	Installed capacity (GW)	Generation (GWh/year)	Under construction (GW)	Planned capacity (GW)
1.	Africa	21.49	94.12	7.49	84.05
2.	Asia	329.74	1107.62	130.48	241.70
3.	Australia	13.47	40.26	0.16	2.49
4.	Europe	178.81	531.00	2.41	13.82
5.	North & Central America	167.04	664.24	5.94	43.65
6.	South America	137.91	607.58	11.33	75.56
	Total	**848.46**	**3044.82**	**157.81**	**461.27**

1.3 HYDRO POWER POTENTIAL IN INDIA

The present installed capacity of power generation in India is 127,055 MW; out of which hydro power is 26%, thermal is 66%, renewable is 5% and nuclear is 3%. The country is still short of power. The shortage is 7% on an average and 11.2% at the time of peaking as per the Sectoral Report, 2007 [5]. The scenario of energy generation from different sources and consumption during years 1990-2002 is as shown in Fig.1.1.

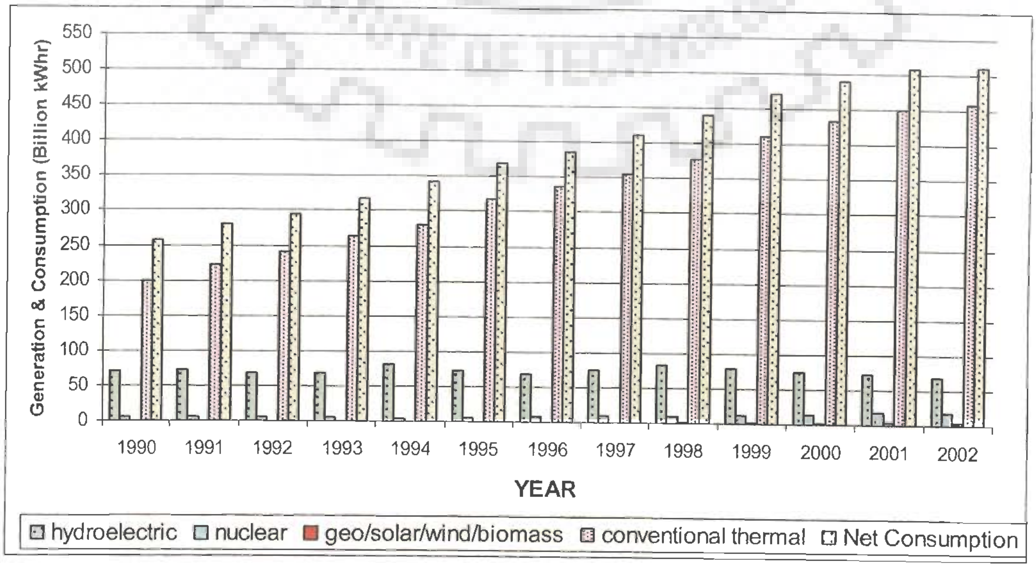

Fig.1.1 Energy generation and consumption in India [6]

India started with total installed capacity of 1362 MW at 1500 sites and per capita consumption of 14 kWh in 1947 when it got its independence. The hydro power capacity increased from 508 MW in 1947 to 20,366 MW in 1994. India's largest hydro power station Nathpa Jhakri for the total installed capacity of 1500 MW and Sardar Sarover of 1450 MW are now complete and in operation [7].

For the purpose of hydro power potential assessment, India is divided into six major river systems. These are Indus, Brahmputra, Ganga, Central Indian River system, East flowing rivers and west flowing rivers as shown in Fig. 1.2. These river systems are further divided into 49 basins. A total potential of 148,701 MW has been estimated at 845 hydro power sites. The exploitable potential is estimated at 60% load factor which comes out to be 84,044 MW as given in Table 1.2. It will generate 442 billion units of electricity per year when fully developed [5].

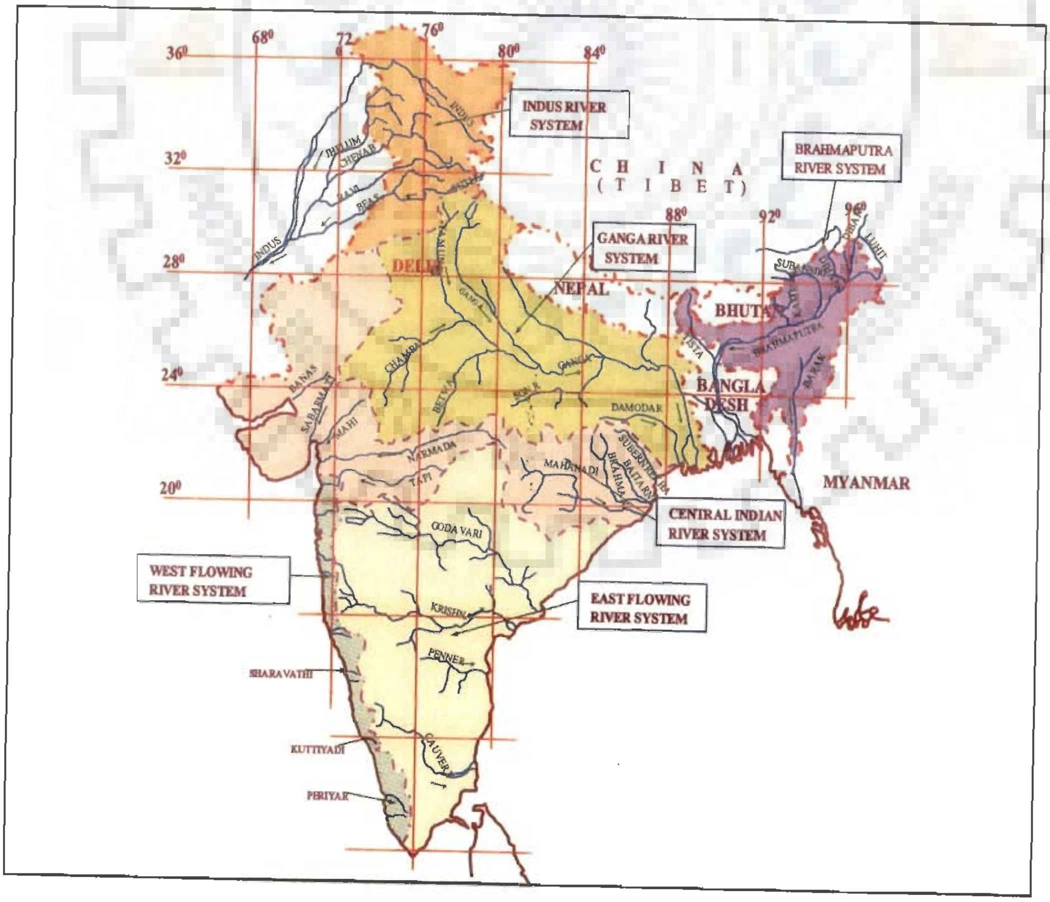

Fig.1.2 Major river systems of India [5]

Table 1.2 River basin-wise hydro power potential in India [5]

S. No.	River system	Hydro power potential (MW)	
		Identified	Exploitable at 60% load factor
1.	Indus	33832	19988
2.	Ganga	20711	10715
3.	Central Indian	4152	2740
4.	West Flowing	9430	6149
5.	East Flowing	14511	9532
6.	Brahmaputra	66065	34920
	Total	**148,701**	**84,044**

Hydro energy has several advantages in comparison to other forms of energy. It is renewable, non polluting, reliable, economic, and in particular it is best adapted for taking peak loads. India has quite large hydro resources. The growth of power sector in India from 1950 onwards is given in Table 1.3. One of the major reasons for shift from hydro to thermal has been the relatively long gestation period of the former. It is a fact that some of the hydro-projects in India have taken inordinately long times. Partly it is inherent in the nature of works involved - dams, tunnels, power houses-underground or in deep excavation, pose some of the most difficult challenges to civil engineering construction. The main environmental factors associated with large hydro power are ; (i) Changes in river regime, (ii) Possibility of induced tremors, (iii) Decomposition of organic matter, (iv) Submergence and impact on flora and fauna, (v) Impact on health and (vi) Rehabilitation of displaced population which is a major social and human problem.

Table 1.3 Growth of power sector in India [8]

S. No.	Year	Thermal	Hydro	Nuclear	Total	Proportion of hydro (%)
1.	1950	1153	559	-	1712	32.7
2.	1960	2736	1417	-	4653	30.5
3.	1970	7906	6383	420	14709	43.4
4.	1980	17562	11791	860	30213	39
5.	1990	43764	18307	1565	63638	28.8
6.	2001	73273	25574	2860	101708*	25.1
7.	2002	76057	26269	2720	105046	25.0
8.	2004	80457	29507	2720	112864	26.1
9.	2006	89962	33193	3900	127056	26.1
10.	2007	90173	33600	3900	127673	27.3

1.4 SMALL HYDRO POWER

Small hydro power (SHP) has already proved as a major contributor to electrification in developing countries with over 50 million house holds and 60,000 small enterprises served by small hydro at village level as well as feeding power to grid networks. About 80% of the world's population lives in developing countries but these countries consume only 20% of global commercial energy. In the developing countries, China is the leading country having 35,000 MW installed capacity through 43,000 SHP stations. The growth rate in Chinese SHP sector is about 9% per year. Other developing countries with significant SHP capacity are India (2045 MW), Brazil (1932 MW), Peru (237 MW), Malaysia and Pakistan (both 107 MW), Bolivia (104 MW), Vietnam (70 MW). The DR Congo (65 MW), Srilanka (114 MW) and Papua Na Guines (20 MW) while Russia and Central Asian States also have large installed capacity (totaling 639 MW). In the last 30 years, China, India, Nepal, Vietnam and many South American Countries have developed large number of micro hydro projects to provide electricity to rural and remote areas [3, 9].

Hydro power stations are the best choice for meeting the peak demand. However, economic and environmental factors seriously restrict the exploitation of hydro power through conventional large capacity projects. The inherent drawbacks associated with large hydro are; large gestation period, large area along with vegetation has to be submerged, shifting of people etc. from the sites. Political and environmental implications have made planners to think for some other alternative to the large hydro. For nuclear power plants also there is a problem of getting proper fuel, processing and safety from radiations. In addition, global warming caused largely by green house gas emissions from fossil fuel generating systems is also a major concern. To overcome the problems associated with conventional sources of energy, most countries including India have shifted their focus to develop non-conventional renewable sources of energy as solar energy, wind, geothermal energy, biomass and small hydro power [10, 11, 12]. About 11,272 MW of power generating capacity based on renewable energy sources has been installed in the country so far against an estimated potential of 84,776 MW. This constitutes about 8.8% of the total installed capacity [13]. Among all the renewable energy sources, small hydro power is considered as one of the most promising source. Energy from small hydro is probably the oldest and yet, the most reliable of all renewable energy sources. In India, the ancestors have used this energy for grinding food grains for centuries; with the result that expertise in this sector today is at par with the most developed nations in the world. Small hydro power development can reduce the load on conventional sources of energy. Technology for small hydro development is mature and proven. Civil works and installation of equipment involve simple processes which offer ample employment opportunities to local people and use locally available material. Gestation period is also short.

Various definitions of "small" exist with respect to hydro power and this depicts the problem of determining the present capacity and future prospects. There is a general tendency all over the world to define small hydro by installed capacity of the power plant. Range of small hydro power defined by different countries is given in Table 1.4.

Table 1.4 Range of small hydro power (SHP) defined by different countries [14]

S. No.	Country	Installed capacity (MW)
1.	Australia	≤ 20
2.	China	≤ 25
3.	Colombia	≤ 20
4.	France	≤ 8
5.	India	≤ 25
6.	Italy	≤ 3
7.	New Zealand	≤ 50
8.	Phillipines	≤ 50
9.	Sweden	≤ 15
10.	Turkey	≤ 50
11.	UK (NFFO)	≤ 5
12.	UNIDO	≤ 10
13.	USA	≤ 30

In India, small hydro schemes are further classified into different categories based on capacity as given in Table 1.5.

Table 1.5 Classification of SHP based on capacity in India [15, 16]

S. No.	Type of hydro power station	Capacity (kW)
1.	Pico	Upto 5
2.	Micro	Upto 100
3.	Mini	101 to 2000
4.	Small	2001 to 25000

Though in the initial phases of the hydro-electric production, micro, mini and small hydroelectrical stations played a crucial role, the economy of scale spurred the growth of medium and large hydroelectric stations, evidently at the cost of the former.

1.5 DEVELOPMENT OF SMALL HYDRO POWER IN INDIA

The pace of development of small scale hydro power in India started almost simultaneously with the world's first hydro-electric installation in 1882 (112 kW at Appleton, Wisconsin, USA). The 130 KW installation in Sidrapong (Darjeeling) in the year 1897 was the first small hydro power installation in India. The other installations were Shivasamundram at Mysore (2000 kW), Bhoorisingh in Chamba (40 kW) in 1902, Galogi at Mussoorie (3000 kW) in 1907, Jubbal (50 kW) in 1911 and Chhaba (1750 kW) at Shimla in 1913. These plants were used primarily for lighting in important towns and are still working. The first low head power plant was built as far back as 1912-1914 near Amritsar, on the Main Branch Lower (MBL) R.D. 101,000 of the Upper Bari Doab Canal System. There were 4 turbines installed on a drop of 3 m with flow of 30 m^3/s and power produced was 525 kW [17]. Some small hydro plants were installed on the upper Ganga canal between 1930 and 1950 and on the Kosi and Gandak canals in the seventies. These installations used large discharges and small heads on canal drops. These small hydro plants came into existence before the proliferation of transmission lines.

A firm footing for the development of small hydro power in India was seen in 1990, when a comprehensive plan for exploitation of 10,000 MW was prepared at central government level. Government has initiated developing demonstration projects with new technical concepts to harness potential in hills as well as on canals.

It was in 1963, when the hydro power had attained the maximum share of 50.62% in the total installed capacity of power generation in the Country. While there is a continues increase in the installed capacity of hydro power stations, the share of hydro power has been reduced to only 25% in 1998. In recent years greater attention is being paid all over the world on the implementation of small hydro electric schemes, in light of their minimal impact on the environment, less initial capital investment and more rapid implementation. Their relevance is being realised particularly in remote areas where there is no electricity or only a weak grid. In India, it has been estimated that a potential of 15,000 MW exists in small hydro. About 5403 potential sites each having capacity upto 25 MW have been identified in various parts of the country with a total potential of 14,305 MW. Already 611 small hydro schemes with a total installed capacity of nearly 2045 MW are under operation and 225 schemes with another 669 MW are under various stages of implementation [13]. Statewise details of small hydro power sites (upto 25 MW capacity) identified, power stations set up and ongoing projects as on March 31, 2007 is given below in Table 1.6 [13, 18]:

1.6 TYPES OF SMALL HYDRO POWER SCHEMES

Small hydro power projects in India can be broadly categorized in two types as ; (i) Small hydro power projects in the hills and (ii) Small hydro power projects in the plains. Hill based small hydro power projects are mostly of medium/high head utilizing small discharges. In these schemes, water is diverted by the weir and intake, conveyed to the forebay, at the entrance to the penstock. The penstock conveys the water to the turbines in the power house to generate electricity. These schemes are further categorized as run of river schemes and dam based schemes. Small hydro power projects in the plains and other region of the country which utilize water regulated for other purposes like irrigation/drinking water canals, small dams etc. are usually of low head utilizing large discharges. These schemes are categorized as canal based schemes and dam toe schemes [19, 20, 21]. Broadly, the small hydro power schemes are categorized as run of river, dam based and canal based scheme.

Table 1.6 State wise details of small hydro power development in India [13, 18]

S. No.	State	Projects identified		Projects set up		Projects ongoing	
		Number	Capacity (MW)	Number	Capacity (MW)	Number	Capacity (MW)
1	Andhra Pradesh	489	552	58	179	11	18
2	Arunachal Pradesh	566	1333	68	45	56	42
3	Assam	60	214	3	2	4	15
4	Bihar	94	214	7	50	9	8
5	Chhattisgarh	164	707	5	18	1	1
6	Goa	9	9	1	0	--	--
7	Gujarat	292	197	2	7	--	--
8	Harayana	33	110	5	63	1	6
9	Himachal Pradesh	547	2268	62	147	16	72
10	Jammu & Kashmir	246	1412	32	112	5	6
11	Jharkhand	103	209	6	4	8	35
12	Karnataka	128	643	72	464	17	92
13	Kerala	247	708	16	98	5	40
14	Madhya Pradesh	99	401	9	51	5	40
15	Maharashtra	253	763	29	211	5	31
16	Manipur	113	109	8	5	3	3
17	Meghalaya	102	230	4	31	3	2
18	Mizoram	75	167	16	17	3	16
19	Nagaland	99	197	10	29	4	4
20	Orissa	222	295	6	7	8	61
21	Punjab	234	390	29	124	-	-
22	Rajasthan	67	63	10	24	-	-
23	Sikkim	91	266	14	39	4	13
24	Tamil Nadu	176	499	14	90	4	13
25	Tripura	13	47	3	16	-	-
26	Uttar Pradesh	220	292	9	25	-	-
27	Uttaranchal	458	1609	89	83	37	74
28	West Bengal	203	394	23	98	16	79
29	A & N Islands	12	8	1	5	-	-
	Total	**5,403**	**14,305**	**611**	**2045**	**225**	**669**

1.6.1 Run of River Schemes

Run of river small hydro power schemes are those, in which water is diverted from a stream without creating any storage in the river. In these schemes, power is generated from flowing water and available head. The output of a run of river plant is subject to the instantaneous flow of the stream [22]. The layout of a typical run of river scheme is shown in Fig.1.3.

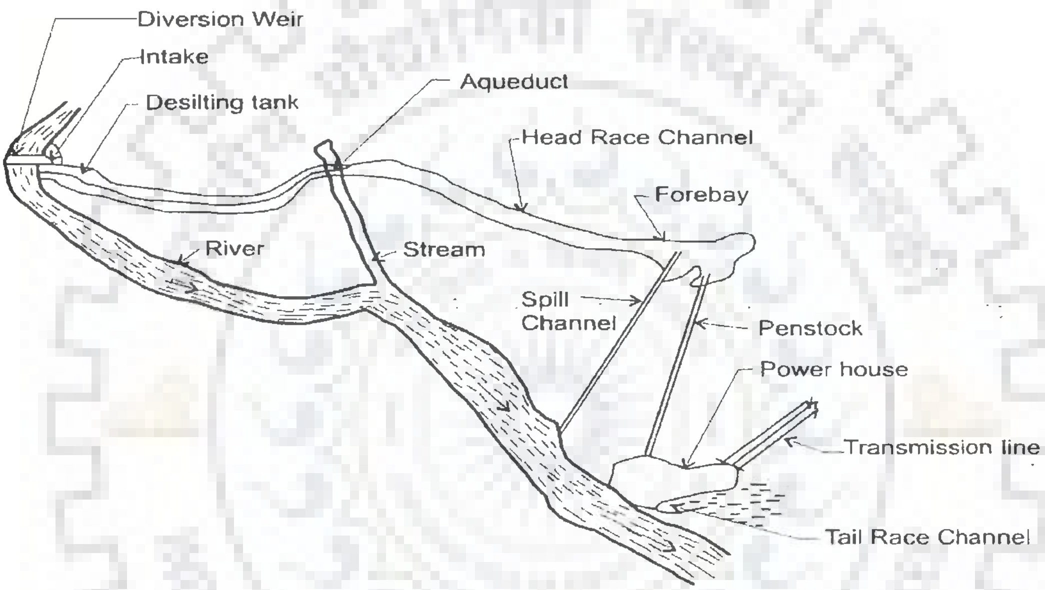

Fig. 1.3 Layout of a typical run of river scheme [20]

1.6.2 Canal Based Schemes

Canal based small hydro power scheme is one which is planned to generate power by utilizing the fall and discharge available in the canal. Falls in the canals are available due to difference in canal slope and topographical slope. These schemes may be planned in the canal itself or in the bye-pass channel. A typical layout of canal based small hydro power scheme is shown in Fig.1.4.

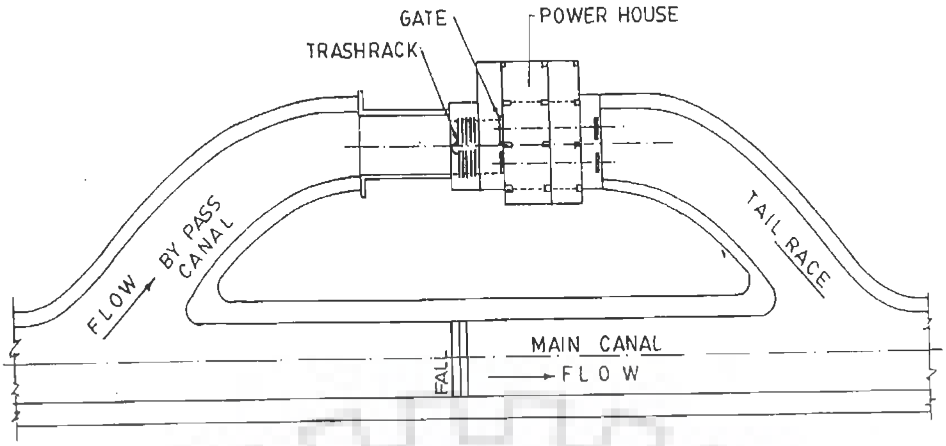

Fig. 1.4 Layout of a typical canal based scheme [19]

1.6.3 Dam Toe Schemes

Dam based schemes are those in which water is stored in the river by constructing a dam across the river for the desired use like irrigation, drinking, flood control. Power is generated at the time of release of water from the dam for the derived use of water. Dam toe power houses can be easily extended at existing dams where power generation was not planned earlier. In dam toe scheme, the intake system forms the part of the main dam. Water is conveyed to the turbine through penstocks installed directly through the body of the dam. The typical layout of dam based small hydro power scheme is shown in Fig. 1.5.

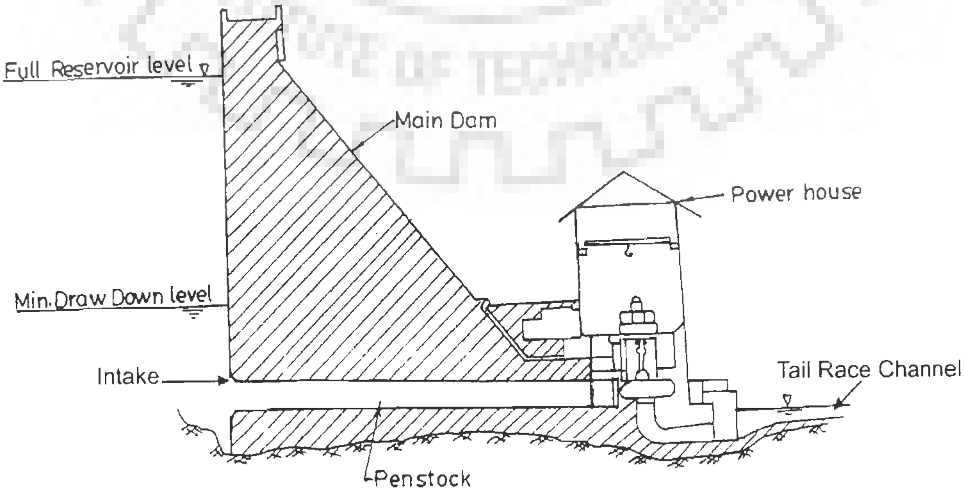

Fig. 1.5 Layout of a typical dam toe scheme [19]

1.7 LOW HEAD SMALL HYDRO POWER SCHEMES

Small hydro power sites are classified into three categories by head as low, medium or high, each category requires different design criteria. Under a head range from 3 m to 20 m, SHP sites are considered as low head SHP schemes. A large number of sites identified for small hydro development normally in irrigation works are in the low-head category. Medium head sites are having head range from 20 to 60 m, while above 60 m head sites are considered as high head schemes. These suggested limits are not rigid but are merely a means of categorizing the sites. Low head small hydro power (SHP) schemes up to 20 m head can be of run of river, dam based, however most of these sites are canal based schemes [23, 24].

The importance of developing canal falls as source of hydro power generation in India has been well acknowledged. A number of canal based hydro power stations have been commissioned and more are in different stages of execution/ investigation. The canal fall hydro power schemes are blessed with the advantages of small gestation periods, easy accessibility and are devoid of submergence; resettlement and other problems of environment and ecology.

Out of 5403 identified SHP sites, 4276 sites in different states of India with an aggregate capacity of 9393 MW have been classified in different categories such as run of river, dam toe and canal based schemes as given in Table 1.7. It is seen that there is a large potential available for development under canal based and dam toe sites.

Table 1.7 Identified SHP sites in India [5]

S. No.	State	Run of river		Dam based		Canal based		Total	
		Number	Capacity (MW)	Number	Capacity (MW)	Number	Capacity (MW)	Number	Capacity (MW)
1	Andhra Pradesh	1	-	3	6	373	244	377	250
2	Arunachal Pradesh	443	1051	-	-	-	-	443	1051
3	Assam	37	115	-	-	3	5	40	120
4	Bihar	2	-	5	8	54	93	61	101
5	Chhattisgarh	75	413	32	45	24	24	131	482
6	Goa	-	-	3	3	1	2	4	5
7	Gujarat	22	44	1	14	264	129	287	187
8	Harayana	-	-	-	-	22	30	22	30
9	Himachal Pradesh	281	1270	-	-	-	-	281	1270
10	Jammu & Kashmir	173	865	-	-	-	-	173	865
11	Jharkhand	66	81	1	1	22	88	89	170
12	Karnataka	30	136	14	30	144	285	188	452
13	Kerala	185	285	10	83	3	5	198	373
14	Madhya Pradesh	20	24	26	136	23	32	69	192
15	Maharashtra	76	69	31	179	96	143	203	390
16	Manipur	99	92	-	-	-	-	99	92
17	Meghalaya	90	197	-	-	-	-	90	197

S. No.	State	Run of river		Dam based		Canal based		Total	
		Number	Capacity (MW)	Number	Capacity (MW)	Number	Capacity (MW)	Number	Capacity (MW)
18	Mizoram	48	105	1	8	-	-	49	113
19	Nagaland	76	77	6	67	-	-	82	144
20	Orissa	58	59	7	16	137	117	202	193
21	Punjab	36	57	11	1	157	212	204	269
22	Rajasthan	-	-	11	5	44	22	55	27
23	Sikkim	70	214	-	-	-	-	70	214
24	Tamil Nadu	68	180	19	11	53	42	140	233
25	Tripura	1	1	2	6	5	3	8	10
26	UT (A & N Islands)	5	1	-	-	-	-	5	1
27	Uttar Pradesh	-	-	23	67	188	200	211	267
28	Uttarakhand	346	1469	-	-	8	9	354	1478
29	West Bengal	57	93	5	2	79	118	141	213
	TOTAL	2365	6899	211	686	1700	1808	4276	9393

Broadly the components of a canal based SHP project can be divided in two parts i.e. civil and electro-mechanical works. The major components of civil works are diversion channel, spillway and powerhouse building. Spilling arrangement is generally carried out through existing canal. It is easier and economical to built small hydro power plant while new irrigation channels being planned or built, civil works of small hydro could be taken up side by side to make works economical. Further the construction of power house building and diversion channel before charging of the canal may save on account of dewatering etc. Also all the infrastructure facilities available for construction of canals may be used for hydro power structure in order to save the cost and time for mobilisation of facilities [25]. The bypass canal could be as close as possible to the existing canal to reduce friction losses to the minimum and from consideration of economy. However, the stability of the excavated slopes/embankment of the canal on the by pass may be of prime consideration in deciding the layout of the scheme.

1.8 POLICY AND INCENTIVES FOR DEVELOPMENT OF SHP PROJECTS

In India the importance of renewable energy development was recognized as early as in 1970. At central government level, Department of Non-Conventional Energy Sources was established in 1982 which was subsequently upgraded to Ministry of Non-conventional Energy Sources (MNES) and renamed as Ministry of New and Renewable Energy (MNRE) since October 2006. Till 1991, the electricity generation and distribution in India was in government sector only, subsequently, it was opened to private sector for development. The present share of private sector in hydro power generation is 3.3% and 12 % in all forms of energy generation. India is an union of states and there is a division of executive and legislative powers between the Indian Union (Central government) and the states. Hydro power is a state subject and interstate rivers are dealt by central government. Hence for hydro power development both the central and state governments are involved.

With the beginning of 21st century, commercialization in the SHP sector took new dimensions. Private entrepreneurs found attractive business opportunities in small hydro. State governments started formulation/ refinement of policies to make them entrepreneurs friendly. The procedure of allotment of sites was stream lined and made more transparent. The government of India announced new electricity act in 2003, national electricity policy in 2005 and tariff policy in 2006 to create a conducive atmosphere for investments in the power sector. The electricity act 2003 has specific provisions for the promotion of renewable energy including small hydro power. It has been made mandatory that every state would specify a percentage of electricity to be purchased from renewables. Small hydro power projects are now governed by these policies and tariff is decided by state electricity regulatory commissions as per tariff policy. A package of incentives include customs duty concession, income tax exemption on SHP projects for power generation for 10 years. Some states of India are also giving sales tax and electricity tax exemption on the electricity generated by SHP projects. Sixteen states have framed policies on SHP. Main features of these policies are as given below [5]:

- Private sector participation in hydro power including SHP has been permitted.
- Wheeling of power has been permitted.
- Power banking is permitted
- Buy back of electricity per unit is generally at the rate of Rs. 2.50, although it varies in different states. Many states provide for annual escalation of rates.
- Third party sale of power is allowed in many states even outside the state.
- States provide other concessions such as lease of land, exemption from electricity, duty, and entry tax on power generation equipment.

- Some states do not levy any water charges while some levy it as a percentage of electricity tariffs.
- All states have appointed nodal agencies to facilitate participation of developers.
- Some states have prescribed the minimum quantum of power produced from renewable sources that the state distribution licensee must purchase.

The Ministry of New and Renewable Energy gives the following subsidies for SHP projects [13].

(i) For special category states (North-Eastern Region, Sikkim, Jammu & Kashmir, Himachal Pradesh and Uttarakhand) the amount of subsidy is Rs. $22.5 \times (CMW)^{0.646}$ millions. For other states, the amount of subsidy is Rs. $15 \times (CMW)^{0.646}$ millions. CMW means capacity of SHP station in MW.

(ii) Subsidy for renovation and modernization of old SHP projects and for completion of languishing SHP projects is limited to 50% of the subsidy amount for new SHP projects. However this support is only for the government sector.

(iii) Subsidy for identification of new potential sites and preparation of perspective plans by state agencies are given in Table 1.8.

Table 1.8 Subsidy scheme for new potential SHP sites in India [13]

S. No.	Schemes	Areas	Up to 1 MW (Rs.)	Above 1 MW and up to 5 MW (Rs.)	Above 5 MW (Rs.)
1.	Survey and investigation	Plain	75,000	1,00,000	1,50,000
		Hilly	1,00,000	2,00,000	3,00,000
2.	Feasibility report preparation	Plain	75,000	1,00,000	1,50,000
		Hilly	75,000	1,00,000	2,00,000

1.9 COST ASPECTS

Successful development of small hydro power depends upon cost reduction for economic viability and ruggedness for operation and maintenance by the type of people available for such operation. The capacity range of small hydro power lies between a few kW to 25 MW. Physical size of each component not only depends on the capacity but head of the scheme also. Parameters affecting cost are physical sizes, efficiency, construction and operating costs. Cost reduction in respect of small hydro project has to be dealt with carefully. The capacity of electro-mechanical equipment should be sufficient enough to convert available hydro energy. The over sizing or over designing should be avoided in order to minimize installation cost. The control system is one of the important components, which is to be designed carefully for safe and reliable operation vis-à-vis total cost [26]. It is an established fact that the unit cost of hydro schemes is inversely proportional to the head under which they operate [10]. If the low head sites, which are hitherto beyond the economic feasible margin, have to be developed to harness the renewable energy contained in them, the economic thresholds has to be reduced. The power generation benefits from the proposed project are the sum of the energy value times the energy production. In the instance of a private purchaser, the difference in their power bill with and without the proposed project is the benefit. The project benefit stream is the annual array of power benefits (plus other project benefits if determined to be appropriate). Project benefit streams should be prepared for the several installed capacities under study. Economic feasibility is positive when the present worth of stream of benefits exceeds the present worth of stream of costs. It is suggested that the internal rate of return method of characterizing project feasibility is employed. The internal rate of return is that discount rate at which the present worth of net benefits becomes zero [25, 27].

The present trend of capital cost of small hydro power projects ranges between Rs. 40 to 90 Million per MW, including civil works and electro-mechanical equipment

[19]. The cost of generation varies from Rs. 1.30 to 3.00 per kWh, depending upon the site conditions. In case of medium and high head schemes in hilly areas the cost of civil works are more while cost of electro-mechanical equipment are more in low head schemes [19]. The life of a small hydro power project is estimated to be about 35 years. Levelised costs over the life of the project compare quite favourably with those for new thermal power projects located away from coal mining areas, as there is no recurring cost on fuel. After the debt-servicing period, cost of generation from small hydro power projects is very small as the water resource is free, and operation and maintenance requires only minuscule expenses. The cost of small hydro power generation can be maintained at attractive levels through higher efficiencies and improved performance obtained from new hydro turbine designs, larger scale and more efficient manufacturing, better levels of operation and maintenance and development of sites in clusters. Small hydro power may turn out to be even more competitive in comparison with conventional power if the classical cost calculations for conventional power also reflect all the external social and environmental costs. Studies have shown that this cost is roughly equal to the commercial cost for conventional electricity, indicating that the total cost to society is actually double their commercial cost [28].

There has been great emphasis on effective utilization of power potential. The question among hydro power engineers is to develop the optimum plan for hydro power plant. Various researchers have contributed on this issue as discussed in the subsequent paraghaphs of the chapter under literature survey.

1.10 LITERATURE REVIEW

The basic components of small hydro scheme can be broadly classified as (i) civil works and (ii) electro-mechanical equipment. Civil works of small hydro power scheme generally comprise of; Diversion weir and intake -is required for diverting the flow of water from the river or stream towards the intake channel; Water conductor -

is provided to convey water diverted from the weir to the forebay through desilting tank; Desilting tank - is provided to remove the silt from diverted water to minimise erosion where water contains silt; Forebay - is a simple structure provided at the end of water conductor with some storage capacity for meeting immediate water demand on starting and to absorb water in case of sudden stoppage of generating units and to provide submergence over penstock intake; Penstock - is a closed conduit carrying water from forebay to the turbine; Spilling arrangement – is provided to spill the access flow from the forebay in case of shut down of power house or running at part load; Power house building - is a simple structure housing the generating units and control arrangements; Tailrace channel - is provided to carry the water discharging from the turbine and convey it back to the flowing stream [29].

Wiser [30] presented renewable energy finance and project ownership which demonstrated the importance of financing in the renewable energy project development process by exploring the effects of financing and ownership structure on the cost of renewable energy facilities. In US most large non-hydroelectric, renewable energy projects were found to be private non-utility generators owned, however now it has been realized that owning and financing own wind power facilities will cost less than purchasing power from independent renewable energy suppliers. The paper briefly discussed the financial cash models. Wind power input, cost, tax and operating assumptions were also described. Cost varies as the treatment of taxes differs among the ownership arrangement. The analysis suggested that the most common form of wind plant ownership and finance, namely private ownership with project financing is the costliest. After all analysis it was found that cost can be varied upto 40 % if prudent care is taken to select the financial and ownership structure.

Frey and Linke [31] described hydro power as a renewable and sustainable energy resource meeting global energy challenges in a reasonable way. The authors traced societies increasing preoccupation with renewability and sustainability issues over the past few decades. They also addressed the question of whether large hydro power should be considered renewable and sustainable. Renewability is a response to concerns about the security of energy supplies from unanticipated interruptions and the eventual depletion of some primary energy sources such as fossil fuels. Sustainability is a response to environmental degradation of the planet and leaving a legacy to future generations of a reduced quality of life.

Layman's Guide Book [32] states that hydraulic engineering is based on the principles of fluid mechanics. Based on the large amount of accumulated experience there exists many empirical relationships to achieve practical engineering solutions with the movement of the water. The failures like seepage under the weir, open channel slides occurred through a lack of proper geological studies of the site.

US Army Corps of Engineers [33] presented discussions of the general, architectural & structural considerations applicable to the design of hydroelectric power plant structures. Discussions could be used in establishing minimum criteria for the addition of hydro power facilities at existing projects, like location of the power house, switchyard, highway, railroad access and other site features. Location of the powerhouse is determined by the overall project development factors like location of spillway navigation locks and accessibility. For location of switchyard, considerations should be given to the number and direction of outgoing transmission lines, however the most desirable and economical location adjacent to the power house was suggested. Highway and railroad should be easily approachable for easy transportation and thus reducing the cost. Other site features included areas like public and employer parking, sidewalks, guard rails and other safety features.

A model was developed primarily to determine whether the work of SHP should proceed further or be dropped in favour of other alternatives. It provided the user, two different methods for cost estimation i.e. the 'formula' and 'detailed' costing method. After the required input data, various factors like power available as function of flow, plant capacity, power curve etc. were calculated. Although it had some limitations like it was designed only for run of river SHP, required single value of gross head. Its condensed formulae enabled the estimation of project costs with good accuracy for pre-feasibility stage studies for small hydro projects [34].

Paish [35] studied presented technology and current status of small hydro power and found hydro power on a small scale is one the most cost effective energy technologies. Survey was done on the current status of hydro potential i.e. how much is technically available and how much is economically viable and how much is yet to be exploited. Although the initial capital cost in setting of a hydro plant may be high but its long-term reliability and lesser environmental effects can't be ignored.

It may not be possible to standardise the layout or design of these power stations, but certain guidelines can be set, based on fundamental principles, and the experience gained from the performance of the numerous existing small hydro projects of the type. The most appropriate solutions however, are evolved after conducting site specific alternative studies including their relative costs [36, 37, 38].

Eliasson et al [39, 40] used Genetic Algorithm method for optimisation of design of hydro power projects. Genetic Algorithm is a computer model which was developed to find the global optimisation of design and layout of hydro power projects by maximising the net profit of the investment.

Linsley et al [41] and Cheng [42] found that maximum economic life for mechanical and electrical equipment in hydro stations is 40 years, for electronic equipment it is 20 years and for civil engineering works 80 years. It is, as such, possible to double the life of power station by rehabilitating mechanical and electrical equipment for relatively small investment. Naidu [43] investigated. Indian rivers, carry huge sediment loads during the monsoon period. He found that, in the Himalayan regions, concentration of silt is high which leads to accumulation of millions of tones of silt in the reservoirs. Despite of elaborate desilting arrangements, silt passes through the generating units at the rate of thousands of tones per day.

Charles et al [44] and Lund [45] studied social and environmental impacts, benefit and long term effects of inter-basin transfers for irrigation and power. They found that there is a possibility of selection of the over/under estimation of design discharge by conventional methods, which may lead to financial loss over the life span of the power project. Evans [46] developed methodology for assessment of sustainability indicators for different renewable energy technology. Varun et al. [47] evaluated life cycle green house gas (GHG) emissions from three run of river SHP plants in India. Angelove [48] derived a method for the calculation of design discharge for small hydro stations by application of dry and average hydrological years, but the method can not be applied for obtaining the optimum benefits, as it is not associated with economic analysis and can lead to inadequate selection of the design discharge for the SHP.

Dudhni et al. [49] assessed small hydro power potential for development in India using remote sensing data and GIS technique. Karlis et al. [50] involved technique for assessment of technical feasibility and economic viability of SHP installations. Lui et al. [51] evaluated economic performance of hydro-electric generating units.

Kahn and Walters [36] developed a computer package for preliminary design of micro-hydro systems for feasibility studies. This may be useful in reducing the design cost of very small projects. A major advantage of this package is computerized storage of relevant planning and design data.

Guillaud [52] discussed various methods of system analysis for planning and operation of multipurpose water resources projects.

Hughes and Narayana [2] developed a non linear programming model to determine size of penstock, type and number of turbines and the installed capacity for run of river SHP schemes. A optimization model was developed with constraints on flow availability, pipe capacity, and turbine-generate rating. The objective function was considered as value of energy annual cost. The model was based on the assumption that turbine-generator selected operate over the entire range of flow, part load efficiency of turbine was not considered. Eliasson et.al. [40] used genetic algorithm for optimum design of hydro power plant by maximise the net profit of the investment.

Walter and James [53] developed a probabilistic approach to sharpen the decision criteria by including probability density functions in the analysis in order to provide unavailable information on the reliability of the outcome. Ignoring uncertainty in input parameters causing assessment errors on a project's economic merit. The developer of a small hydro power site needs to accurately predict the anticipated revenues from the project over a period of year. Authors [54] have used Monte Carlo method for stochastic modeling of stream flow for evaluation of SHP site.

Montes et al. [55] presented an overview of renewable energy in Spain. Power sector is a basic constituent for the development of worldwide economy and its evolution is based on making quality compatible with service.

Most appropriate technology mix for use in small hydro projects is to include efficient and cost effective options in turbines, governors, alternators, penstocks, civil structures, transmission network, construction monitoring, environmental preservation and improvement and operation and maintenance. Rugged equipment; fail-safe design and suitability for unattended operation are required. This is primarily aimed at reducing civil works. There are many redundancies in the layouts which can be eliminated, like reducing the length of water conductor system, eliminating by pass, reorientation of power house, etc. and a layout which is most optimum to the given site shall be chosen. It is not possible to make a general statement which turbine type is best suited for a special low-head hydro-application. The decision may differ from one turbine to the other, dependent on head, site conditions and size of turbines [56, 57, 58].

Under a study it was found that small hydro proves a challenge to a consultant since the works have to be carried out within small budget limitations [59]. The engineers will have the opportunity to design the entire project instead of one component of a major hydro project [60].

Sharma [61] found that power plant is a complex system comprising of various types of equipment having different span of useful life and are subjected to varying pace of technical development. The benefits can be maximised through optimal selection of equipments. He discussed the developed optimisation technique for design of power plant using genetic algorithm. This methodology was applied for uprating and refurbishment of existing power plants.

In low head SHP schemes use of siphon intakes may eliminate intake gates thus cost can be reduced. This will also improve flow conditions as the flow in conduit can be cut off more quickly and completely as compared to gated intakes. The system is more convenient and reliable in operation. The main disadvantages of this system is that their application range is limited to diversion type plants where fluctuations of head race level is less than 5 m [62]. Aslan et.al. [63] carried out sensitivity analysis for design of SHP plants and presented a case study of SHP plant.

Ramos et al. [64] discussed different components in SHP station and flow behavior across them. The hydraulic design of the Small hydro plants with various configurations was discussed. The various hydraulic transients and dynamic effects, which occurred in open channel, penstock and surge tanks, were analysed.

Gordon [65] discussed design criteria for exposed penstocks for high head schemes. Sihang and Quanwei [66] discussed the problems occurred in SHP during operation of the power plant. Fentzloff [67] discussed benefits of submersible power plants in low head installations and stressed that the construction of submersible plants requires highly experienced engineers. Three categories of mechanism to control the flow of water in hydro power plant. (i) to shut off the flow (ii) to prevent excess water hammer and (iii) to maintain frequency were found under a study carried out by Gordon [68].

The electro-mechanical equipment is considered to be the equipment and system required to develop the energy available in impound or flowing water and to convert it into electrical energy, to control and regulate it and to transmit it to the power grid. The major electro-mechanical component of power plant are the inlet valve, intake and draft tube gates, turbine, generator, governor, control and protection equipment and substation for transformation of power to the transmission line.

In terms of space requirement and cost of the major items, turbine and generator constitute major share of the total electro-mechanical equipment. Types of turbine and generator used under different operating conditions were discussed and available in the literature [69, 70].

Montanari [71] used flow duration curves, efficiency curves of two types of turbines to find out most economically configuration with Michell-Banki and propellor turbines. Hughes et al [2] developed a non linear programming model to determine conveyance pipe size, type, number of turbines and installed capacity for run of river hydro power schemes. Constraints on stream flow availability, pipe velocity, turbine generator rating were accounted for in the model.

Dube and Nguyen [72] developed a non linear algebraic model of Kaplan turbine to simulate transients in a hydro power system. Mehta et.al. [73] developed a methodology using unsteady flow conditions behind axial and mixed flow turbine runners for performance of turbines.

Siervo et.al. [74, 75], Schweiger et. al. [76] and Lugaresi et.al. [77] presented modern trends and developments in design of francis and Kaplan turbines. Scheidl et.al. [78], Layland et.al. [79] and Maurer [80] developed new concept for medium size bulb turbine, variable speed bulb turbines with generator and semi Kaplan turbines for SHP plants. Scheweiger et.al., [81] compared the turbine perameters for small and large size axial flow turbines. Thapa [82] discussed erosion problems in hydraulic turbines and measured the wear rate of turbine materials due to sand erosion.

Goyal et.al. [83] and Soeresen [84] presented recent developments in control systems for small hydro power schemes. Majumdar [85] carried out dynamic stability analysis of a remote small hydro power station connected to infinite bus through long transmission line.

Gordon [86, 87, 88, 89] discussed the advancement in technology for SHP development. Use of computers to control and operate small hydro plants and possibility to operate the plant from a remote location was discussed by him. For small hydro plants, induction generators were recommended to eliminate expensive governor for major reduction in cost of electro-mechanical equipment. Further, fact was found that range of turbines is now so vast that engineers have difficulty in selection of the economic configuration for the power plant.

Wang et al. [90] presented dynamic Analysis of a grid linked small hydro induction generator system in South Taiwan. The mathematical models like; Induction generator model, hydraulic turbine prime mover model, electro-mechanical model, power factor correction capacitor bank model were employed. The system under load importing, exporting, sequentially starting three phase balanced fault were simulated. The small hydro induction generator system include three identical SHPs consisting of a 3-phase power transformers, an induction generator and a power factor correction capacitor bank for each set. The simulation results were found to be acceptable and shown satisfactory operation under the simulation condition.

Pugh [91] discussed hydraulic model studies on bulb turbine in order to investigate possible simplifications in the design of the intake flow passages for bulb turbine and to determine head losses associated with it. Smooth, undisturbed turbine performance was found to depend on intake design of turbine. Models of four types of designs were taken into account and discharge, velocity and pressure measurements were carried out. It was found that the intake, which did not have entrance curves and whose corners as square had more than twice as much loss as the others.

Gorban et al. [92] estimated the theoretical power limit of turbines in free fluid flows. The first model was developed by Betz for rectilinear flows with 59.3% efficiency for propeller type turbine, however he neglected the curvature of the fluid streams which led to overestimation. A new CGS model was suggested and the comparison leads to the conclusion that a 3-D helical turbine would be preferable to any propeller in free water flows.

Sehgal [93] developed the design guidelines for spillway gates including radial gates, vertical lift gates, and flap gates including inflatable gates and their application. A clear view about which gate is to be used under various requirements was presented.

Sadrul et al. [94] discussed the selection of turbine for low head micro hydro systems in Bangladesh. In Bangladesh most of the potential sites have low head and upto 10 MW also with seasonal variation. Head, discharge data were considered for turbine selection. Specific speed was also taken into account for selection of turbine, operating at its optimum efficiency.

Nilsson et al. [95] computed the behaviour of turbulent flow in complex domains and used for the computation of the flow through a Kaplan turbine.

Ardanuy et al. [96] discussed the potential advantages of variable-speed hydro-electric generation. They found the variable speed generation schemes as of greater flexibility of the turbine operation in situations where the flow or the head deviate substantially from their nominal values. The variable speed option would be more advantageous for high specific speed turbines.

Widden et al. [97] analysed a low head hydro power station having siphon system with aeration and found to be the most efficient system. They described that the most preferred turbine for low head is Kaplan turbine, but civil engineering needed for Kaplan turbine is substantial to be about 50% of the project cost. This high cost can be curtailed by converting water pressure to air pressure. An air turbine smaller inside and cheaper than a water turbine for similar power and pressure ratio was suggested.

Cattley et al. [98] illustrated some of the current machine designs available for recovering power form low head hydraulic sources. They discussed current opportunities and future research needs by throwing light on the most promising devices and further modification of existing machines.

Balint et al. [99] mentioned that the numerical simulation of three-dimensional flows in hydraulic turbines is established as one of the main tools in design, analysis and optimization of turbo machines. A methodology for computing the three dimensional flow in Kaplan turbines was presented. Both velocity and pressure field results were presented, with a particular focus on the runner blades pressure distribution.

Gordon et.al. [100, 101, 102] developed correlations for quick estimation of cost based on head and capacity. Woods et al [103], Gulliver et al [104], Krouse et.al. [105] and Mudrock et.al. [106] carried out economic analysis of energy production from hydro power plants through a simple technique of benefit cost ratio with an uncertainty. The results of uncertainty analysis may be used to gauge the risk involved in project implementation.

Gordon [107] developed a simple methodology for checking first order cost of hydro power projects. This methodology was based on a satisfied analysis of cost data of 170 projects. The accuracy of such estimate was found ±40% to 50% percent. In feasibility stage accurate topographical maps, final hydrological studies detailed geological studies and sufficient engineering designs to define the project quantities were suggested to be available. Accuracy of estimates at this stage is within ±15 to 25 percent. The third stage is pre tender stage includes further investigations to define the nature of the foundation of all the structures, tender drawings, find bill of quantities. Accuracy of the estimates based on detailed work was suggested to be within ±10 percent. The final stage is award of contract. The cost of the development was suggested within ±5 percent. The author has developed correlation of cost of hydro power projects with respect to head and capacity based on the data available. These correlations are largely applicable to large hydro power schemes having medium and high heads.

Gordon [108, 109, 110] and Whittington et.al. [111] also developed methodology for cost estimation of hydro power projects. Gordon and Noel [112] developed a simple methodology for estimating the likely minimum cost of small hydro power sites. The study was based on data of 141 sites. The cost of small hydro power sites was divided into three components, site costs, equipment cost and engineering administration. The relationships developed were based on generalized conditions and the specific and unusual circumstances were not considered. These relationships did not account for specific physical, economic or business environment of the sites. The methodology can be useful to discard those sites where cost is higher than the affordable cost of alternative energy.

Newbury and Hutt [113] studied the addition of a 500 kW unit to an existing 500 kW SHP station and found that replacement of existing power station with larger one to house both the units was uneconomical. The economized solution was to construct a new power house adjacent to the existing one to house additional unit.

Orgayar et.al. [114] developed methodology for cost estimates of electro-mechanical equipment of SHP plants.

The major problem in run of river schemes is prediction of a valid flow regime for the site. The author has presented a methodology for optimum design of run of river scheme based on maximum economic rate of return [115].

In low head small hydro power plants, the cost of power house in civil works and cost of turbine in electro-mechanical works has been found significant. Percentage wise bifurcation of cost of various components has been presented and technological aspects was discussed [116].

In order to minimize the cost and complications, specifications of the components must be appropriate to the scheme as a whole. The design should be site specific and must be able to overcome the unique problems of each site. Small hydro puts challenge to its designers by having wide range of options, few restrictions on innovative ideas and the opportunity for a small group to conceive, design and commission as a unique project [117, 118]. Gordon et al. [119] described intake for dam based scheme to prevent heavy silt. Murray et al. [120] described type of turbine and economic aspects for SHP installations. The cost of a hydro plant is a function of head and capacity. Based on the available cost data of SHP plants, a correlation was developed as function of head and capacity of the plant.

Muir and Niyimbona [121] developed an approach for evaluation of small hydro power projects implementation. Such an approach was found to be useful in having a database, ranking and screening of projects. Cost of power house building forms a significant part of the scheme. Use of proper turbine and handling equipment may save the cost [122, 123].

Laught [124] described development of water resources projects in Central Java, Indonesia. Integration of small hydro at major irrigation facilities were discussed and plant optimization and economic viability was worked out. It was found that integration of SHP plants with a large multipurpose project is economically more attractive rather than operating each facility separately.

Hosseini et al [125, 126] developed a method to calculate the annual energy of the run of river SHP plants using Excel and Matlab softwares. The method was used to analyses and estimates the cost. Nouni et.al. [127] evaluated techno-economic feasibility of micro hydropower projects for decentralised power supply in remote locations of India. Chedid and Rahman [128] designed a SPV-wind hybrid power system and used linear programming (LP) techniques to minimize the average production cost of electricity while meeting the load in a reliable manner.

Eker [129] suggested the optimization in the design of governors for hydro-turbine speed control in power generation. A single input multi output (SIMO) design approach using dynamic weighted functions of the polynomial roboust governor was developed. Proposed roboust governor was found to have significantly improvement in performance. Voros et.al. [130] developed an empirical model for maximising the economic benefits of the investment for SHP plants.

Kaldellis et al. [131] developed a complete sensitivity analaysis to estimate the techo-economic viability of small hydro power plants in Greece in order to achieve the target of creating new SHP stations of total capacity over 600 MW. Based on the data collected for run of rivers schemes and dam based, calculations were made to demonstrate the impact of main techno-economic parameter on the behaviour of SHP ventures for 10 or 15 years of operation. Installation capacity factor, annual escalation rate of local market and electricity price were found to be the factors affecting the viability of SHP. The predicted internal rate of return (IRR) values of a SHP installation were found to be greater than 18 % for most of the cases, in comparison with local economy inflation rate of 3.5% and with corresponding market annual cost of 6-8 %.

1.11 FORMULATION OF PROBLEM

Large potential of untapped hydro energy is available in flowing streams, river slopes, canal falls, drainage works and irrigation and water supply dams. This energy available near rural consumption centres can be exploited by small hydro power stations and can meet significant rural energy needs of the country. Future irrigation and drainage works can be specifically designed for economic small hydro power generation. Injected in existing grids these plants can be designed to establish distribution grids and reduce energy losses. Far-flung and remote area can be fed by such power plants by suitably designed autonomous power systems. A large part of this power is in low head and ultra low head (below 3 m) range. So far very less potential could be developed due to remoteness of sites, paucity of funds, relatively large per kW installation cost, shortage of trained manpower, power purchase arrangement with state governments, uncertainties in geological conditions and hydrology. Potential of small hydro power available on canal falls, which falls under the range of low head can be easily and quickly exploited as they have established hydrology, geology and proximity of load centres. In view of these problems a study is carried out for development of low head small hydro power schemes, which are mainly on canal falls near load centers and generally have proper connectivity in terms of access and power evacuation.

To bridge the gap between demand and supply of the electricity, the vast potential available in low head range of small hydro need to be developed. For development of this potential huge investment is required. Now such projects are being developed as commercial projects so their financial viability is must and investors are very careful on cost aspects. For high and medium head small hydro power schemes, which are mainly run of river schemes, the schemes are site specific and installation cost is governed by cost of civil works. For low head schemes, the cost is governed by the cost of civil works and electro-mechanical equipments. For such schemes the machine sizes are relatively larger and so size of powerhouse, thus there is scope for cost optimisation for such schemes.

Literature survey reveals that many studies to optimise various components of small hydro power were carried out. These studies aimed to optimise specific components of small hydro power schemes. For low head SHP schemes, relatively large discharges are handled, thus size of machines become bigger. The cost of such projects depend on both civil work as well as electro-mechanical equipment. No study has been reported so far for the optimisation of low head small hydro power installations. Keeping this in view the present study is carried out to fulfil the following objectives;

i. Study of various components of low head small hydro power schemes.
ii. Carry out the sizing of various components under civil works and selection of electro-mechanical equipment for different schemes.
iii. Computation of cost of different components, based on determined sizes for low head small hydro power schemes.
iv. Development of correlations for cost of various components for different schemes under different conditions in order to determine the total installation cost.
v. Financial analysis for cost optimisation of different schemes based on developed correlations for cost.


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CHAPTER–2

SMALL HYDROPOWER SCHEMES AND THEIR COMPONENTS

2.1 GENERAL

Small hydropower is a clean source of power, produced when water turns a hydraulic turbine. Hydro-turbines convert water pressure into mechanical shaft power, which is used to drive an electric generator, or other machinery. The power available is proportional to the product of pressure head and volume flow rate of water. The power generated for any hydro system is given by the following equation [20];

$$P = gQH\eta \tag{2.1}$$

Where, P is the rated output power (kW), g is the acceleration due to gravity (m/s^2), Q is the discharge passing through the turbine (m^3/s), H is the effective pressure head of water (m) across the turbine and η is the combined efficiency of the generating units comprising of turbine and generator. Small hydropower potential is available in high hills as well as in plain areas. In hilly areas, the streams have steep gradients or vertical falls thereby offering high heads in short stretch of the stream.

2.2 TYPE OF SHP SCHEMES

As mentioned in Chapter- 1, small hydropower schemes are categorized in three types of schemes i.e. canal based, run of river and dam based. Based on head, these schemes are defined as high head, medium head and low head schemes. Low head schemes could be canal based, run of river and dam toe while, high and medium head schemes are run of river and dam based schemes. Small hydropower projects in the hills, where small streams are available, are mostly medium and high head schemes utilizing small discharges. In case of high head schemes, there is uncertainty about the geology and hydrology. In India most of these schemes are in Himalayan region. Himalaya is a young mountain, its difficult, remote and steep hilly terrain do not have firm geology. There are several cases of occurrence of avalanches in snow bound areas. In middle and lower Himalayan region, land slides are very common in rainy season, which affects the layout of SHP scheme. Due to these uncertainities, medium and high head schemes are considered site specific. The low head schemes have to handle large quantities of water. Thus size of the civil structures as well as generating equipment is large. Low head schemes in the canals meant for irrigation system have established hydrology and are free from geological and discharge uncertainities.

2.2.1 Run of River Scheme

In run of river scheme, the power generation depends on instantaneous flow of water, which is not same throughout the year. Water availability varies in different seasons. Also in same season, every year water availability is not the same. Thus uncertainty about water availability is there. Fig. 2.1 shows a schematic of a typical run of river SHP scheme. The first and foremost aspect for site selection is to check whether the stream on which development is envisaged has any existing power station or has more potential for development on upstream or downstream of the proposed site. This would ensure proper planning for overall development of the power potential available in the stream.

Run of river schemes comprise of a diversion structure across the stream to divert the water, water conductor system including desilting tank and power channel, forebay, penstock, power house and tailrace channel. The head for power generation is created by the difference in the water level at the diversion site and the water level of the stream at its junction with the tailrace. The discharge for power generation is obtained from inflow discharge of the stream at the diversion site. The best combination of head and discharge, with due consideration of topographical geological and hydrological aspects determine the most appropriate layout for the scheme. In such schemes geological and hydrological investigations are more important as these are not planned on existing facilities. The criteria for selection of scheme and components should include logistics in terms of accessibility. Inaccessible locations should be given the last preference as creation of infrastructure facilities for such schemes would involve considerable time besides additional costs.

2.2.2 Canal Based Scheme

These schemes are planned in the canal itself or in the bye-pass channel. The power house is located in the canal alignment with intake on the upstream and tailrace on the downstream of the fall. In most of the running canals, it is not possible to locate the power house in the canal alignment itself as it requires the closure of canal for considerable period during the construction. Fig. 2.2 shows a schematic of a typical canal based SHP scheme. These schemes can be planned in the existing canal system or canal system under construction. If a canal system is under planning, consideration must be given so that concentrated drops at certain locations are available for power generation. In case of existing canals, two or more number of drops can be clubbed together to provide the consolidated single drop in the bye-pass channel for power generation.

It is easier to build an economical small hydro plant while an irrigation canal is being built, as civil works cost reduces due to avoidance of re-excavation, demolition, rebuilding, raising banks of canal etc. In canal based SHP projects the major components of civil works are diversion channel, spillway and power house building. Spilling arrangement is generally carried out through existing canal. It is easier and economical to build small hydropower plant while new irrigation channels being planned or built; civil works of small hydro may be taken up side by side to make civil works economical [132].

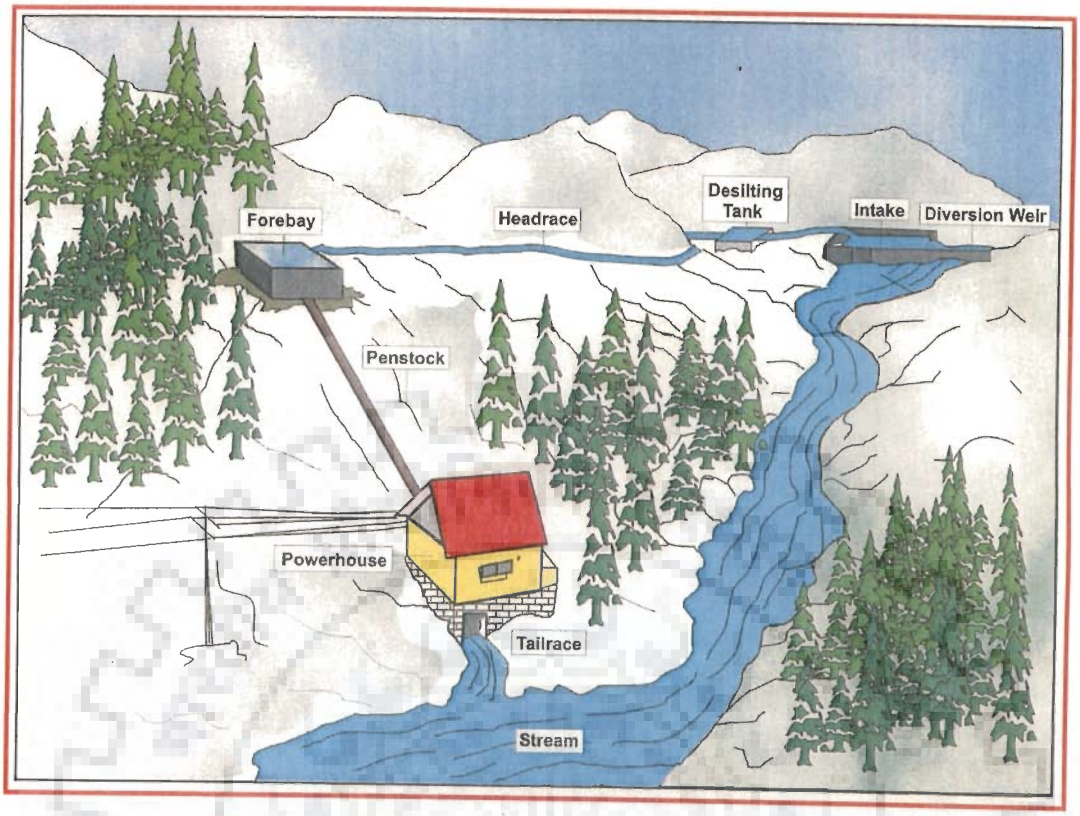


Fig. 2.1 Schematic of typical run of river SHP scheme [19]

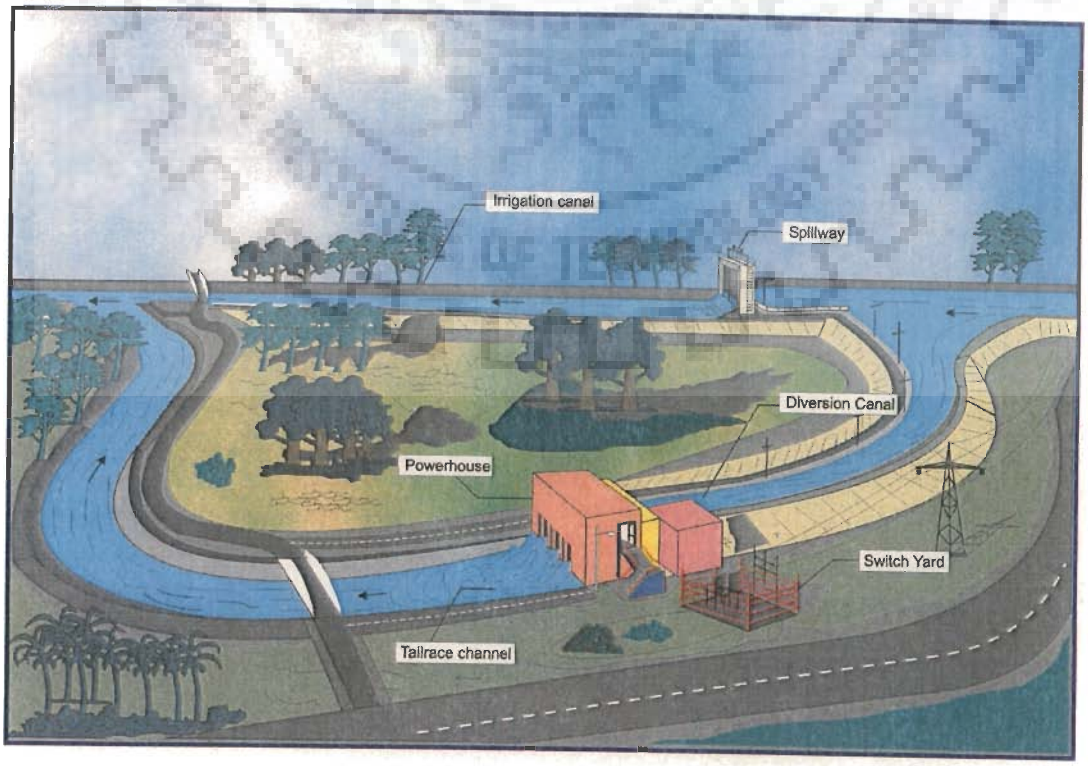


Fig. 2.2 Schematic of typical canal based SHP scheme [19]

Further the construction of power house building and diversion channel before charging of the canal will save on account of dewatering etc. Other infrastructure facilities available for construction of canals shall be used for hydropower structure in order save in the cost and time for mobilisation of facilities.

2.2.3 Dam Toe Scheme

As discussed above, water availability in rivers is not same throughout the year. The maximum availability is in rainy season which last for 3-4 months in a year. Dams are constructed to store this seasonal water for flood mitigation, supply of water for irrigation and drinking needs. When water flows from dam outlets under pressure due to water level difference between upstream and downstream of the dam, there is a possibility of power generation. These schemes are known as dam toe hydropower schemes. However, in case of dam based schemes water is diverted from the reservoir created by building the dam through water conductor system and power house is build away from the dam. These schemes could be under high head or low head categories in large hydropower and dam is generally part of the hydropower scheme.

In dam toe based schemes, power house building is located at the toe of the dam and penstock is taken through the body of the dam. The major components of civil works are intake, penstock, power house building and tail race channel. These schemes are on the existing irrigation facility like irrigation dams/anicuts/weirs and cost of the dam is not considered as the part of SHP sceme. Since the facility is already existing, there will be no question of eco-damage due to development of SHP schemes. Dam toe SHP schemes are generally in low head range.

A schematic of dam toe scheme SHP scheme is shown in Fig. 2.3. Irrigation sluices available in the dam can be used for dam toe schemes in order to reduce the cost and the sluices can be modified to act like direct intake.

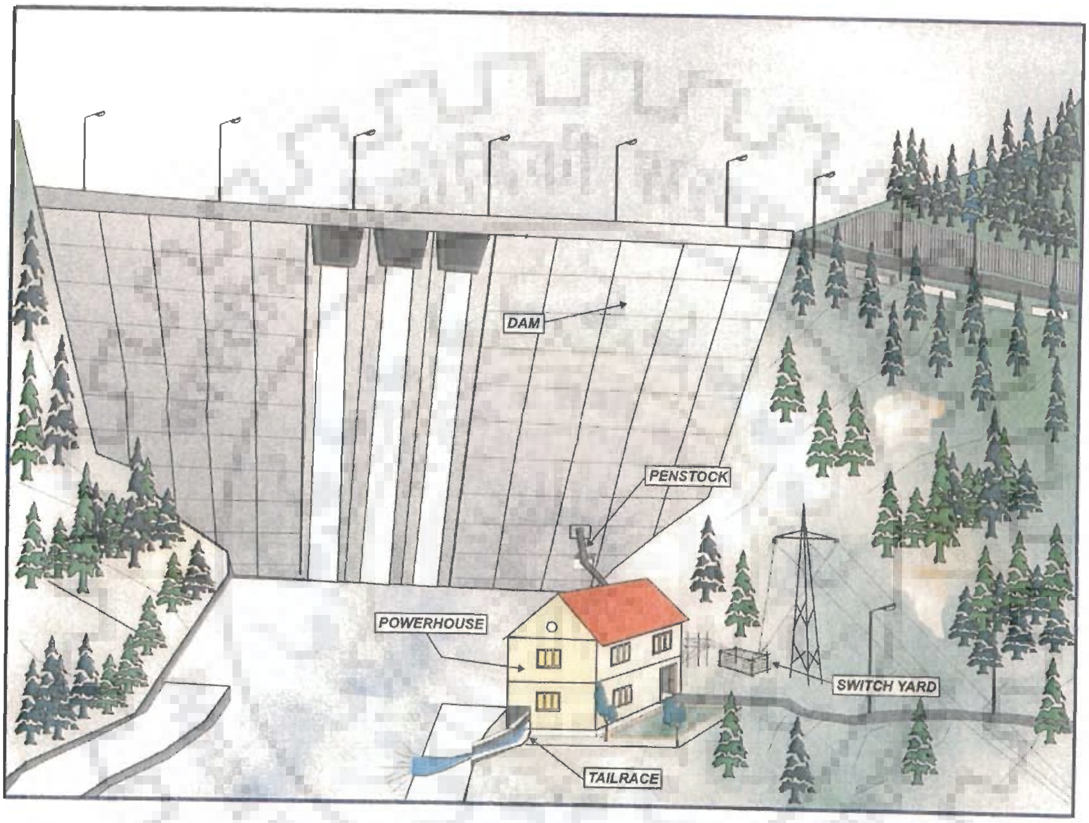


Fig. 2.3 Schematic of typical dam toe SHP scheme [19]

2.3 BASIC COMPONENTS OF SHP SCHEMES

Basic components of a SHP schemes are categorised into two parts (i) civil works and (ii) electro-mechanical equipment. Most of the components are common in different types of schemes, however, some components are different for a different schemes. A broad classification of SHP components is given in Fig. 2.4.

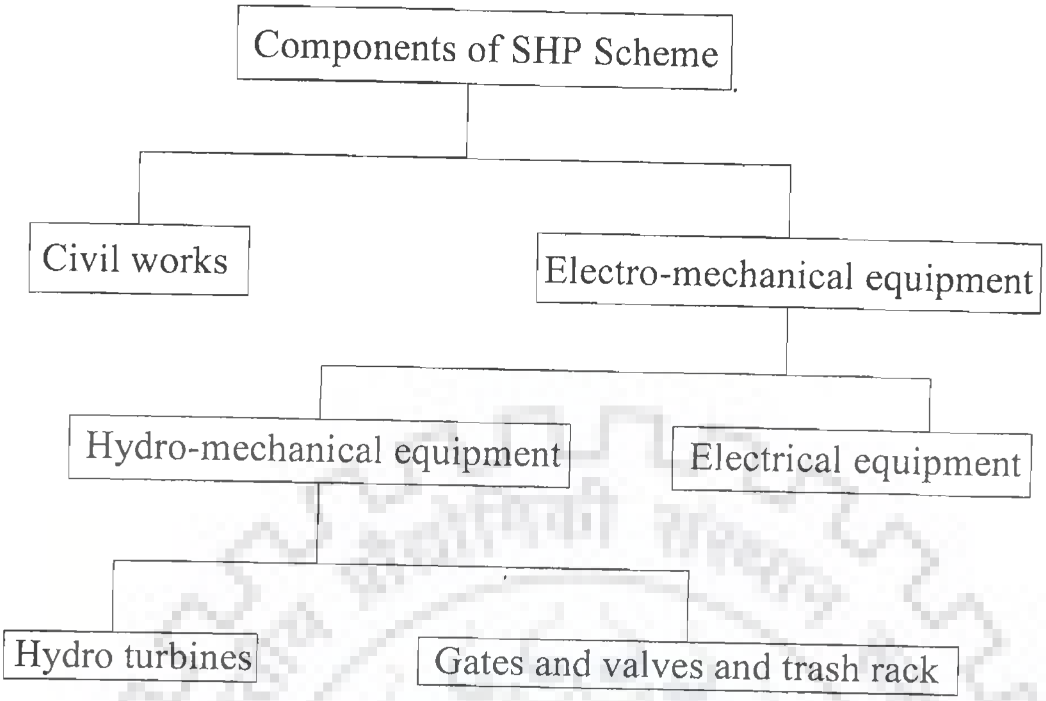


Fig. 2.4 Different components of SHP small hydro power schemes

2.3.1 Civil Works Components in Run of River Schemes

The components of civil works in run of river scheme are same for low head and high head schemes. Following are the civil works components of run of river schemes;

i) Diversion weir and intake structure
ii) Desilting tank
iii) Power channel
iv) Forebay or balancing reservoir
v) Surge tank
vi) Penstock
vii) Powerhouse building
viii) Tail race channel

2.3.1.1 Diversion weir and intake structure

The diversion structure known as weir or barrage is provided across the river to divert the water to the water conductor system through intake structure. The intake structure to a hydropower scheme is provided to prevent river borne debris and large flows from being funneled into the intake, especially during heavy rains. At the same time, there is a need to ensure that an adequate flow of water is diverted in the water conductor system. It might either channel the flow toward the intake or simply provide the required depth of water at the intake for flows to enter on its own accord. Where the stream bed is susceptible to erosion, weir also maintains the level of the stream bed constant near the intake otherwise the stream bed might erode so badly that the stream eventually will be too low for water to flow into the intake.

The choice of barrage or weir as diversion structure depends upon site requirements. For higher capacities and wider river, barrage is provided to ensure more reliability. Barrage is a gated structure across the river to regulate the flow while weir is a permanent, semi permanent or temporary structure over which water flows. For small capacity scheme and smaller streams, weir is provided. Weirs of different type are discussed below.

2.3.1.1.1 Trench weir

The hilly streams carry big boulders during flood season, which destroy the over-ground structure constructed across the river and thus restricts the choice of adoption of different alternatives for weir. The trench-type weir for diversion structure reduces this problem to a significant extent. This type of weir consists of a trapezoidal trough located below the river bed with top kept at the bed level of the river. The intake structure located at the end of the weir either on left or right bank is an integral part of the weir. The intake structure should preferably be at such location as to clear the width of the stream of minimum water level condition and protected adequately for high flood level conditions. Trench weir is provided in stream having slopes steeper than 1:15. Thus these are generally not provided in low head schemes [133].

2.3.1.1.2 Weir comprising boulders in wire crates

These weirs are of semi permanent type and provided by encasing boulders in galvanised iron (GI) wires to divert the water from the stream.

2.3.1.1.3 Bush and boulder weir

Bush and boulder type weir structure is a very simple type of structure utilizing boulders available in the vicinity of the stream. These are suitable in very small streams, but liable to be washed off during heavy monsoons and hence requires periodical replacement. These weirs are recommended for very small capacity schemes upto about 100 kW [38].

2.3.1.1.4 Concrete weir

These weirs are permanent type of weir made of reinforced cement concrete and are commonly used in low head run of river SHP schemes.

2.3.1.1.5 Inflated weir

It was initially known as Ferricon, now known as inflated on rubber or canvas dam/weir are being constructed in large numbers in China, France, Germany, USA and Japan. This is relatively new technology and yet to be used in India.

In this type of weir, the rubber bag is bolted on concrete floor laid at river bed level or the weir crest. The rubber bag comprises of multiple interwoven layers of chloroprene rubber and nylon, which provide excellent friction and weather resistance properties. Inflation and deflation are controlled automatically with the help of a monitoring and control pumping/valve system. The rubber bag is filled either with air or water. Rubber weir has the advantages like ease of automation, rapid installation, low maintenance requirements, flushing of silt, passing the floods safely and ability to give precise flow regulation.

2.3.1.1.6 Coanda weir

Coanda weir named after Henri-Marie Coanda involves the tendency of water to follow a surface over a row of horizontal wedge wire bars perpendicular to the flow. A curved acceleration plate at the top of screen establishes to the accelerate flow. The screen is installed along the crest of diversion weir and is shaped in the ogee spillway configuration. The screen is fabricated to high tolerance from stainless steel. It has various advantages of self screening property not only avoid maintenance of intake but also installation of desilting tank is avoided.

2.3.1.1.7 Siphon intakes

Siphon intakes are used on penstock in small hydro projects. Siphon Intakes have advantages of convenience of operation, elimination of intake gate/valve, ice formation in cold climate, improve run away conditions and silt entry reduction. However, it has limited application for reservoir based plants having head race water level fluctuation less then 5-6 m. In India, siphon intake integrated with vertical turbines have been installed on ultra low head canal falls SHP plants [134].

2.3.1.2 Power channel

Power channel is the important component of run of river SHP scheme which conveys the water from intake to forebay. It is also known as water conductor system. The water diverted through intake carries lot of silt which is removed by providing desilting arrangement in the water conductor system. The power channel portion between intake and desilting tank is known as intake or feeder channel. The power channel between desilting tank and forebay is known as head race channel. Tunnel can also be provided in place of open channel or pipe in some portion or in whole portion depending upon the site requirement. This choice depend on the topography and geological formation of the area.

2.3.1.3 Desilting tank

Desilting tank is provided where the water contains large quantities of coarse silt to minimise erosion damages to the turbine runner. The extent of desilting requirements depend on the quantum and type of silt carried by the stream and the runner material. Generally, hill streams carry appreciable quantity of silt and sand during rainy season. These are more harmful due to the fact that development of such streams is generally for high heads and abrasion efforts become more pronounced with increasing head. To trap the pebbles and other suspended matter desilting tank is generally provided in the initial reaches of the water conductor [135].

2.3.1.4 Serpent sediment sluicing system

The `Serpent Sediment Sluicing System', or simply `S4', was invented by H. Stole in 1988. The patented S4 concept has now developed from an idea, through a research and development process, to a commercial product, and the first two commercial S4 installations began to operate in Nepal during the 1994 monsoon season, at two plants built and operated in a private sector company.

The `serpent' is a heavy-duty rubber tube which seals a silt between the settling basin and a flushing channel along the bottom of the basin when the tube is filled with water. The flushing channel is provided with a gate at its downstream end, and an operating valve is applied for filling or emptying the serpent. When the serpent is gradually dewatered, it rises and opens the slit like a zip fastener. The sluicing area moves along the bottom of the basin with the silt opening. The serpent floats in the basin while sand and silt are settling out. To flush the basin, the serpent is filled with water and the flushing gate opened. The silt opening will then move in the opposite direction, thus moving the sluicing area through the entire basin.

2.3.1.5 Forebay

Forebay is provided at the end of water conductor system. Main function of the forebay is to provide immediate water demand on starting the generating units. It also provides enough depth of water over the penstock to prevent vortex formation and air entry. The location of the forebay should be carefully chosen in rock/soil strata. The structure should be leak proof so that it retains the water stored. Apart from the need for secondary settlement, another function of the forebay is to provide adequate submergence for the penstock mouth so that the transition between open channel to pressure flow in a pipe can occur smoothly. The important components in a forebay are; (i) spillway, (ii) silt flushing, (iii) penstock intake and (iv) trash rack.

In case of flow entering the forebay exceed the flow flowing through the penstock, or the valve to turbine is closed during heavy rains or excess flows enter the canal from stream or from run off uphill of the canal, then the excess water is to be disposed off through spillway. Spillway is provided in forebay to become operative in case of sudden load rejection or at partial load on machines. An opening with its bottom at the maximum water level may be provided at a suitable location on the forebay and connected to a natural drain through spilling channel. Suitably spillway channel is provided to safely dispose off the excess inflows.

Incoming water may carry sizable quantities of floating debris, in such conditions forebay functions as a final settling basin. Then debris are removed through a silt flushing pipe. A trash rack is provided at the inlet to the penstock to prevent floating material from entering the penstock and turbine. Drainage arrangement is also required when forebay is being repaired.

2.3.1.6 Balancing reservoir

At some sites, where lean season discharge is very low and not sufficient to run the turbine, it is preferred to have a balancing reservoir for storage of water for some hours in a day and utilized for power generation for some hours. It is called diurnal storage. The functions of balancing reservoir are same as forebay. The main purpose of the balancing reservoir is to store water during off-peak hours to supply the same during peak hours and thus meet peak electricity demand.

2.3.1.7 Surge tank

Surge tank is provided to relieve the water hammer pressure within the penstock under conditions of load rejection and acceptance. In case of a completely closed pressurised water conductor system, it is necessary to provide a surge tank at the meeting point near the horizontal or gently sloping head race conduit and steeply slopy penstock. When the length of the water conductor conduit is less than five times the head on the machines, surge tank is not necessary. In case of low head small hydro schemes generally surge tank is not required, however they are usually necessary component of medium and high head SHP schemes where length of penstock under high pressure zone is more.

2.3.1.8 Siphon spillways

A siphon is essentially conduit located above the hydraulic grade line. The existence of sub-atmospheric pressure enables water to be sucked up above the upstream free surface level before it is discharged at a lower level. The mechanism or operation may be explained by reference to the simple siphon arrangement. A gradual rise of water level is assumed on the upstream. Flow does not commence until water rises above the crest of the siphon, at this stage it spills over in the same manner as over a weir. A further rise leads to an increase in velocity and removal of some of the air collected at the summit through entrainment in the flow. Since the outlet is water sealed there can be no replenishment from the atmosphere.

2.3.1.9 Penstock

The penstock is a pipe that conveys water to the turbine under pressure. It can be installed either above or below the ground. The buried penstocks are safe from landslides, falling rocks, bush fires and tampering. The penstock above ground is subject to temperature variations. Penstocks in the cold climate should be buried or covered with the jute cloth in case these are laid on the ground surface. The alignment of penstock is not always straight and there has to be horizontal and vertical bends enroute penstock. At bends due to change in direction of flow, stresses are developed. To counter these stresses, anchor blocks are provided at these bends. Support piers are used for straight reach of exposed pipes, primarily to prevent the pipe from sagging and becoming over stressed. The alignment of the penstock should be on a ridge and the stability of the penstock slopes needs to be ensured by proper geotechnical evaluation and providing suitable protection measures as required. The penstock intakes are provided with trash-racks which prevent trash debris etc. and in cold climate, ice from entering racks into waterways.

New material for penstock such as high density polyethylene (HDPE), poly vinyl chloride (PVC) and glass fiber reinforced pipe (GRP) are being used world wide. Most of these are being manufactured and available in India also. Though these materials are not cost effective compared to conventional steel penstocks which are readily available in India and are commonly used, but offer better hydraulic efficiency, ease in installation and transportation.

2.3.1.10 Power house building

Powerhouse building is provided to house main generating control and protection equipment. It protects the turbine, generator and other electrical and mechanical equipment from rain and other weather effects. It also include space for control, erection, maintenance, office and sanitary facilities. The size of powerhouse should be enough to accomodate turbo-generating equipment with sufficient space on all sides to permit easy access for installation, operation, maintenance and repair. Powerhouse also houses inlet valve and other auxiliary systems like cooling water, drainage and dewatering systems, auxiliary power system, emergency and standby power system and equipment, lighting system, instrumentation protection and control system, ventilation system, station grounding, fire fighting equipment etc. The layout and size of powerhouse building depends upon the type of turbine, orientation of turbine, number of units, installed capacity and head.

There are three types of power house structures i.e. indoor type, semi-outdoor and outdoor type. Powerhouse is further divided into three main parts i.e. main power house structures, erection bay and service area. Selection of the type of power house is made on the basis of economic analysis. The connection between power house and switchyard equipment are usually of three types i.e. main transformer connections, control cables and power supply to switchyard and oil piping. For architectural requirements, exterior design should be such that it is an aesthetically pleasing structure. Design should be such that every component should relate to their function and should appear beautiful. Exterior details include roofing, decks, walls, entrances, draft tube deck, stairs, railings and skylights. Pitched roofs are preferred because of lower maintenance. All entrances should be located not only for proper and efficient operation of the plant but also to obtain pleasing exterior architectural design. Skylight can present leakage and maintenance problems and should therefore be limited to use in visitors areas. Interior design of power hourse covers visitor's facilities, control room facilities, generator room and auxiliary spaces and personal facilities. Certain interior details like floor and wall finishes, acoustical tile ceiling, door trim, plumbing fixtures are revealed in order to obtain reasonable uniformity and to a high standard of quality [20, 136].

In low head small hydropower schemes size of machines are bigger, thus height of the building are more to facilitate the movement of crane for maintenance. This needs a big power house building. By providing removable roof, the height of the power house building can be reduced substantially

2.3.1.11 Tail race channel

The tailrace channel having capacity as the design discharge of turbines and sufficient slope is provided to clear the discharges from the machines swiftly. The individual tailrace channels of each generating unit are connected to a common channel outside the power house building, which is turn, is connected to the river. The tailrace should be properly aligned with adequate bed slope to divert the discharge coming out of the power house to the stream. The tailrace should take into account high flood level of the stream to prevent back water flow from the stream to the power house.

2.3.2 Civil Works Components of Canal Based Schemes

In canal based SHP schemes the major components of civil works are diversion channel, spillway and power house building. The powerhouse building is the same as discussed under the components of run of river scheme and other components are discussed as below.

2.3.2.1 Diversion channel

Diversion channel is provided to divert the water from the main canal and convey to the hydro turbines in powerhouse building. The diversion channel should be as close as possible to the existing canal to reduce friction losses to the minimum.

2.3.2.2 Spillway

Spillway is provided to pass the surplus water which is not required for power generation. In case of load rejection, whole water need to be passed through spillway. Spillway is provided either in the main canal or in diversion channel. In spillway automatically operated gates are provided so that they become operational in case of load starts decreasing.

2.3.2.3 Tail race channel

The tail race channel is usually short, open canal, which leads the water from the powerhouse back into main canal after power generation. In canal based SHP scheme, it is the part of diversion channel where powerhouse is built in diversion channel.

2.3.3 Civil Works Components of Dam Toe Schemes

Dam toe schemes consist of mainly intake, penstock, power house building and tail race channel. The intake and penstock are constructed in parallel to the outlet works, to ensure that irrigation water supply releases are not interrupted during periods when the power plant is not working. The powerhouse intake and penstock can be incorporated into the diversion works or spillway or constructed as a separate facility in an abutment. In toe of dam projects, since located below the storage reservoirs, they get silt free water. Therefore sediment abrasion of turbine components is not a problem with this type of schemes. In dam toe scheme the intake is site specific however, other components such as penstock, powerhouse building and tail race channel are same as under run of river schemes discussed above. The intake is a gated structure provided for regulation of flow for power generation [137].

2.3.4 Hydro-Mechanical Equipment

Hydro-mechanical equipment includes hydro turbines, gates, valves and trash rakes. Out of these, hydro turbines play an important role which can be said as a heart of small hydro power station. The selection, type and specification of other equipment in the SHP station are dependent upon the hydro turbine. Similarly some civil structure, their dimension and design also depend upon the type of hydro turbine suitable for the scheme. Therefore, turbine is considered very important as it affects civil works on one side and electrical equipment on the other. The type of equipment are same for all type of SHP schemes.

2.3.4.1 Hydro turbines

Hydro turbines are defined as the hydraulic machines, which convert hydraulic energy into mechanical energy. This mechanical energy is used in running an electric generator, which is directly coupled to shaft of the turbine, thus the mechanical energy is converted to electrical energy. The electric power, which is obtained from the hydraulic energy, is known as hydroelectric power. Hydro turbine can go from a speed at no load to full load in 4 to 10 seconds and it can drop load instantly without any damage. Due to its simplicity, the hydraulic turbine can be made fully automatic and can be designed to operate with little attention.

Various types of hydraulic turbines have been developed to meet varying requirements of different types of SHP developments. Out of the various types of hydraulic turbines a suitable type has to be selected to match the specific conditions under which the hydraulic turbine is to operate so as to attain the high order of efficiency. The selection of hydraulic turbines of any SHP scheme having specific data such as head and discharge has an important role in the smooth functioning of the scheme. Selection of hydro turbines has a direct influence on SHP scheme, which by nature are complex and site specific in planning, design and construction. The hydraulic turbines govern the size of the SHP plants. Hence it is imperative that proper type, size and number of hydraulic turbines are selected with extreme care so as to achieve economy.

Based on the working principle, turbines are classified as given in Fig. 2.5.

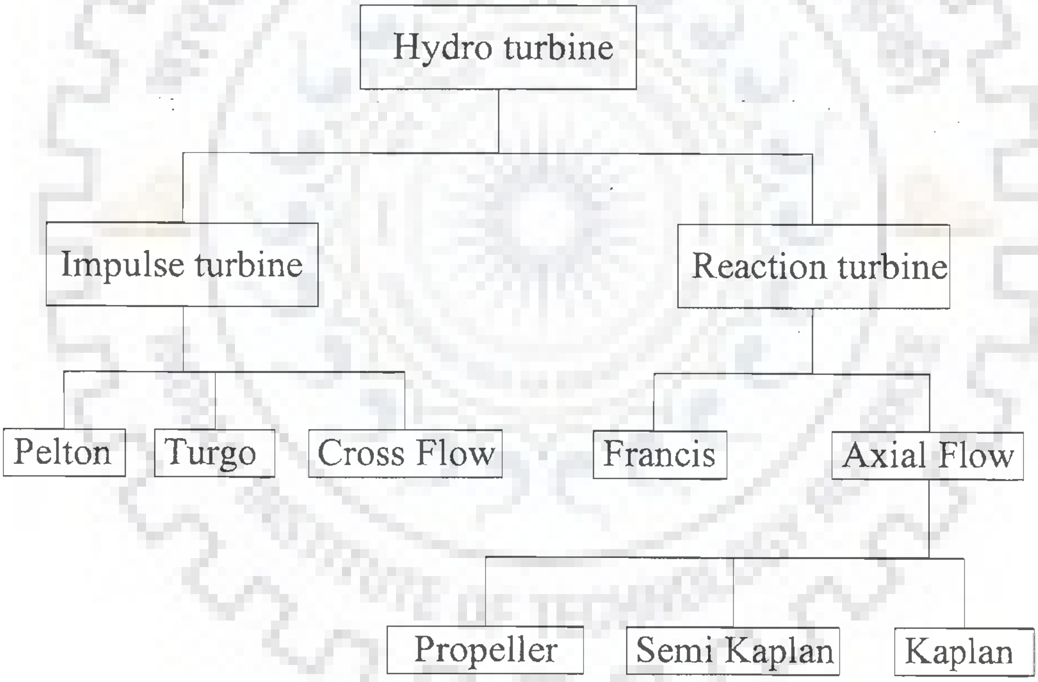


Fig. 2.5 Classification of hydro turbines

Basically hydro turbines are classified as impulse and reaction turbines. The various types of turbines are discussed as follows;

2.3.4.1.1 Impulse turbines

In impulse turbine, the available energy is converted into kinetic energy before coming in contact with the runner. The penstock is connected with the nozzle and the energy available at the inlet in the form of potential energy is transformed into kinetic energy in the nozzle. The water coming out of the nozzle is in the form of a free jet, which strikes with a series of buckets mounted on the periphery of the runner. The water comes in contact with only few of the buckets at a time. Once the water comes out of the nozzle, the pressure is atmospheric throughout and the casing do not have any hydraulic function to perform but it is necessary only to prevent splashing and to lead the water to the tail race, and also act as a safeguard against accidents. Control of the turbine is maintained by hydraulically operated needle nozzles in each jet. In addition, a jet deflector is provided for emergency shutdown. The deflector diverts the water jet from the buckets to the wall of the pit liner. This feature provides surge protection for the penstock without the need for a pressure valve because load can be rapidly removed from the generator without changing the flow rate. Control of the impulse turbine may also be accomplished by the deflector alone.

Runners on the modern impulse turbine are a one-piece casting. Runners with individually attached buckets have proved to be less dependable and, on occasion, have broken away from the wheel causing severe damage to powerhouse. Maintenance costs for an impulse turbine are less as they are free of cavitation problems. Excessive silt or sand in the water however, will cause more wear on the runner of an impulse turbine than on the runner of reaction turbines because of higher head. The runner must be located above maximum tailwater to permit operation at atmospheric pressure. This requirement give an additional head loss.

Impulse turbines can be mounted horizontally or vertically. The additional floor space required for the horizontal setting can be compensated by lower generator costs on single nozzle units in the lower capacity sizes. Vertical units require less floor space and are used for large capacity multi-nozzle units. Horizontal shaft turbines are suitable for small hydro applications.

Multi-jet turbines are costlier than single jet turbines. Abrasive material entrained in the water erode the buckets of a multi-jet turbine more rapidly than in the case of a single jet per runner. For the same rated head and flow conditions, increasing the number of jets results in a smaller runner and a higher operating speed. Therefore, whether vertical or horizontal, multi-jet turbines tend to be less costly for comparable outputs because the cost of the runner represents about 20% of the cost of the entire turbine. A deflector is normally used to cut into the jet when rapid power reductions are required such as a complete loss of connected-load. The deflector is mounted close to the runner on the nozzle assembly and typically is provided with its own servomotor.

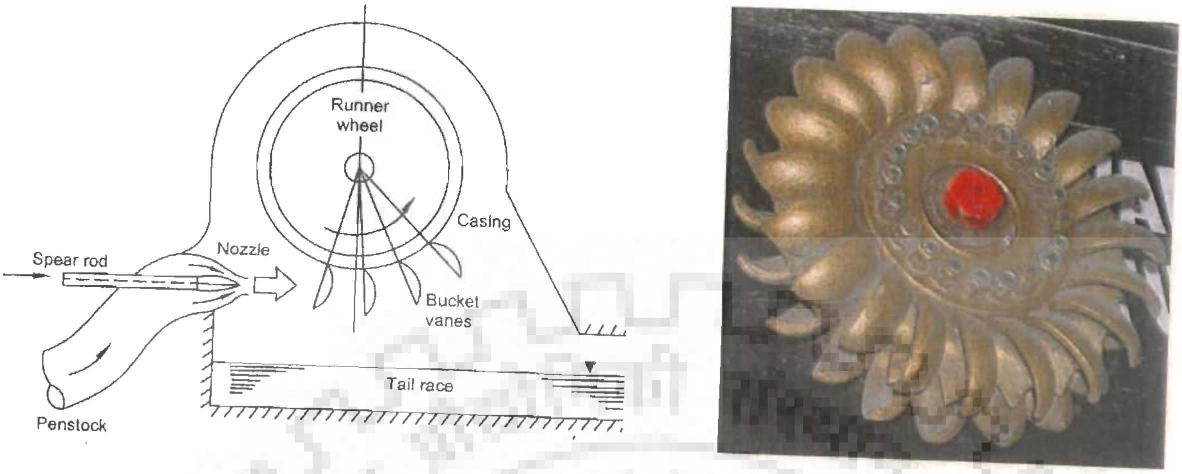
The types of impulse turbines are; Pelton, Turgo- Impulse and Cross flow turbine. The difference between a Pelton unit and a Turgo is that, on a Turgo unit, the jet enters one side of the runner and exits the other side. The Turgo unit operates at a higher specific speed, which means for the same runner diameter as a Pelton runner, the rotational speed can be higher. A cross flow turbine is an impulse type turbine used for low capacity plant upto 100 kW. Peak efficiency of the cross flow turbine is less than that of other turbines. Guaranteed maximum efficiency of indigenous available cross flow turbine is about 60-65% [38].

(i) Pelton turbine

It is a high head, free jet, tangential flow impulse turbine. The runner of a Pelton turbine consists of a circular disc on the periphery of which a number of buckets are attached. The shape of the bucket is of a double hemispherical cup or bowl. Each bucket is divided into two symmetrical parts by a dividing wall which is known as splitter. The jet of water strikes on the splitter of a single bucket at a time, in tangential direction to the periphery of runner. The splitter divides the jet into two equal parts such that the axial thrust on the runner neutralizes and the jet comes out at the outer edge of the bucket. A notch is cut at the tip of the bucket, which facilitate the striking of the jet at the centre of the bucket without any obstacle to the incoming jet by the portion of the bucket coming in front of the jet. The power output of the runner is controlled by adjusting the opening of the jet nozzle by the movement of a spear shaped needle. The movement of the spear is controlled by the governor. Fig. 2.6 shows main parts and runner of a Pelton turbine [138].

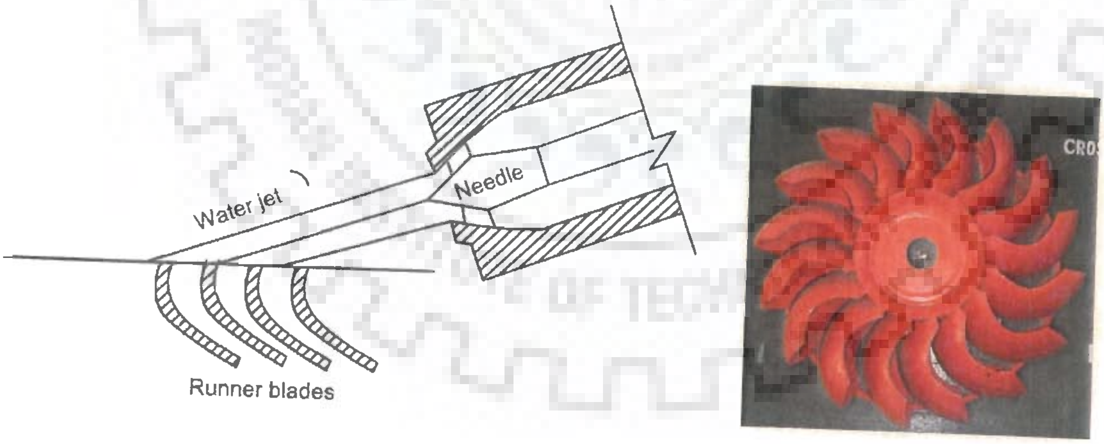
(ii) Turgo-impulse turbine

In turgo-impulse turbine, the shape of the bucket is such that the jet of water strikes the plane of its runner at an angle of around 20° rather than remaining within the same plane. Water enters the bucket from one side and comes out from other side, thus there is no interference of incoming jet and the water coming out from the buckets. Hence, in case of turgo-impulse turbine the water jet can strike more than one bucket (generally 2 to 3) at a time, which is not possible in Pelton turbine. Turgo-impulse turbine has higher specific speed (N_s = 20 to 70) than Pelton turbine. Fig. 2.7 shows position of jet with respect to runner blades and runner of turgo-impulse turbine [21].



(a) Main parts (b) Runner

Fig. 2.6 Pelton turbine [138]

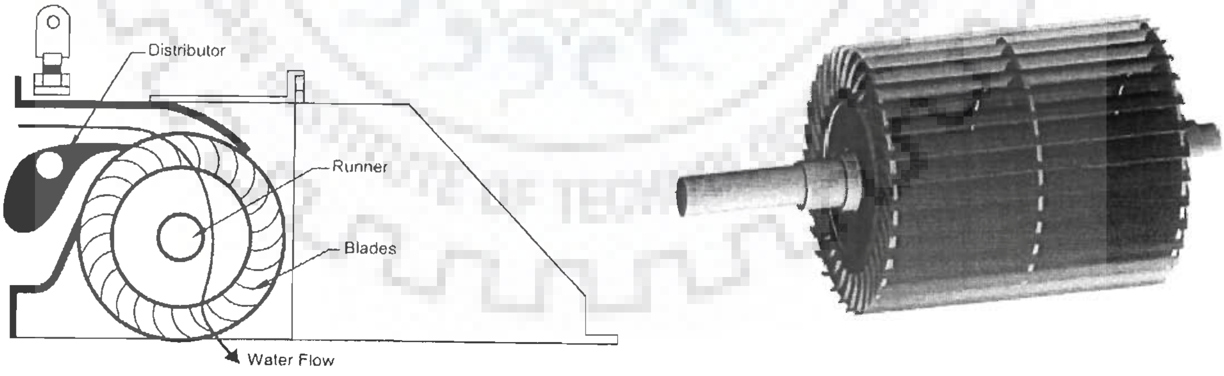


(a) Position of jet with respect to runner blades (b) Runner

Fig. 2.7 Turgo-impulse turbine [21]

(iii) Cross flow turbine

In cross flow turbine all the pressure energy is converted into kinetic energy in the nozzle itself. As the gap between the nozzle and the runner is very small, the pressure near the outlet of the nozzle is higher than atmospheric pressure, therefore a small portion of energy is in the form of reaction. The drum shaped runner of cross flow turbine is built of two parallel discs connected near the rim by a series of curved blades. For obtaining higher part load efficiency, the guide vane/nozzle is split into two valve sections – one covering two-third and the other covers one-third section of the runner. As the blades are curved radially, there is no axial thrust there by eliminating the necessity of thrust bearings. The peak efficiency of cross flow turbines is however less than Pelton or turgo turbines. In cross flow turbine, because of the symmetry of the blades the length of the buckets can be increased upto any desired value and hence the flow rate. Cross flow turbine has specific speed range from 20 to 80. Fig. 2.8 shows main parts and runner of cross flow turbine [138].



(a) Main parts **(b) Runner**

Fig. 2.8 Cross flow turbine [138]

2.3.4.1.2 Reaction turbines

Reaction turbines are the turbines in which water pressure can apply a force on the face of the runner blades, which decreases as it proceeds through the turbine. It operates with its runner submerged in water. The water before entering the turbine has pressure as well as kinetic energy. All pressure energy is not transformed into kinetic energy. The moment on the runner is developed by both kinetic and pressure energies. The water leaving the turbine has still some of the pressure as well as the kinetic energy. The pressure at the inlet to the turbine is much higher than the pressure at the outlet. Thus, there is a possibility of water flowing through some passage other than the runner and escape without doing any work. Hence a casing is essential due to the difference of pressure in reaction turbine. The reaction turbines can be further classified into two main categories based on the direction of flow of water in the runner as discussed below [139].

(a) Mixed flow turbine: In these turbines, water enters from outer periphery of the runner, moves inwards in radial direction and comes out from center in axial direction. Francis turbine covers under mixed flow turbine.

(b) Axial flow turbines: In these turbines, water enters from the wicket gates to the runner in the axial direction, moves along the axial direction and comes out in axial direction. Axial flow turbines are; tubular turbine, vertical turbine, bulb turbine, straflow/rim turbine and pit type turbine.

(i) Francis turbine

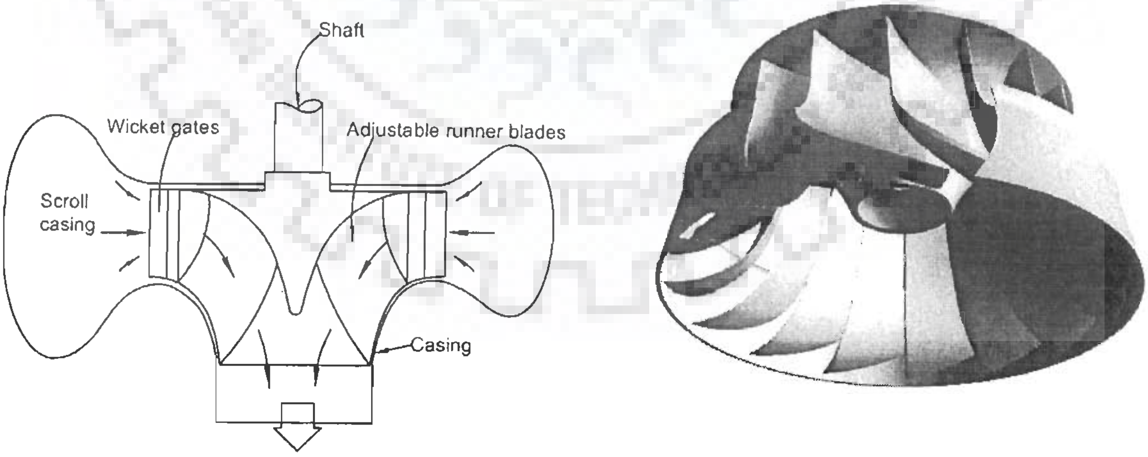
Francis turbine is an inward mixed flow reaction turbine in which water enters in the runner from the guide vanes towards the centre in radial direction and comes out of the runner in axial direction. It operates under medium heads and also requires medium discharge. A part of the head acting on the turbine is transformed into kinetic energy and the rest remains as pressure head. There is a difference of pressure between the guide vanes and the runner which is called the reaction pressure, and is responsible for the motion of the runner. The movement of the runner is affected by the change of both the pressure and the kinetic energies of water. After doing its work the water is discharged to the tail race through a closed tube of gradually enlarging section known as the draft tube. The free end of the draft tube is submerged deep in the tail water, thus, making the entire water passage totally enclosed. Some of the important characteristics of Francis turbine are:

a. The operating speeds of Francis turbine are lower than Propeller turbines hence the physical size of the Francis turbine is bigger than the Propeller turbine, for the same operating conditions.

b. The efficiency of the Francis turbine lies in between the Propeller and the Kaplan turbines.

c. It has specific speed range 80 to 400.

d. It has higher peak efficiency than Impulse turbines but has poor part load efficiency and is not suitable where the fluctuation in discharge is high. Fig. 2.9 shows main parts and runner of Francis turbine.



(a) Main parts **(b) Runner**

Fig. 2.9 Francis turbine [139]

(ii) Axial flow turbines

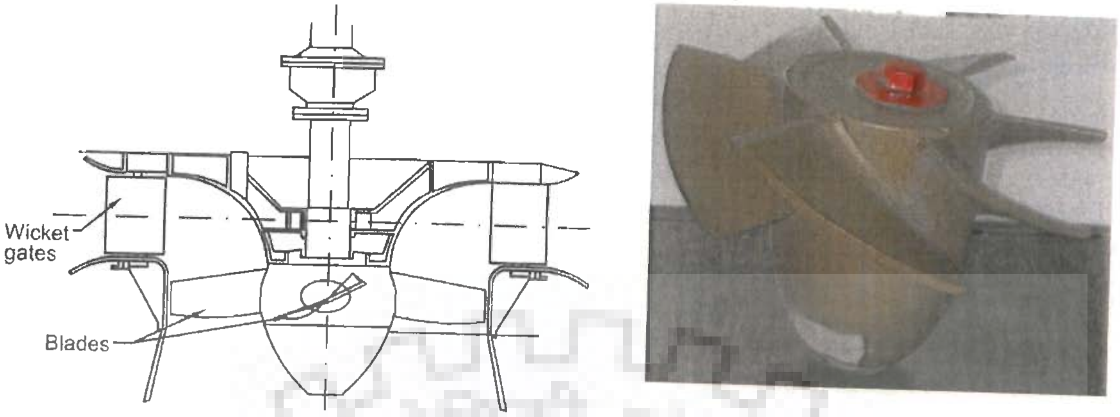
Axial flow turbines are those in which flow through the runner is aligned with the axis of rotation. In axial flow turbines, water flows parallel to the axis of the turbine shaft i.e. water enters and leaves the turbine in axial direction. These turbines are applicable for low head and large discharge conditions having specific speed range of 340 to 1000. Axial flow turbines can be divided in different categories depending upon the layout and control of wicket gates and runner blades [140]:

a. Tubular turbine

Tubular turbines are axial flow turbines in which turbine is encased inside a tube which is a water passage and the generator is kept outside the tube. Tubular turbine is equipped with wicket gates and runner blades. Tubular turbines can be connected to the generator directly or through a speed increase and can be mounted horizontally or slanted. Depending upon type of casing construction, tubular turbine can be classified as S-type, L-type and split type. For installation of the generator and speed increaser outside the water passage, a bend is provided in the tube in case of S-type and L-type turbine whereas in case of split casing type the upstream portion of the tube is split up into two or more portions for the same purpose. Fig. 2.10 shows main parts and runner of Kaplan turbine [141, 142].

b. S-type turbine

S type turbine is encased inside a tube which is a water passage and bend in the water passage is provided to permit the installation of the generator outside the water passage. It provides the flexibility of locating the generator depending on the site conditions either upstream or downstream, vertically or horizontally or in an inclined axis. It is best suited for sites with high discharge in proportion to head. Fig. 2.11 shows lay out of a S-type tubular turbine [138].



(a) Main parts **(b) Runner**

Fig. 2.10 Kaplan turbine [141]

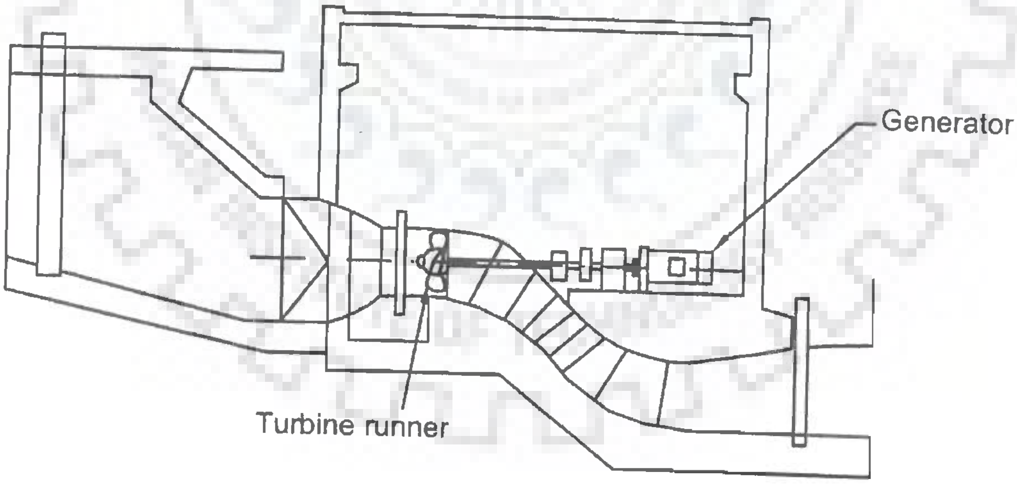


Fig. 2.11 Layout of S-type tubular turbine [138]

c. Vertical turbines

These turbines are mounted with a vertical shaft. Vertical units are equipped with a wicket gate assembly to permit operation of the unit on line at synchronous speed, to regulate the speed and load. The wicket gate mechanism units are actuated by hydraulic servomotors. Vertical units require less flow area but deeper excavation and more height in the power house building.

d. Bulb turbine

Bulb turbine is a horizontal turbine directly coupled to the generator which is enclosed within a steel casing known as bulb. The Bulb unit is completely submerged in the water passage. In this turbine flow is straight without any bend. The water flows axially towards the unit in the centre of the water conduit and passes the generator, the main stays, guide vanes, runner and draft tube into tailrace channel. In case of bulb turbines, spirel case is not required. Due to straight flow efficiency of bulb turbines is more.

In larger units, an access passage is provided in the bulb enclosure but in smaller units no access is provided hence the plant has to be dewatered during maintenance of generator. These turbines are applicable to low head ranges from 2 to 25 m. Fig. 2.12 shows main parts of Bulb turbine [20].

e. Pit turbine

Pit type turbine is a variation of bulb type turbine. This type of turbine is coupled to the high speed generator through step up bevel gears. The relative efficiency of these turbines is low because of gear box.

f. Straflow or rim turbine

In this turbine, the turbine and generator form a single unit lying in one vertical plane. The generator rotor rim is connected to the runner periphery followed by the stator wrapped round the rotor. The turbine is axial flow type and the efficiency is higher. The overall efficiency of the stratflow unit is comparable to that of Bulb units. Fig. 2.13 shows main parts of straflow turbine [143].

These Axial flow turbines are further classified as propeller, semi-Kaplan and Kaplan based on control in movement of runner blades and wicket gates.

g. Propeller

Propeller type turbines have fixed blades and movable wicket gates. In power station with propeller type turbine, intake gates can be provided in place of butterfly valve for shut off. In propeller turbines, wicket gates, regulate the flow as per load variations to run the turbine at constant speed.

h. Semi-Kaplan

The semi-Kaplan turbine has fixed wicket gates and adjustable runner blades. The semi-Kaplan turbine has better part load efficiency than propeller turbine. Also it provides more stable and noise full performance.

i. Kaplan turbine

It was developed by Viktor Kaplan, an Austrian professor in the year 1913. Kaplan turbine has adjustable runner blades and moveable wicket gates.

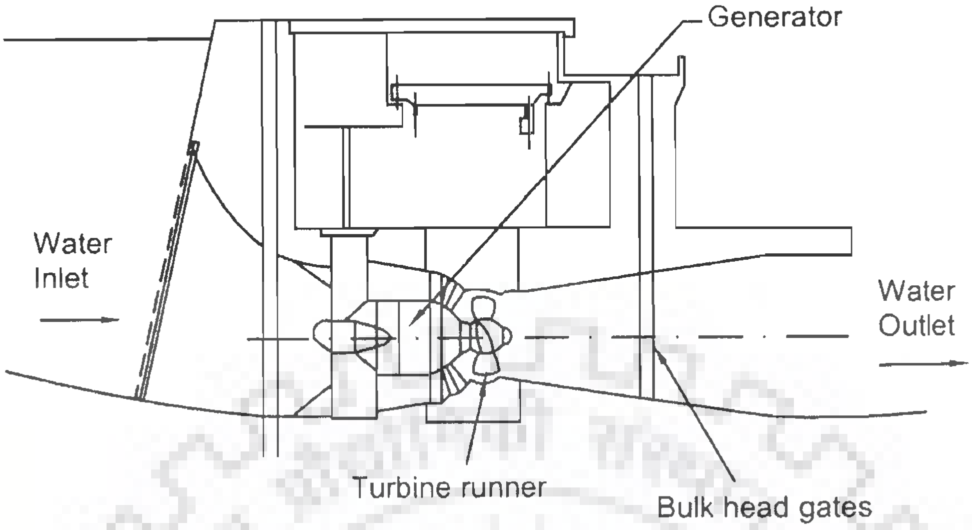


Fig. 2.12 Main parts of bulb turbine [20]

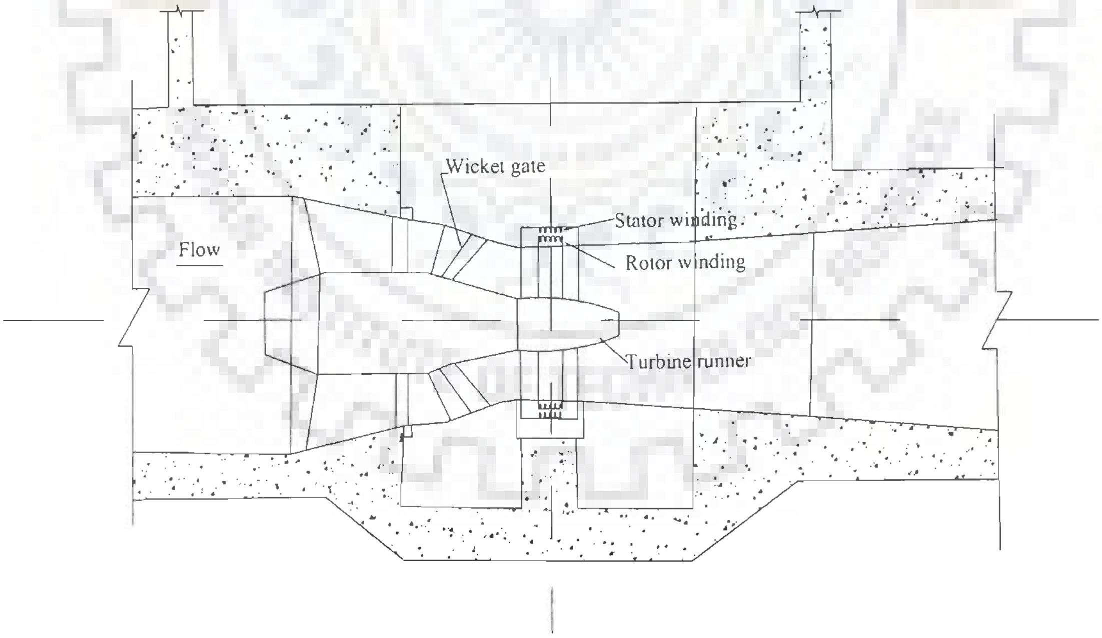


Fig. 2.13 Main parts of straflow turbine [143]

2.3.4.2 Trash racks

The trash rack is of a coarse type, which means that the clear spacing between bars, is such large that only drift such as cake of ice roots, trees and timbers are prevented from entering to the power house. The details and general construction of trash racks vary with the service required, configuration of the trash rack structure and depth of water. In canal intake where the height of rack is small a single rack section of required length extending from the water surface to the floor of the intake is provided.

In case of dam toe installation the trash racks are submerged considerably below the water surface. In such case, trash rack is provided in multiple rack section bolted together and are kept in position by bolts.

In run of river schemes, the trash racks are provided at the entry of penstock in the forebay/ balancing reservoir. These trash racks are provided as a single rack section extending from the water surface to the flow.

2.3.4.3 Gates and valves

Gates and valves are hydraulic control equipment and their purpose is to regulate / control the flow of water. The main difference between a gate and a valve is on account of contact of water on the various sides of the closing arrangements. Construction of valve is such that the closing member operates and remains within the water passage way, while in case of gates only the upstream side of the gate is in contact with water. In gates, the closing member is moved from an external position while in case of valves the closing arrangement is directly in the flow passage and all the sides of the closing member come in contact with water when water flows in the passage [136].

2.3.4.3.1 Gates

Gates can be classified based on head, functions, material, location of installation and operational considerations. However, terminology used to designate various types of gates has a wide variation and there is no uniformity in their nomenclature [20]. Also there is no particular process for the selection of gates. The types of gates used in the SHP schemes are as given in Table 2.1.

Table 2.1 Type of gate used in SHP schemes

S. No.	Function	Type of gates
1.	Used as intake / draft tube gates	Vertical lift gates
2.		Slide gates
3.		Bulk head gates
4.		Fixed wheel gates
5.	Used under unbalanced head conditions	Emergency or guard gates
6.	Used to retgulate flow	Regulating gates
7.	Used in high head schemes	Wheel or roller mounted gates
8.		Stoney gates
9.	Used as spillway gates	Caterpiller or coaster gates
10.		Hinged gates
11.		Tilting gates
12.		Radial gates
13.		Tilten gates
14.		Drum gates
15.		Fish belly gates
16.		Circular type gates
17.		Rolling gates
18.		Cylindrical gates

2.3.4.3.2 Valves

Applications of valves at hydropower facilities can be categorized by the type of their function as; closure, flow control, energy dissipation and pressure control. Closure or shut-off valves provides a positive conduit closure against flow. Flow control valves throttle flow both to regulate the discharge pressure and vary the flow rate. Energy dissipation valves are specialized flow control valves that reduce the head on water releases. Pressure control valves can limit the pressure rise in the conduit or piping system. Valves can be placed at an intermediate position in the pipe or at the end of the pipe.

In hydropower projects, the valves are used in penstock and in the scouring sluices. The valves in the penstock are seldom of regulating type, they operate usually either fully closed or fully open. The valves in the scouring, sluices are of regulating type, where they can operate under partially open condition also. The penstock valve is useful if the penstock needs quick dewatering. The turbine valve is necessary if the scroll casing needs dewatering. Different types of valves provided in SHP schemes are as given in Table 2.2 [20].

Table 2.2 Types of valves used in SHP schemes

S. No.	Type of valves	Function
1	Sluice valve	Used to control flow
2	Butterfly valve	Used in large conduits
3	Spherical valve	Operate under balanced load conditions
4	Needle valve	Used to regulate the flow
5	Howell bunger valve	Used for energy dissipation at high heads

2.3.5 Generator

Generator transforms mechanical energy into electrical energy. There are basically two types of generators: Synchronous and Induction. The Induction generators are also called as asynchronous generator.

2.3.5.1 Synchronous generator

The synchronous generator is a rotating machine, generating single or three phase alternating current (A.C.) with a frequency proportional to its rotational speed. It consist of a stationary member called stator comprising windings and a rotating member called rotor, containing magnetic field. The rotor may be a permanent magnet (for very small output) or an electro magnet whose coils or windings are fed by an external D.C. source called excitation. The rotating magnetic field (created by the rotor) induces voltage and current in the stationary windings. The generator voltage at constant frequency (the speed of the rotor) must be kept at synchronous speed. The synchronous speed is represented by the expression given below [136];

$$\text{Synchronous speed } N = 120 \times f / p \qquad (2.2)$$

where;

N is Speed in RPM

f is frequency in Hz

p is number of poles

2.3.5.2 Induction generator

Induction generator, consist of a stationary winding called stator, enclosed by the machine frame and a rotor with a short circuited winding. Placing a 3-phase A.C. current on the terminal of the 3-phase stator winding, creates a rotating magnetic field in the machine which rotates at a speed, called synchronous speed N . depending on the supply frequency and the number of poles. The rotating field flux cuts the short circuited rotor winding (or conductor bars in the case of a squirrel cage rotor) where it induces voltage and current, which in turn produce torque on the rotor. The rotor must always rotate below or above the synchronous speed i.e. at a slip, otherwise there is no cutting of flux by the rotor conductors and hence no torque is developed. The induction machine operates as a motor when running below synchronous speed and as a generator when the rotor is above synchronous speed. Therefore any induction motor can be used as a generator, by driving at above synchronous speed. The difference between the synchronous speed, N and the rotor speed, n_r is called slip speed, n_g , represents the speed of the rotating field viewed from the rotor [21].

$$\text{Slip speed, } n_g = N - n_r \qquad (2.3)$$

$$\text{Slip, } S = (N - n_{r)} / n_s \qquad (2.4)$$

If slip S is negative, i.e. rotor speed is more than synchronous speed, the machine operates as generator. If slip S is positive, i.e. rotor speed is less than synchronous speed, the machine operates as motors.

2.3.6 Governor

Governing means regulation of speed of the generating machine. The main function of governor is to maintain a constant speed when load on the turbine fluctuates. The governor is therefore the point of coordination between the turbine and external control of flow of water leaving to the runner, in proportion to the load. In case of Francis turbine, its closes or opens the guide vanes and in the case of reaction turbine, it moves the runner blades in addition to closing of wicket gates.

2.3.6.1 Governing system

A complete turbine governing system consists of three main components as follows;

i. The governor executes the control processes.

ii. The servo system transmits the electrical signal from the governor into an oil flow. This may be amplified in one or several steps before moving the guide vanes.

iii. The oil hydraulic system supplies sufficient quantities of pressure oil to the servo system, also maintaining sufficient spare pressurized oil for emergency situations.

The main parts of turbine governing system are shown in Fig 2.14.

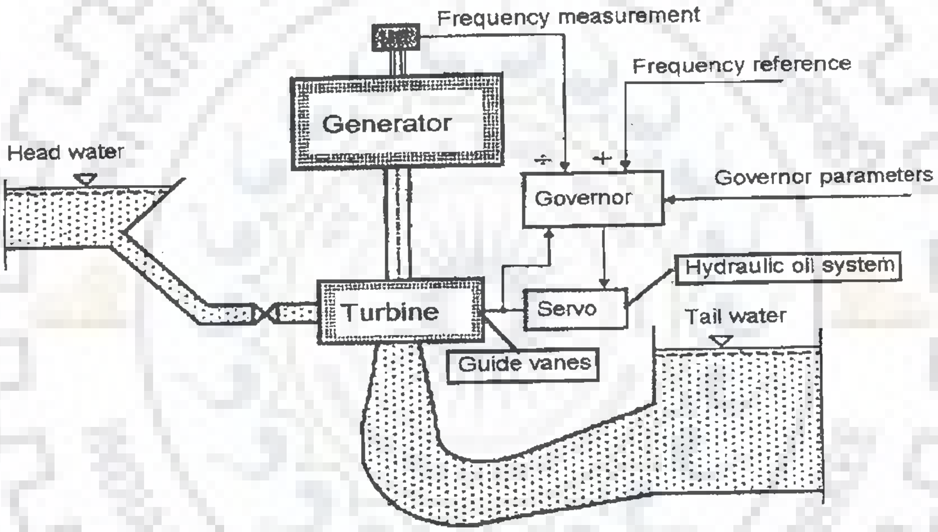


Fig.2.14 Hydro power plant with speed governor principle [138]

2.3.7 Electrical and Mechanical Auxiliary Equipment

In the powerhouse, there are several equipments which are known as electrical and mechanical auxiliary equipment. It is not necessary that all these equipments as listed below will be required in each plant. Their requirement depends upon the type of turbine generator control and protective system planned for the scheme. The different types of electrical and mechanical auxiliaries are given below [144];

(i) Control boards (ii) Storage battery and chargers (iii) Inverter (iv) Carrier current equipment (v) Generator voltage switchgear, buses, and surge protection equipment (vi) Lightning transformers and switchgear (vii) Unit auxiliary power transformers (viii) Generator neutral grounding equipment (ix) Water supply system for cooling water (x) Dewatering system (xi) Insulating and lubricating oil transfer, storage and purification systems (xii) Compressed air systems (xiii) Fire protection systems (xiv) Heating, ventilation and air conditioning system (xv) Turbine flow meters (xvi) Water level transmitters and recorders (xvii) Station drainage system (xviii) Transformer oil pumps and coolers

2.3.8 Transformer and Switchyard

Main power transformers are provided to convert electric power from one voltage level to another. In hydro-electric plants, large step up transformer perform the task of delivering power produced by the generator to the transmission system. Most of these transformers are unit connected i.e. generator is directly connected to step up transformers with or without a generator breaker. These power transformers are known as generator transformers. Power transformers are liquid immersed and generally located outside. Other smaller transformers provide auxiliary and local power need of the power plant. These are unit auxiliary or station transformers. Unit auxiliaries transformers are tapped from generator bus in case of unit connected transformers. The auxiliary transformers are dry type.

The general arrangement and design of outdoor switchyard is based on the voltage and capacity of the main busses and transmission lines, number of generator and transformer, transmission line bays required, location of the main power transformers, direction of transmission lines leaving in the yard and topography of the space available. The switchyard is planned to provide adequate space for the safe movement for maintenance of equipment and for the future movement of circuit breakers and other major equipment to position without disturbing existing buses and equipment. An anti climbable wire net fencing approximately 2 m high with lockable gates are provided to enclose the entire switchyard [145, 146].

CHAPTER-3

SIZING OF COMPONENTS OF LOW HEAD SHP SCHEMES

3.1 GENERAL

As discussed in previous chapters, low head schemes cover run-of-river, dam toe and canal based SHP schemes, accordingly, the type of small hydro power schemes and their components have been discussed in Chapter-2. In decision making for development of a SHP project, economic and financial viability is very important along with technical feasibility. The cost of project is estimated based on data availability in terms of survey data, location of project, drawings, specifications and prices of various items. In order to estimate the realistic cost of SHP scheme, detailed investigations for topography, hydrology, environment and ecology, geology, construction material are required to be carried out in detail. Prices of different items, preliminary layout and drawings of the components of the project and specifications of hydro- mechanical and electrical equipments are also required. Layouts of SHP schemes are considered to be site specific, however, these can be standardized by considering some criteria.

Under this chapter, steps involved in the development of a SHP project have been discussed. An attempt has been made to carry out the sizing of components in order to analyze the cost of the project. The cost sensitive parameters have been identified and discussed. Based on the cost sensitive parameters, the sizing of different layout of low head SHP scheme has been evolved. The standardised layouts have been considered for further cost analysis and optimisation, based on the sizes in subsequent chapters.

3.2 STAGES FOR DEVELOPMENT OF SHP PROJECTS

The development of small hydro power schemes follows well defined two main stages; (i) project formulation and planning and (ii) implementation of the project. Each stage takes the project a step forward in the development cycle based on the findings from the actual and previous stage. The major part of investigation includes, data collection and planning takes place in the first stage, while detailed engineering designs of components, procurement of material and equipment, construction of civil works, commissioning and start up of installations are carried out in second stage.

3.2.1 Project Formulation and Planning

This is pre-construction stage. All investigations, data collection, project formulation, feasibility study, report preparation is carried out during this stage. Several planning parameters, comprehensive data and informations are required for investigation of small hydro power resources and planning of SHP projects. The main data are derived from the studies of topography, hydrology, geology and materials. The steps involved in project formulation and planning are presented in Fig. 3.1.

This stage comprises of two parts. In the first part, prefeasibility study is carried out based on data collected on topography, hydrology, geology and environmental constraints by reconnaissance survey of the project area. The project found non-feasible is dropped and feasible projects are taken up for part-2 study.

In part-2 of this stage of SHP development, detailed survey and investigations on topography, hydrology, geology, material availability, environmental aspects are carried out. Based on the data collected water power analysis, technical and financial details are worked out and feasibility report is prepared. Feasibility report is a comprehensive document containing project objectives, scope of project, location, topography, hydrology, geological aspects, environmental aspects, details of works such as civil, hydro-mechanical and electrical equipments, broad specifications of the civil works/equipments, size of components, estimated cost of components, economical and financial analysis. Based on the techno-economical analysis, feasibility of the project is presented in the report.

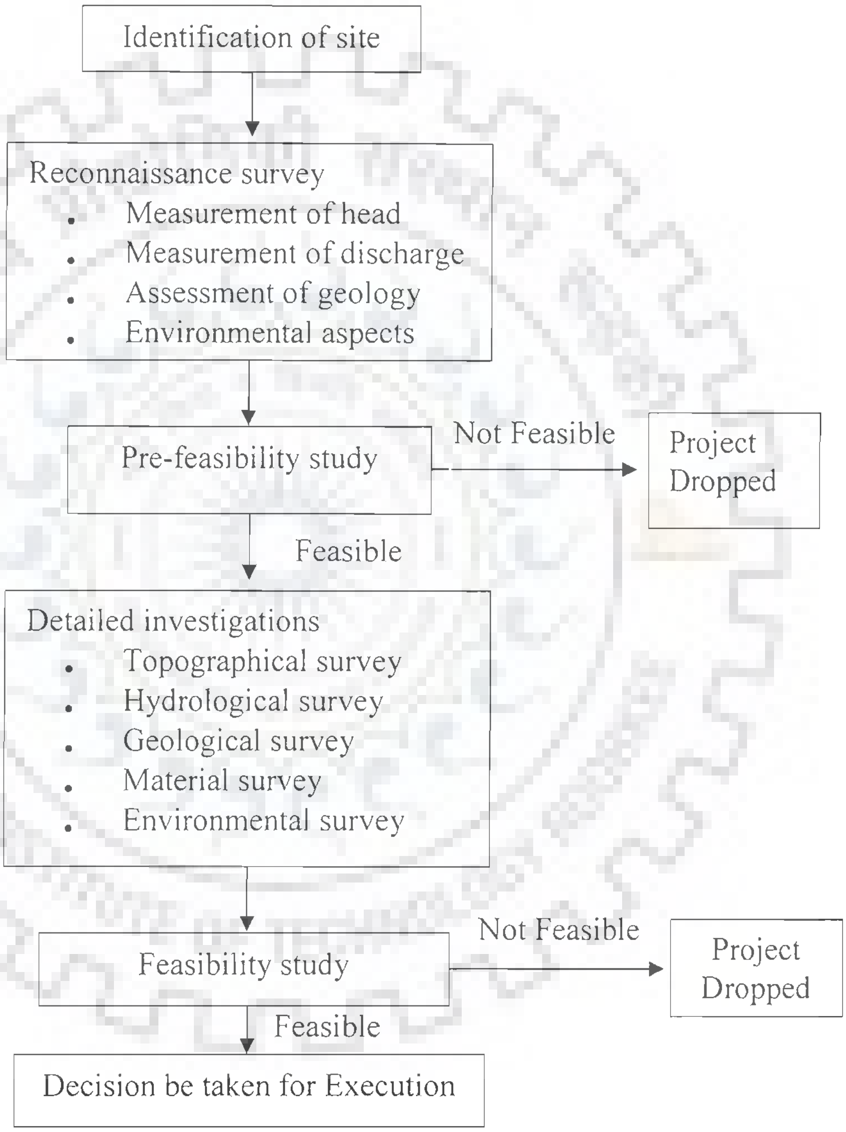


Fig. 3.1 Steps involved in project planning

3.2.2 Project Implementation

The feasibility report is the logical conclusion of investigations, planning, technical, economic and financial evaluation of SHP project. Techno-economically proven projects are taken up for the implementation. Following approval of a project for construction and allocation of funds the definite implementation is undertaken. The construction schedule is prepared taking into consideration the availability of manpower, materials and equipment and the rate at which construction funds can be obtained. The execution of project involves several activities in different stages. First stage i.e. pre-construction stage involves activities such as (i) statuatory clearances i.e. land acquision, environmental, power evacuation arrangement, power purchase agreement, (ii) engineering designs and (iii) preparation of tender documents, invitation of bids, evaluation of bids and award of work to the prospective bidder. After the placement of order for construction of civil works and installation of equipment, second stage i.e. construction stage takes place. During this stage procurement of materials and equipments, construction of civil works, installation and commissioning of equipment is carried out.

Small hydro power projects are considered as complex projects involving different disciplines for designs, construction, supplies, erection and commissioning of the equipment. For timely implementation of the project, proper co-ordination, quality control, monitoring of time schedule and financial management is required.

The project planning study requires substantial investment in terms of time, efforts and finances to determine the feasibility of the project. After carrying out all these efforts, if the project is found techno-economically non-viable, all the investments made will become a waste exercise. Therefore, it has been attempted to develop a methodology for assessment of cost of the project to know the realistic cost of the project for determination of its techno-economical viability before undertaking detailed investigations so that only feasible projects are undertaken for detailed investigations and implementation.

3.3 COST SENSITIVE PARAMETERS

The cost of SHP schemes is site specific based on type of scheme, type of components, land and infrastructural facilities required for execution. The cost of components constitute the major portion of installation cost, which is governed by the physical sizes of the components, construction methodology, type of layout, soil conditions and type of equipment. The sizes of civil works are governed by their discharge carrying capacity and discharge is computed based on head and capacity of the scheme. In electro-mechanical equipment, turbine and generator contribute major portion towards the cost. The size of turbine is represented by its runner diameter while size of generator is governed by the capacity and speed. The speed of generator depends on the speed of turbine. The runner diameter and speed of turbine are related to the head and capacity of the scheme. Therefore, head and capacity considered as most cost sensitive parameters.

Further, as India is a vast country, it consists of different regions having different type of soils. The earth crust consists of two main components, i.e. rock and soil. Rock is defined as hard and compact natural aggregate of mineral grains cemented by stones and permanent bonds. Soil is defined as a natural aggregate of mineral grains, loose or moderately cohesive, organic or inorganic in nature that has the capacity of being separated by simple mechanical process. In case of small hydro power projects, the concern is mainly with 10 to 15 m top mantle of soil. An understanding of soil deposit at the project site is helpful tool in planning the foundation of the project. Soils are classified on the basis of soil depth, color, texture, structrue, chemical composition, and the presence of certain diagnostic horizons. Diagnostic horizons are based on combinations of thickness, color, chemistry and texture. Soil consists of organic matter, soil organisms like micro Fauna and flora and flaura and inorganic matter such as macro and micro materials [147, 148].

Broadly soils are categorised as residual soils formed by weathering of rocks but located at the place of origin and transported soils classified according to the mode of their transportation and deposition i.e. by flowing water, wind, gravity and ice.

The various types of soils available are popularly termed as sand, silt, clay, gravel, black cotton, peat, boulder, rocks etc. From the excavation cost point of view, the soil is classified broadly as ordinary soil, soft rock and hard rock. The cost on excavation is different for the different type of soils. Ordinary soil and soft rock are excavated manually or mechanically without using blasting. Hard rock need blasting for excavation. Hence extra safety measures are required and it becomes the costliest for excavation in hard rocks. In case of hard rocks, the bearing capacity of soil is more and also there is no problem of dewatering during construction. The power station and associated structures are constructed near water bodies i.e. canal or river. When, water table is high, in that area lot of expenditure has to be incurred on dewatering to facilitate construction. The problem/expenditure on dewatering is not there in case of soft rocks or hard rocks. In the present study ordinary soil, soft rock and hard rock are considered for cost analysis.

As discussed in chapter 2, there are three types of SHP schemes; canal based, dam toe and run-of-river. Canal based schemes come under low head category where as dam toe and run-of-river schemes cover low head as well as medium and high head categories. Further various components under different schemes have also been discussed. It is seen that the dam toe and run-of-river schemes under medium/ high heads are more site specific due to variation in topography. It is also seen that all SHP schemes have their basic components like water conductor system, electro-mechanical equipment and power house building, but the type and size of these components are site specific and according to the type of scheme. Keeping this in view, under the present study, all the components are discussed and sized specifically for all the three schemes in order to standardize the cost. The components of a SHP scheme are devided into two major categories (i) Civil works and (ii) Electro-mechanical equipment.

Civil works components are different in different type of schemes. Hydro-mechanical equipment such as gates, valves and trash racks have been considered alongwith civil works wherever required. Turbines being major hydro-mechanical equipment have been considered under electro-mechanical equipment. However, electro-mechanical components are similar for same head and capacity irrespective of type of scheme.

In order to determine the cost of the components of low head SHP projects under various schemes, the sizing of the components are evolved. Components of SHP scheme under civil works and electro-mechanical equipment are sized /selected based on the head and capacity of the scheme.

3.3.1 Components of Canal Based SHP Schemes

The canal based SHP scheme has a simple layout to generate electricity from the water flowing in the canal at available fall. The power house can be planned in the canal itself or in the diversion channel. Following layouts have been considered for sizing and cost analysis.

i. Power house building in diversion channel and spillway in main canal

As shown in Fig. 3.2, a diversion channel (bye pass channel) has been taken off from the main canal to establish power house building. The fall structure in the main canal is provided with gated structure to allow surplus water to flow in case power house is utilizing lesser discharge than available in the canal.

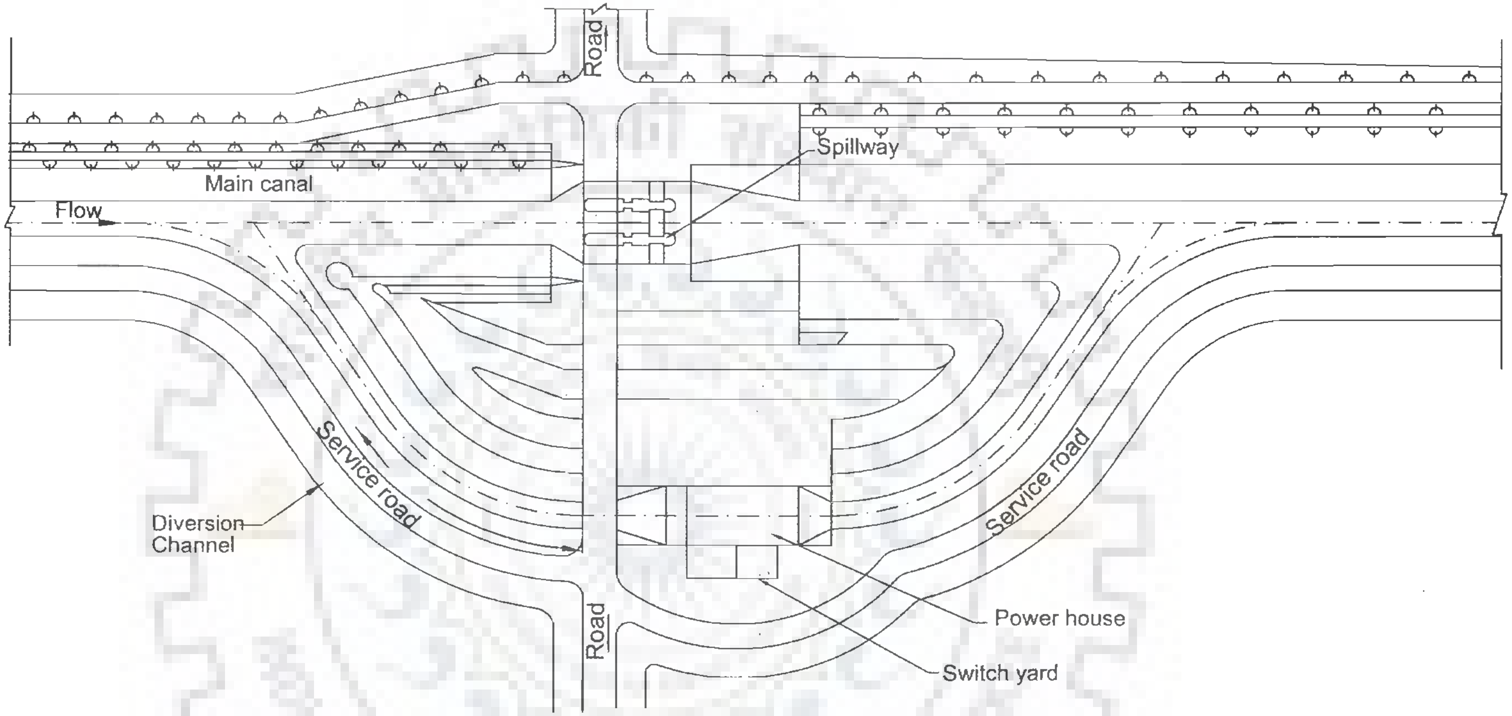


Fig. 3.2 Layout of canal based SHP scheme with power house in diversion channel and spillway in main canal

Depending upon site condition location of power house and spillway can be interchanged i.e. power house building in main canal and spillway in bye pass channel. The design criteria will remain same in both the alternatives.

ii. Power house building and spillway combined in main canal and diversion channel

As shown in Fig. 3.3, power house building and spillway is provided in the main canal and there is no structure in the diversion channel. This has been considered to have better regulation in combining power house and spillway together. Generally canals are meant for irrigation purpose and canal closure can not be afforded for longer period required for construction of power house and spillway. Thus diversion channel is provided to facilitate the water flow during construction period and additional safety inflow regulation.

iii. Power house building and spillway combined in main canal without diversion channel

As shown in Fig 3.4, power house building and spillway are provided together in the main canal and no diversion channel is provided. Such arrangement is applicable in case of new canals under construction or being planned. This type of layout can also be considered where, canal closure for construction period of power house and spillway can be afforded.

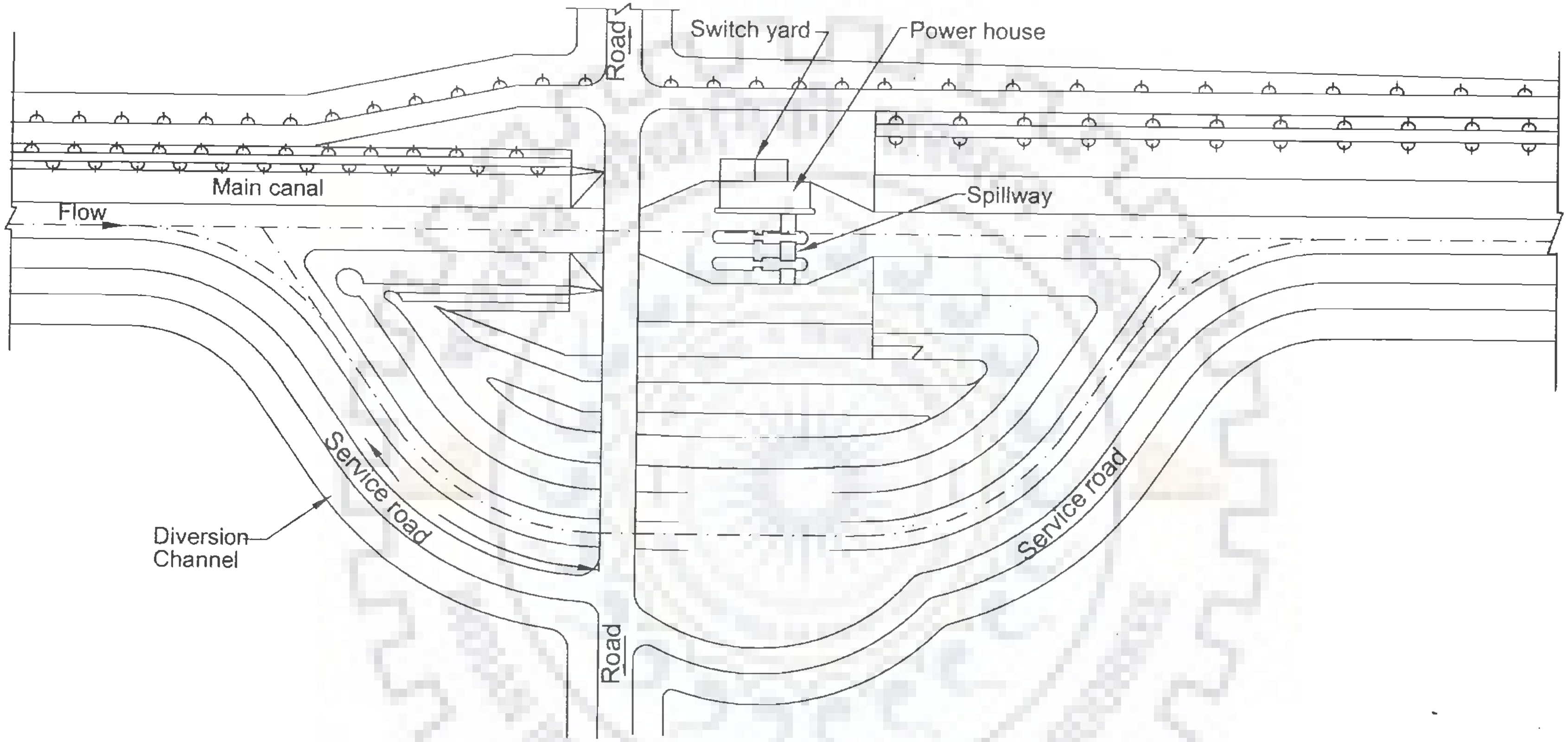


Fig. 3.3 Layout of canal based SHP scheme having power house and spillway combined in main canal and diversion channel

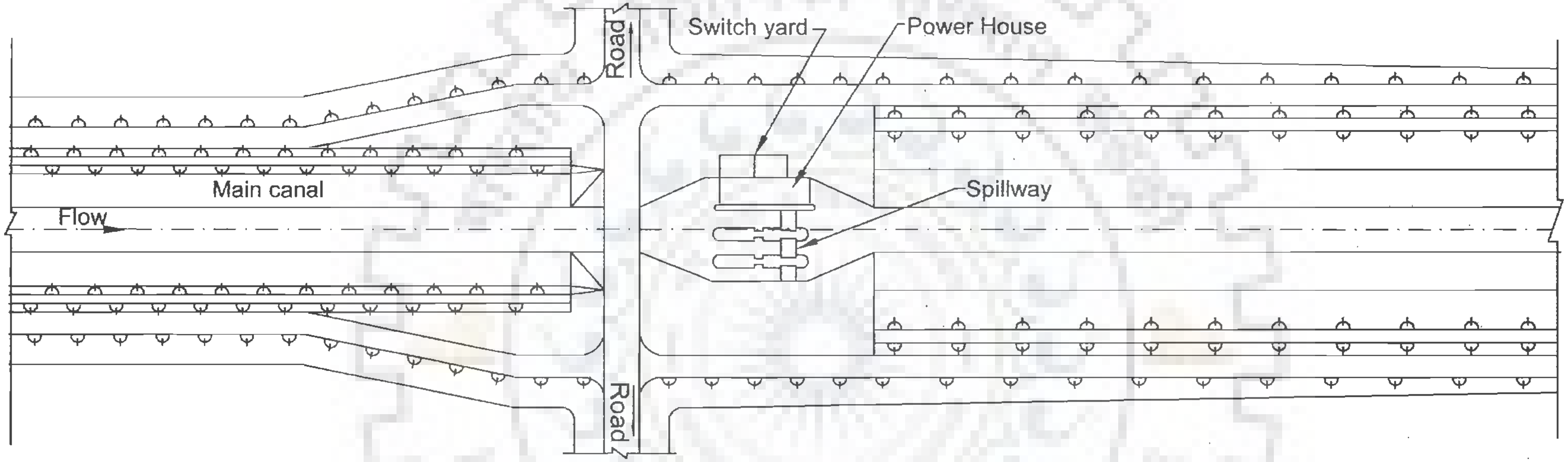


Fig. 3.4 Layout of canal based SHP scheme having power house and spillway combined in main canal

3.3.1.1 Civil works

In order to analyse the cost of various components which come under civil works of canal based SHP schemes, the main components are considered for sizing. Based on the hydraulic design, the sizes of various components have been worked out. The structural design as per the existing projects has been considered for all the cases.

3.3.1.1.1 Diversion channel

The channel has been considered as trapezoidal with plain cement concrete (PCC) lining. The channel cross section is designed as most efficient hydraulic section. The diversion channel is designed by using Manning's formula expressed by the following expression [149] ;

$$Q = \frac{AR^{2/3} S_l^{1/2}}{n} \qquad (3.1)$$

Where,

Q	is Discharge, m^3/s
A	is Area of cross section, m^2
R	is Hydraulic radius, m
S_l	is Longitudinal slope of channel, degree
n	is Manning's roughness coefficient

For most efficient hydraulic section hydraulic radius is worked out by using following expression [149];

$$R = h / 2 \qquad (3.2)$$

Where,

h	is the water depth, (m)

Channel cross sections are designed based on the design discharge, for different head and capacities. Being concrete section, manning's coefficient (n) is taken as 0.018 [149]. A typical cross section of diversion channel is shown in Fig. 3.5.

G.L.- Ground level.
F.S.L.- Full supply level.

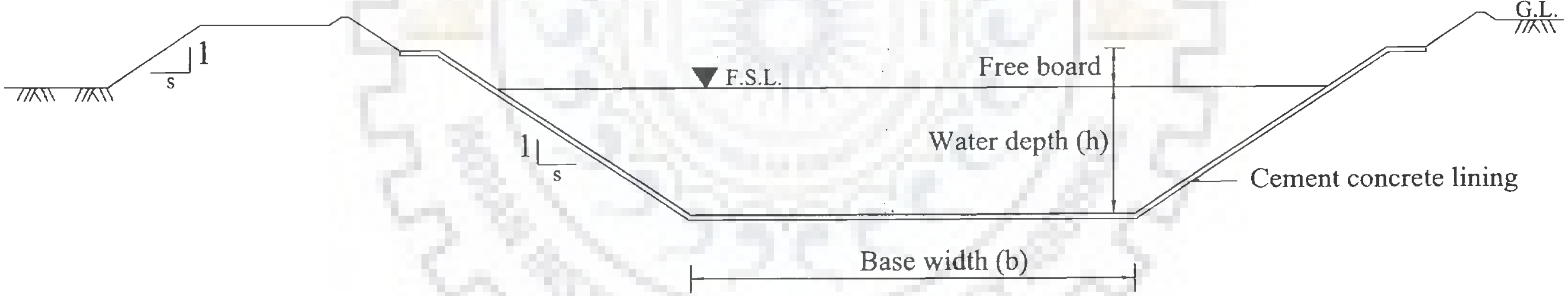


Fig. 3.5 Cross section of diversion channel

3.3.1.1.2 Spillway

The capacity of the spillway has been considered to pass the surplus water equivalent to the design discharge of the canal. It is designed by using the following expression [149].

$$Q = CLH_S^{3/2} \tag{3.3}$$

Where;

Q is Discharge in, m^3/s

C is Discharge coefficient

L is Length of spillway crest, m

H_S is Head over spillway crest, m

The material for spillway structure is considered as reinforced cement concrete (RCC). Automatically operated radial gates are considered over the spillway crest to operate the flow and the crest of spillway is considered as broad crested, accordingly discharge coefficient (C) was taken as 1.7 [149]. A typical arrangement of spillway is shown in Fig. 3.6.

3.3.1.1.3 Power house building

A RCC frame structure has been considered for powerhouse building. The layout of power house building is worked out based on runner diameter (D) and type of turbine considered for power house building at different head and capacity by using following expressions [69];

$$D = \frac{84.6\theta_3 (H)^{1/2}}{N} \tag{3.4}$$

$$\theta_3 = 0.0223 (N_s)^{2/3} \tag{3.5}$$

$$N_s = \frac{N\sqrt{P_u x\ 1.358}}{H^{5/4}} \tag{3.6}$$

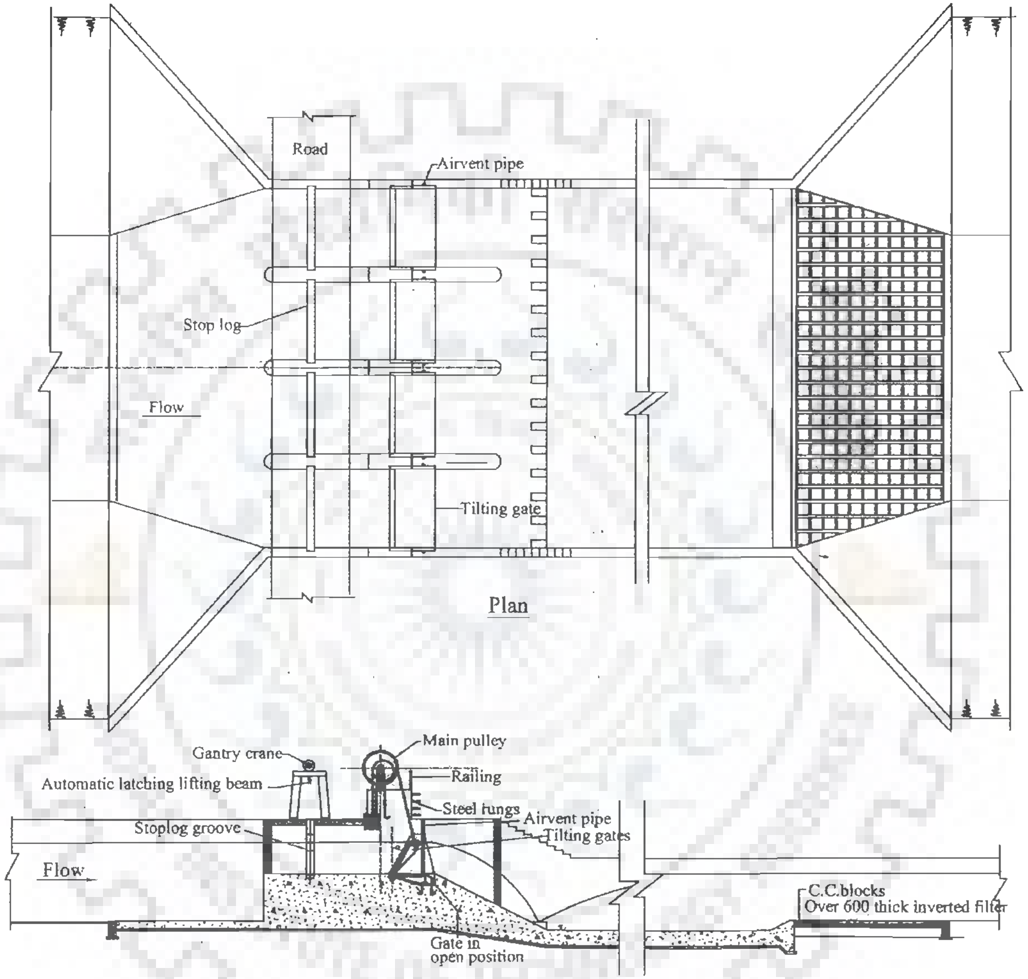


Fig. 3.6 Plan and section of spillway

Where,

θ_3 is the velocity ratio at discharge diameter of runner

N_s is the specific speed of turbine, metric

N is the rotational speed of turbine, RPM

H is the rated net head, m

P_u is the rated unit output power at full gate opening, kW

The sizing of powerhouse building with layouts having different type of turbines has been carried out as per IS: 12800 (Part-3) [69] as detailed below;

3.3.1.1.4 Layout with tubular turbines

Length of power house building along the flow = 8.0 x D

Width of power house for one unit = 2.1 x D

Centre to centre spacing of machines = 3.0 x D

Additional space of 3 to 8 m depending on size of machine has been provided on one side of the machine for erection purposes. The plan of powerhouse building with tubular turbine is shown in Fig. 3.7. The dimensions of power house in term of runner diameter are shown in Fig. 3.7 and Fig. 3.8.

3.3.1.1.5 Layout with bulb turbine

Length of power house building along the flow = 5.0 x D

Width of power house for one unit = 2.7 x D+ 1.8 m

Centre to centre spacing of machines = 3.0 x D

Additional space of 3 to 8 m has been provided on one side of the machine for erection purposes. The plan and longitudinal section of powerhouse with bulb turbine are shown in Fig 3.9 and Fig. 3.10.

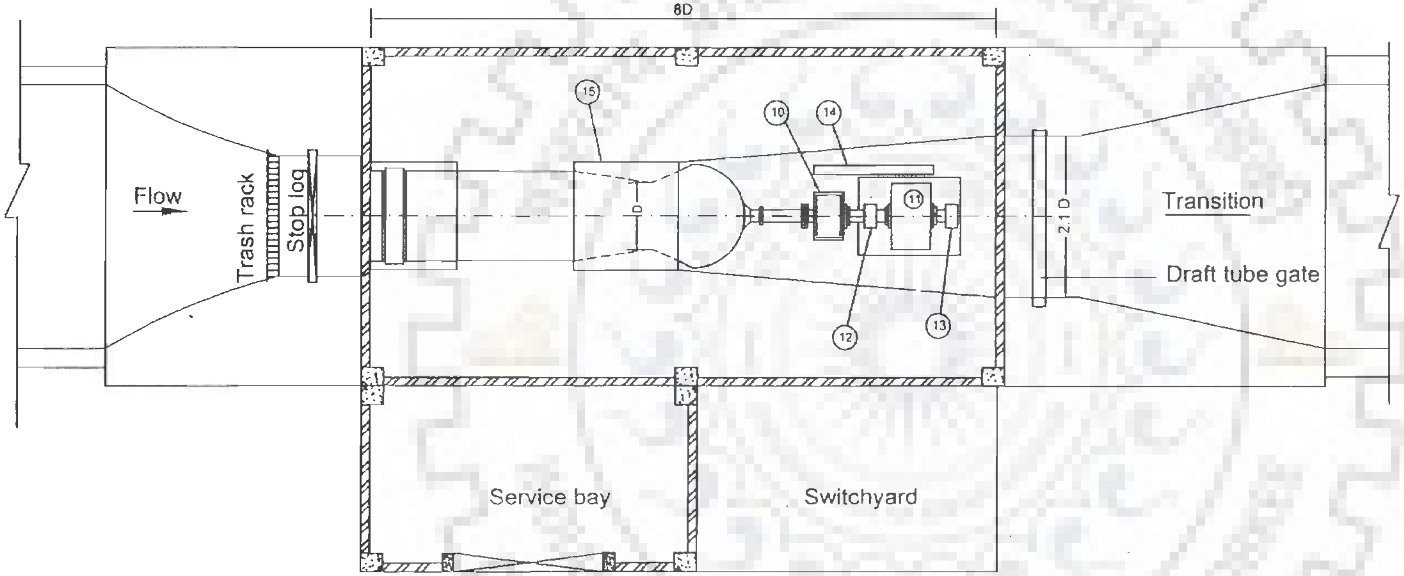
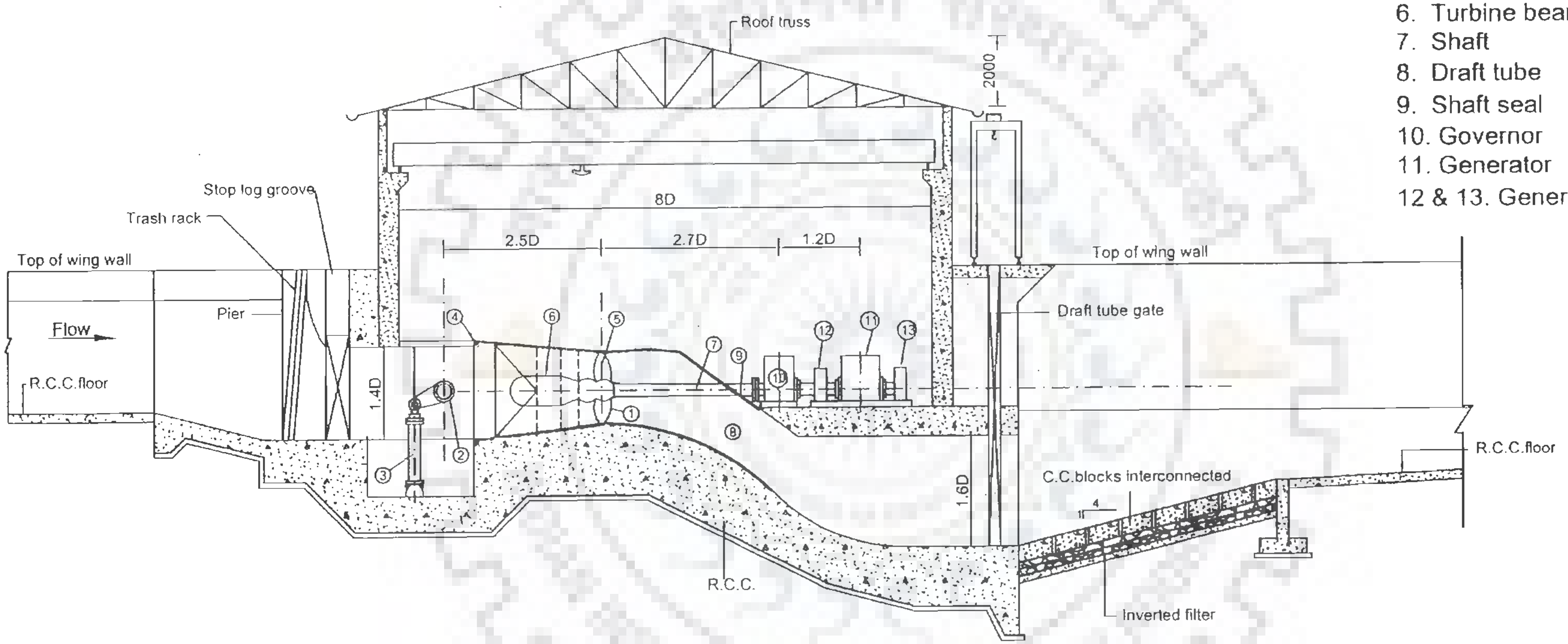


Fig. 3.7 Plan of power house building having tubular turbine

Equipments marked

1. Runner
2. Main inlet valve
3. Valve servo motor
4. Stay vane
5. Runner chamber
6. Turbine bearing
7. Shaft
8. Draft tube
9. Shaft Seal
10. Governor
11. Generator
12. Generator bearing
13. Generator bearing
14. Control and protection cubicle
15. Turbine



Equipments marked

1. Runner
2. Main inlet valve
3. Valve servo motor
4. Stay vane
5. Runner chamber
6. Turbine bearing
7. Shaft
8. Draft tube
9. Shaft seal
10. Governor
11. Generator
12 & 13. Generator bearing

Fig. 3.8 Longitudinal section of power house building having tubular turbine

Equipments marked

1. Generator
2. Turbine
3. Governor
4. Generator breaker
5. Control panel
6. Neutral ground cubicle
7. Surge and protection cubicle
8. Sump pumps
9. Air compressor and tank

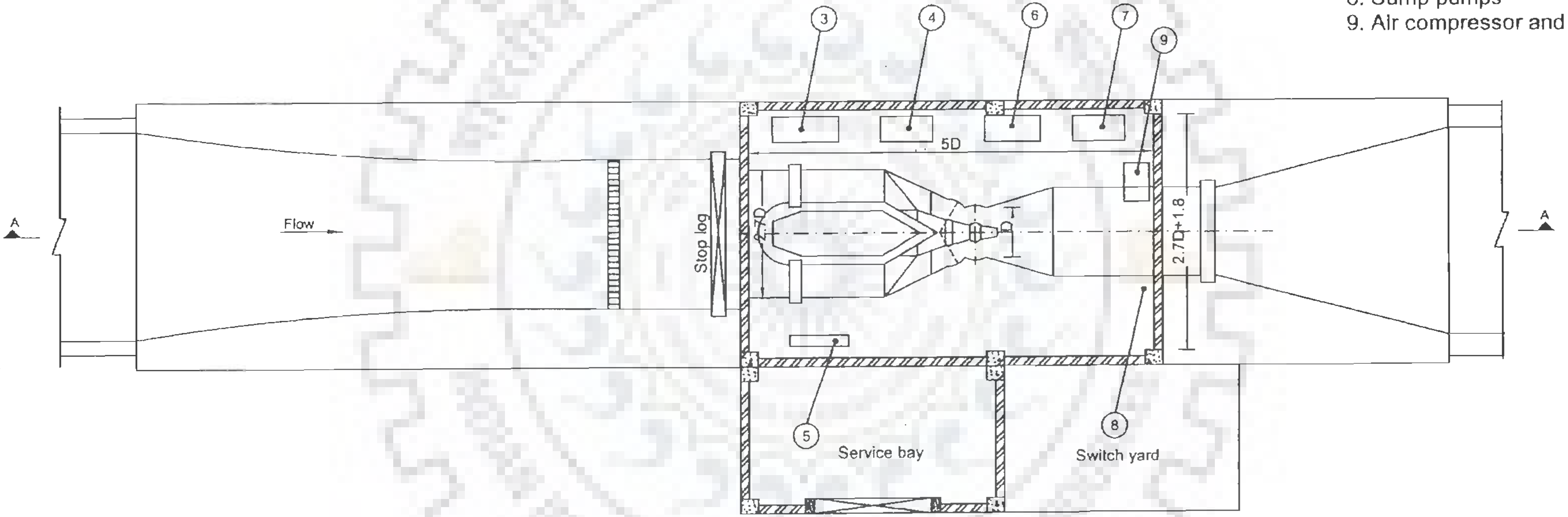


Fig. 3.9 Plan of power house building having bulb turbine

Equipments marked

1. Generator
2. Turbine

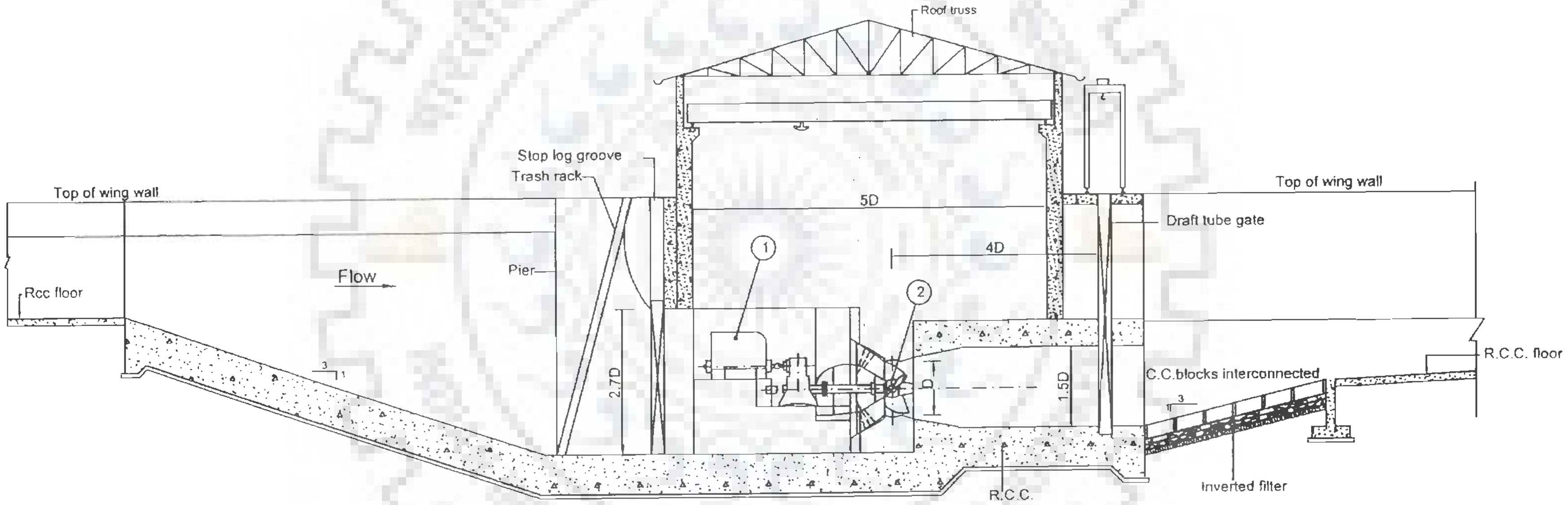


Fig. 3.10 Longitudinal section of power house building having bulb turbine

3.3.1.1.6 Layout with vertical turbine

In order to determine the size of powerhouse building, dimensions of scroll casing and draft tube are worked out in terms of runner diameter (D) as per IS:12800 (Part 3) [69] and are detailed below.

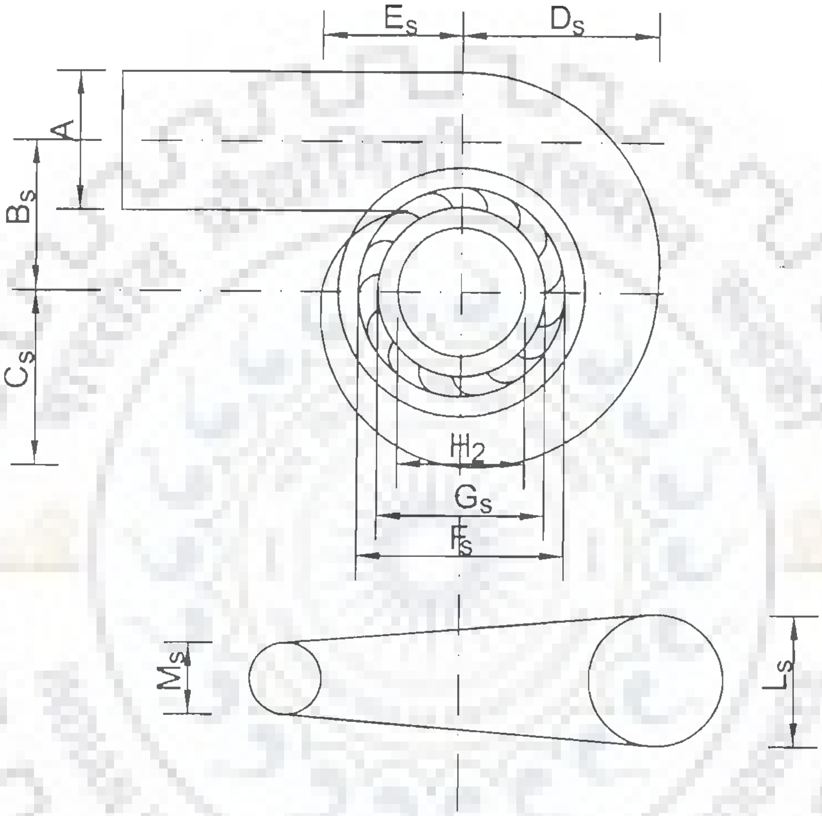


Fig. 3.11 Plan and section of scroll case [69]

$A_S = 1.15$ D, $B_S = 1.25$ D, $C_S = 1.45$ D,

$D_S = 1.63$ D, $E_S = 1.15$ D, $F_S = 1.40$ D,

$G_S = 1.18$ D, $H_S = 1.04$ D, $L_S = 1.1$ D,

$M_S = 0.6$ D

Dimensions of draft tube are determined as per IS:12800 (Part 3) [69]

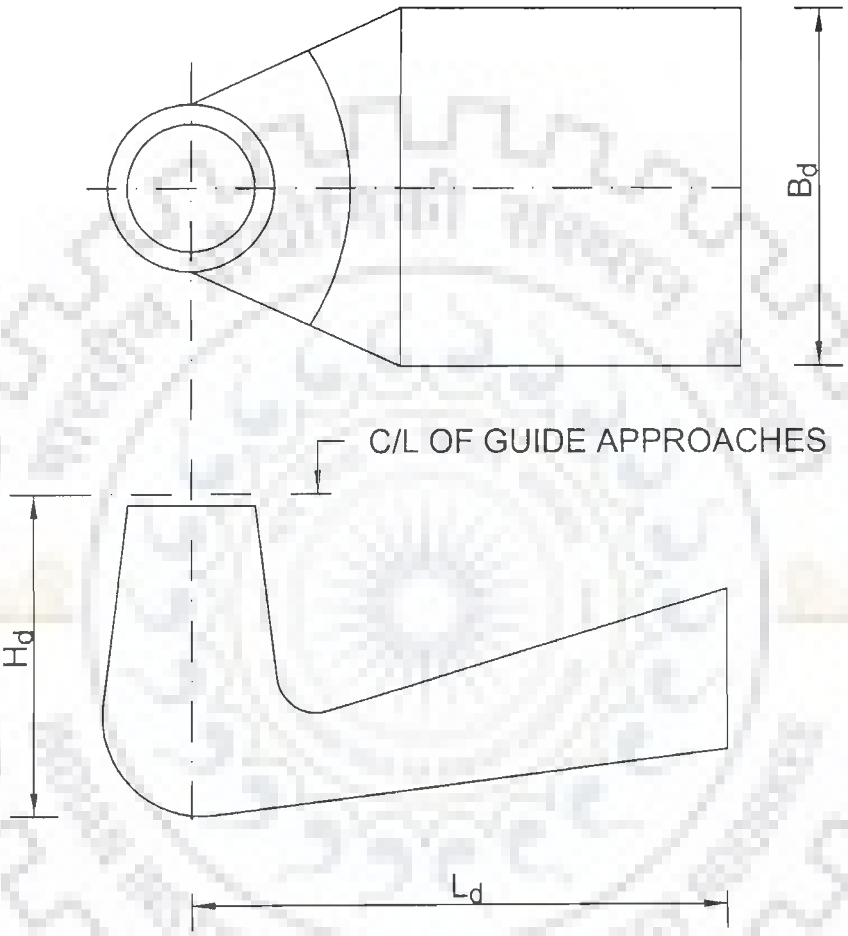


Fig. 3.12 Plan and section of draft tube [69]

Depth of draft tube, $H_d = 2.65 \times D$

Length of draft tube, $L_d = 4.5\ D$

Width of draft tube, excluding pier, $B_d = 2.95\ D$

Based on the dimensions of scroll case and draft tube, the size of power house building has been worked out. The typical plan and longitudinal section of powerhouse with vertical turbine are shown in Fig 3.13 and Fig. 3.14.

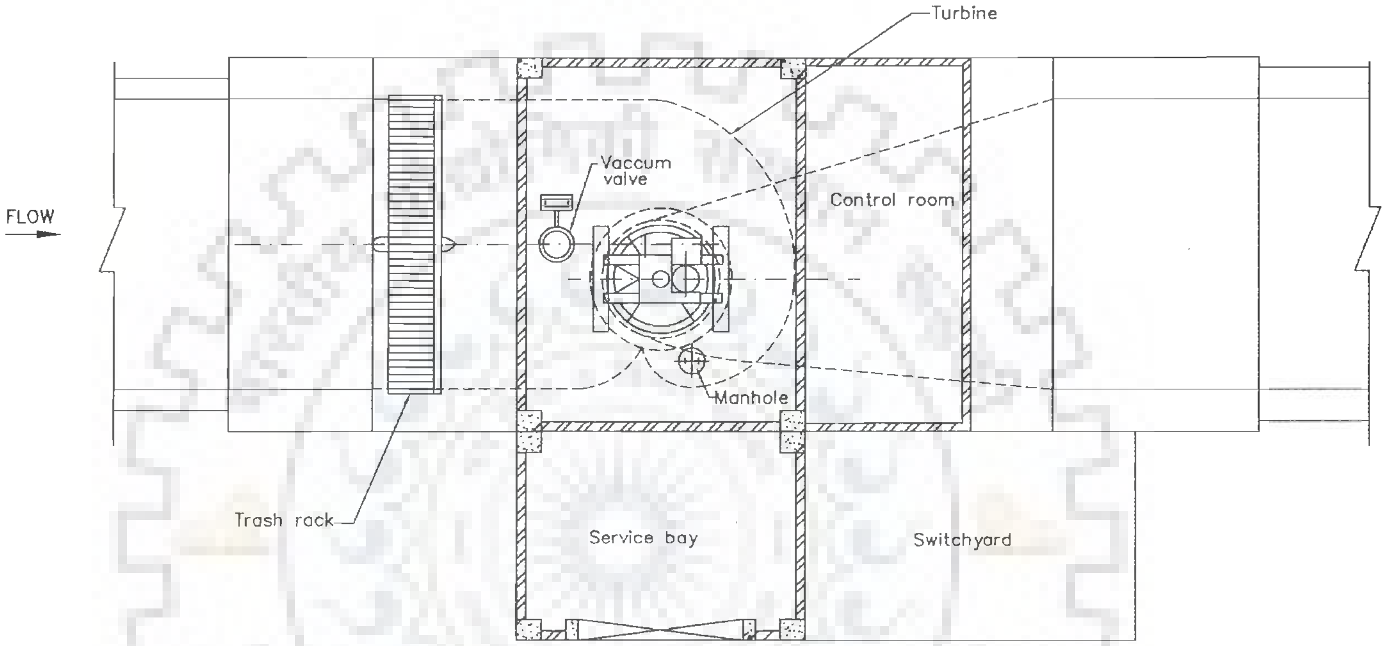
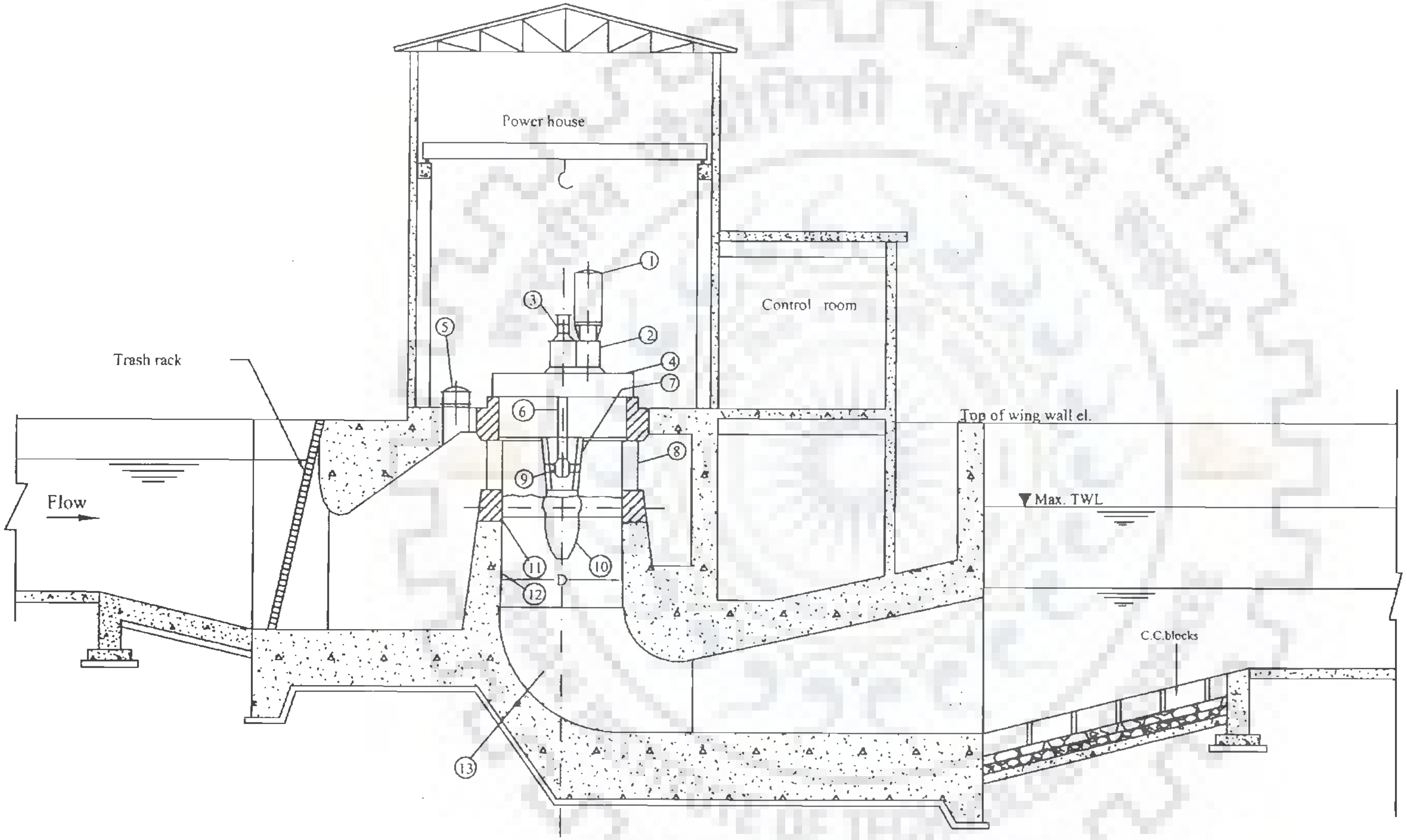


Fig. 3.13 Plan of power house building having vertical turbine



LEGEND	
S.NO.	DESCRIPTION
1.	Generator
2.	Speed increaser
3.	Servomotor
4.	Chassis
5.	Vaccum valve
6.	Turbine shaft
7.	Head cover
8.	Distributor
9.	Guide bearing
10.	Runner assembly
11.	Discharge ring
12.	Draft tube cone
13.	Draft tube elbow

Fig. 3.14 Longitudinal section of power house building having vertical turbine

3.3.2 Components of Run of River SHP Schemes

Components of run-of-river schemes are generally site specific. As discussed in chapter-2, there are alternatives in the components of the scheme such as; different types of diversion weir; trench weir, bush and boulder weir and sloping glacis to be selected on the basis of site conditions. Selection of forebay or surge tank on balancing reservoir is also site specific. In the present study, a simple scheme having diversion weir and intake, intake and head race channel, desilting tank, forebay and spillway, penstock, powerhouse building and tail race channel has been considered. The components of civil works considered for sizing of a run of river SHP scheme under low head are discussed as follows:

3.3.2.1 Diversion weir and intake

Different type of diversion weirs have been discussed in Chapter-2. Under the present study, sloping glacis type of weir is considered as it is the most suitable type of weir in low head schemes where river slope is mild. The weir is designed to pass highest flood discharge and the intake is designed to draw design discharge to pass through water conductor system for power generation. A typical layout of diversion weir considered under the present study is shown in Fig 3.15.

3.3.2.2 Intake and head race channel

Intake channel in between intake and desilting tank and head race channel from desilting tank to forebay is designed to carry design discharge required for power generation. The design criteria has been considered on similar lines as for diversion channel. Total length of intake and head race channel is considered 50 times of the head, based on experience on such projects. In high head schemes there could be steep slopes or vertical falls and the length of channel becomes site specific.

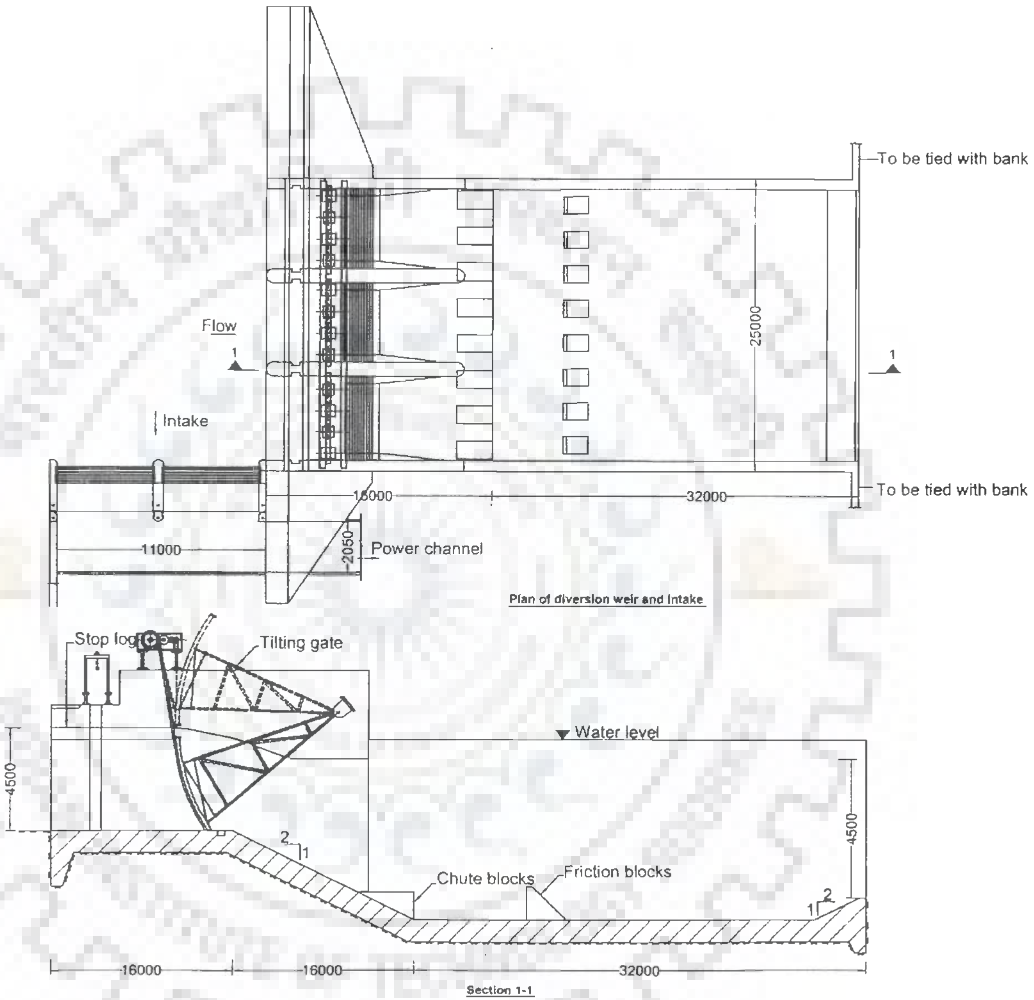


Fig. 3.15 Diversion weir and intake for run of river schemes

The channel cost depends on its length for a particular cross section and the length of channel increases with the head. Thus to have more realistic cost, analysis has also been carried out for cost of channel based on discharge and length.

3.3.2.3 Desilting tank

Desilting tank is considered as a RCC tank to remove silt entered into water conductor system so that silt free water reaches the forebay and then to turbine. As a normal practice 15% of design discharge is taken for silt flushing. Thus desilting tank is designed for 15% more than design discharge. In low head schemes, desilting tank is designed to exclude silt particles coarser than 0.5 mm. In high head schemes silt particles coarser than 0.2 mm need to be removed. The desilting tank is designed for horizontal velocity of flow as 0.6 m/s and settling velocity of particles as 0.06 m/s [133].

The velocity of water flow is reduced by providing more width in the desilting tank than channel. Such reduction in velocity reduces the bed shear stress and the turbulance. Reduction in the velocity, shear stress and the turbulance, the bed material stops from moving and also causes part of suspended load to desposit. Length (L_T), width (B_T) and water depth (d_T) of desilting tank is designed by using followings expression [133] ;

$$B_T \times d_T = Q_S / V_h \tag{3.7}$$

$$L_T = d_T / V_f \tag{3.8}$$

Where,

V_h	is horizontal velocity of flow, m/s
V_f	is fall velocity of silt particles, m/s
Q_S	is design discharge for desilting tank, m^3/s

Fall velocity (V_f) is worked out from the curve shown in Fig. 3.16 [150]. Corresponding to 0.5 mm particles size, fall velocity comes out to be as 0.06 m/s. The transitions in upstream from intake channel are provided at 12.5° an angle of and in the downstream from desilting tank to head race channel at 30° [23].

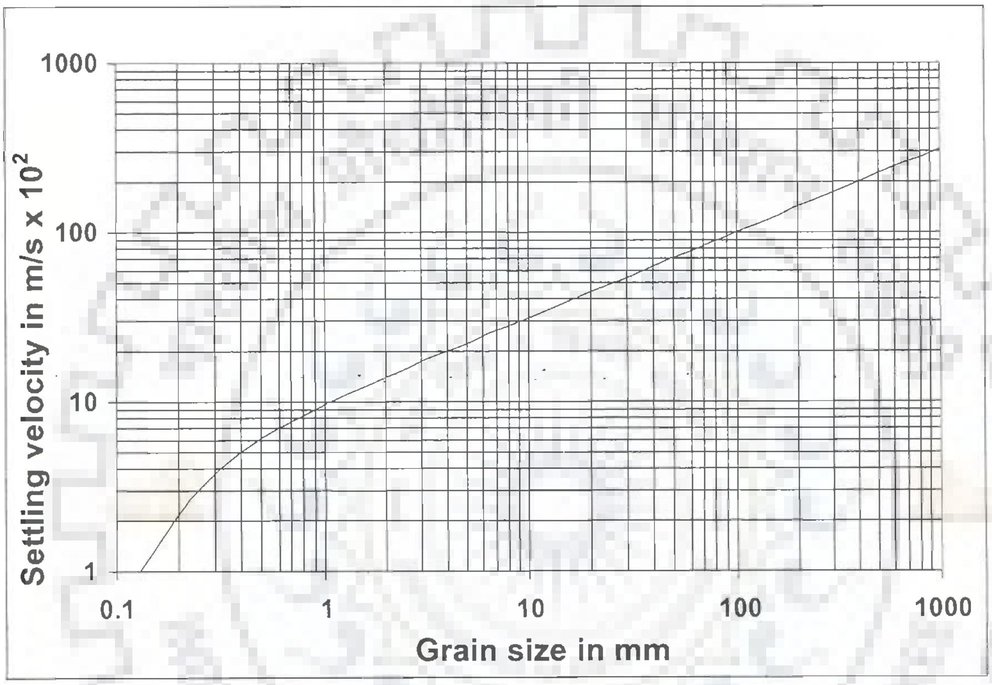


Fig. 3.16 Settling velocity for quartz grains [150]

A typical arrangement of desilting tank considered is shown in Fig. 3.17. For flushing of silt collected in the desilting tank, hoppers with silt flushing pipe are provided. Silt flushing pipes are discharged in the nearby stream at a level higher than high flood level in the stream.

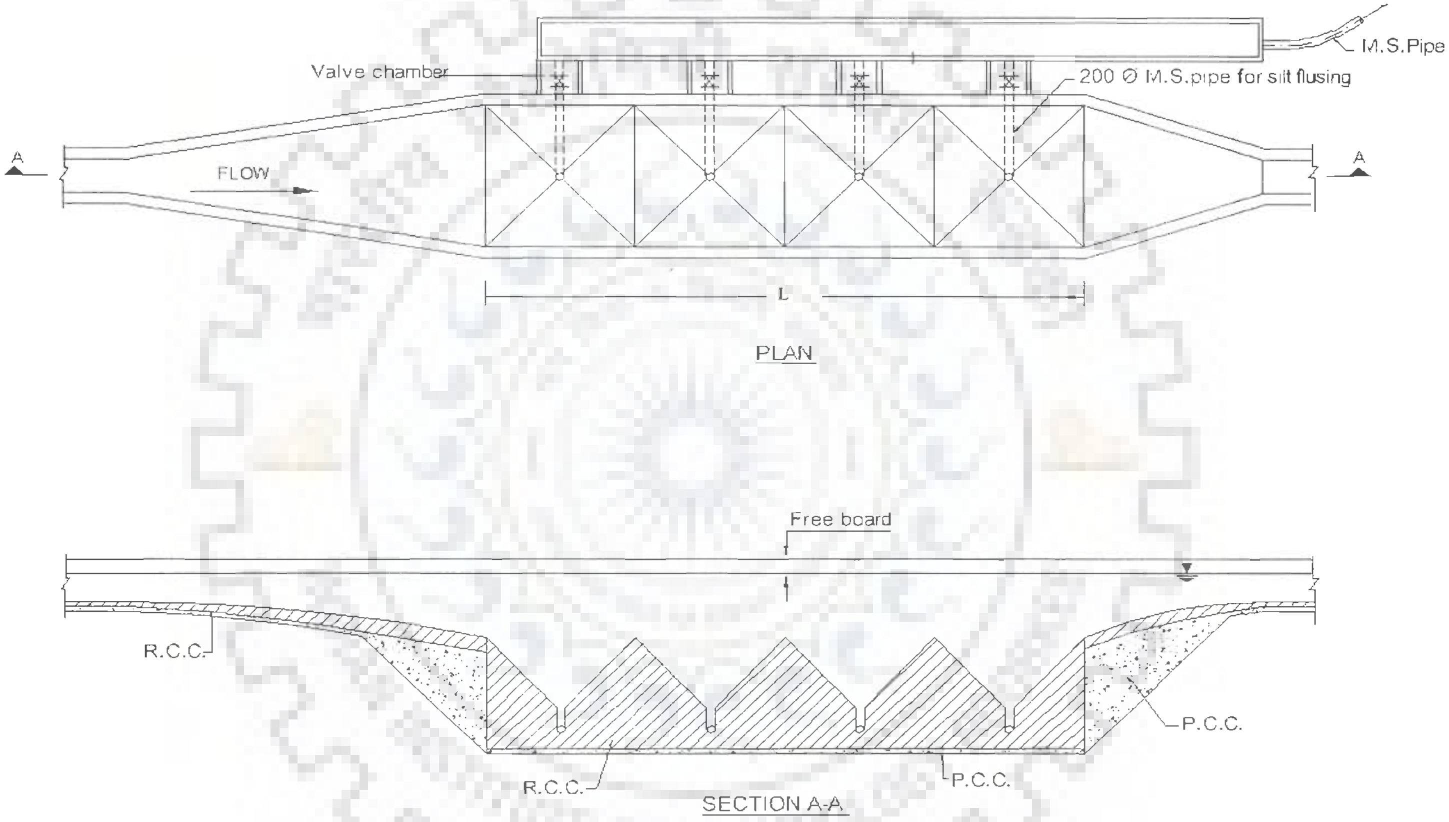


Fig. 3.17 Desilting tank for run of river scheme

3.3.2.4 Forebay

Spillway and spill channel are integral part of forebay in run-of-river scheme. These are designed as RCC structures. The forebay is designed for 2 minutes of storage capacity [151]. The volume (V_f) of forebay tank is worked out as;

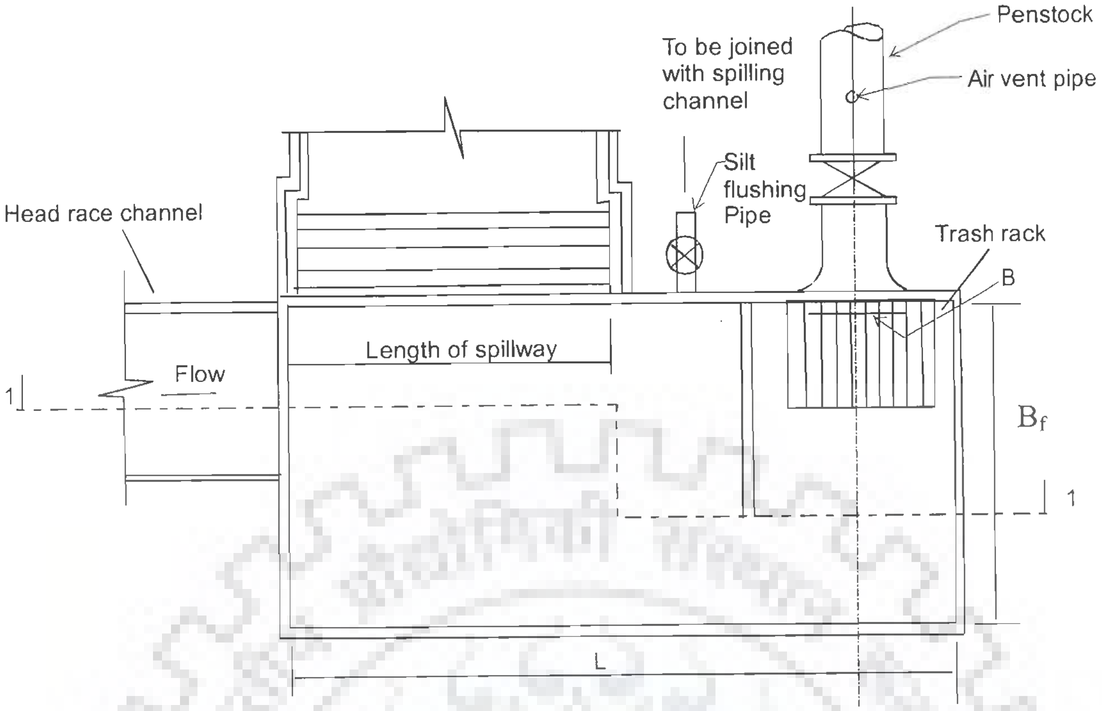
$$V_f = L_f \times B_f \times H_f = 2 \times 120 \qquad (3.9)$$

Where, L_f, B_f and H_f are length, width and water depth of forebay repsectively and Q is the design discharge in m^3/s. The depth of forebay has been considered on the basis of cover over the bell mouth entry to the penstock. A trash rack is also provided at the entrance to the penstock to check the floating material for not entering in the penstock. A typical arrangement of forebay is shown in Fig. 3.18. The height of forebay walls are worked out considering water depth, head over spillway and free board.

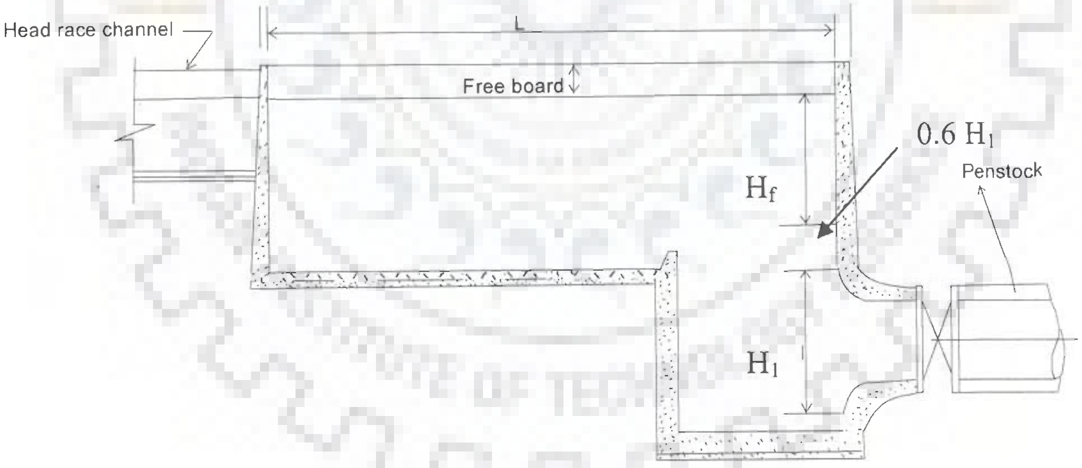
3.3.2.5 Penstock

In low head schemes, lengths of penstock are short, thus one penstock for each machine is considered to reduce loss on account of branching of pipe near the powerhouse. Steel penstock is considered in the analysis. The velocity of water in the penstock (V) is determined by using the following expression [23] to determine the diameter of penstock.

$$V = 0.125\ \sqrt{2gH} \qquad (3.10)$$



PLAN



SECTION 1-1

Fig. 3.18 Forebay for run of river scheme

Where, H is the net head, (m).

Thickness of penstock is determined as [20];

$$t = \frac{pd}{2f_s e} + 2mm \tag{3.11}$$

Where,

t	is penstock shell thickness, (mm)
p	is designed water pressure (static head + pressure rise due to water hammer), N/mm^2
d	is internal diameter of penstock, (mm)
f_s	is allowable stress in steel, (N/mm^2)
e	is joint efficiency

As a practice, additional 2 mm in thickness is considered for corrosion.

The length of penstock is site specific and varies with the head of scheme. In the analysis, length of penstock is considered 2.5 times of the net head based on the experience on such projects.

3.3.2.6 Spillway

Spillway is provided on one side of forebay and designed on similar line as discussed under the components of canal based schemes.

3.3.2.7 Power house building

The criteria for sizing of powerhouse building for such schemes has been considered on similar line as considered for canal based schemes.

3.2.2.8 Tail race channel

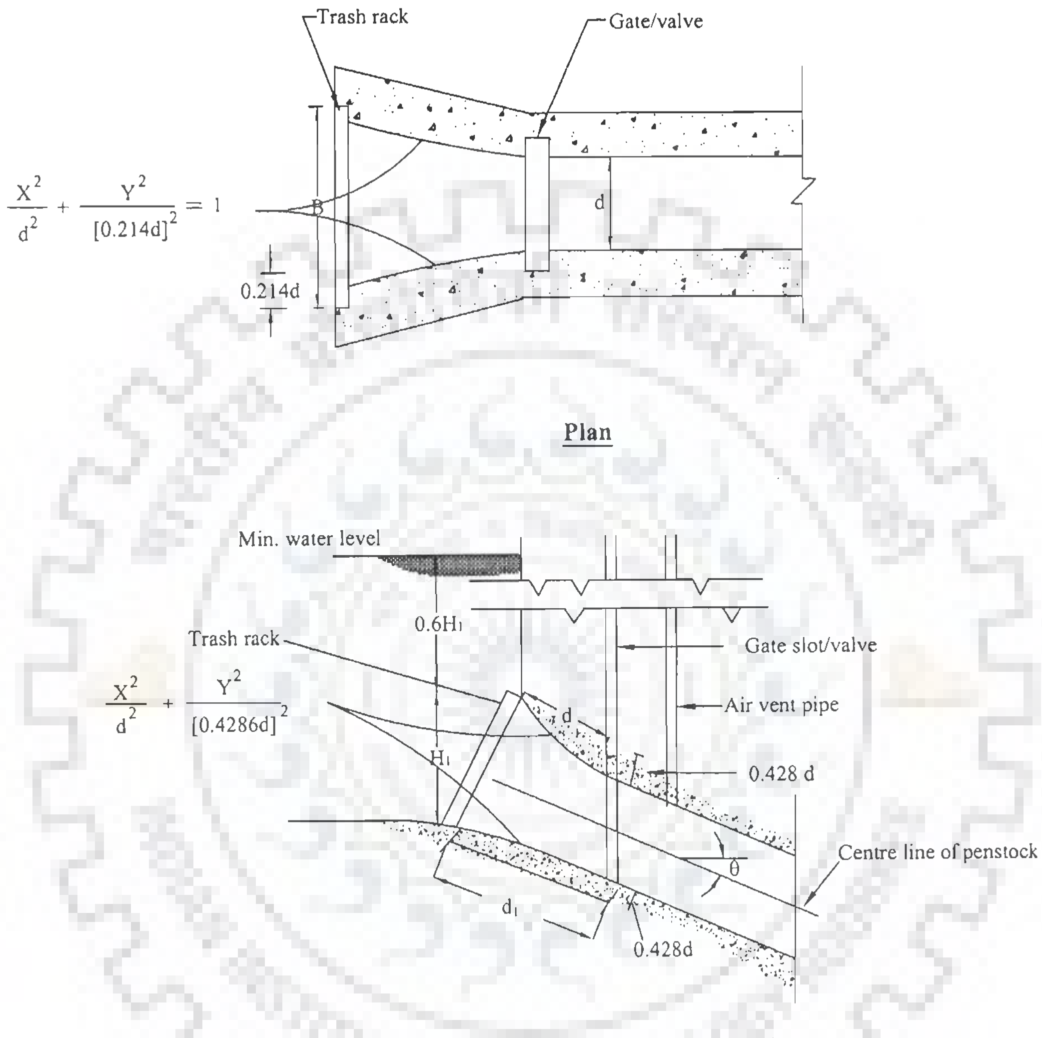
In the analysis length of channel is taken as 30 m based on experience on such projects as location of powerhouse is generally very close to the river bank. The design criteria for tail race channel for such schemes has also been considered on similar lines as considered earlier for diversion channel of canal based schemes.

3.3.3 Components of Dam Toe SHP Schemes

The design criteria of penstock, power house and tail race channel have been considered on similar lines as discussed under the components of canal toe and run of river schemes. The details for selection and sizing of other civil works components are as follows:

3.4.3.1 Intake

Intake is provided on the upstream side of the dam to facilitate flow in the penstock. The intake consists of trash rack to prevent floating material and gates for regulation of water flow. The intake opening is designed as a bell mouth to minimise the head loss. The height of intake is fixed by considering size of penstock and minimum draw down water level in the reservoir to avoid air entrapment in the penstock. The bell mouth portion of intake is considered in RCC with trash racks and gates as fabricated steel structures. The bell mouth details are shown in Fig. 3.19 and the dimensions with respect to penstock diameter are given in Table 3.1. In order to keep head loss as minimum in the trash rack, the velocity of water through the trash rack is kept as 1 m/s and the size of trash rack is worked out for 50% clogging [151].



Plan

Sectional elevation

Fig. 3.19 Bell mouth at penstock entry of dam toe scheme [151]

Table 3.1 Dimensions of bell mouth of a dam toe scheme

S. No.	Diameter of penstock (mm)	Height of bell mouth of pentock, H_1 (mm)	Length of bell mouth opening, d (mm)	Min distance of gate slot from trash rack (mm)	Width of bell mouth opening, B (mm)
1.	1700	3400	1700	1275	2429
2.	2100	4200	2100	1575	3000
3.	2500	5000	2500	1875	3571
4.	3000	6000	3000	2250	4286

3.4 ELECTRO-MECHANICAL EQUIPMENT

The major electro-mechanical equipment considered are as; turbine, generator, transformer, switchyard equipment and station auxiliaries. Auxiliaries include mechanical as well as electrical auxiliaries. Various equipments considered under present study are described as follows;

3.4. 1 Turbines and Governing System

Turbine has a considerable influence on the cost and performance of the whole hydro power plant. Improper selection of turbine may lead to high initial and running cost, low efficiency with difficult controls. The problems associated with turbine selection are technical, economical and site specific. The selection of turbine affects the cost of civil works as well as electrical equipment such as generator. Thus, overall effect of type of turbine on the cost effective performance of the hydro power plant is important and the choice of turbine must be done with due care. Factors governing the selection of turbine are: (i) head and discharge, (ii) specific speed (iii) variation of head (iv) maximum efficiency (v) part load efficiency (vi) initial cost of civil works (vii) number of units (viii) running and maintenance cost (ix) cavitation characteristics and (x) transportation limitations.

Scientifically, turbine can be selected on the basis of specific speed which takes care of all the important working parameters. Though, in case of overlapping range of specific speed, more detailed analysis in terms of operation requirements and cost is to be done to arrive to the most suitable type of turbine. The specific speed of turbine is given as [136];

$$\text{Specific speed metric Ns} = \frac{N\sqrt{P_u \times 1.358}}{H^{5/4}} \qquad (3.12)$$

where,

N is Rotational speed, RPM.

P_u is unit power output, kW

H is Head, m

Fig. 3.20 gives the selection chart for different types of turbines according to the specific speed.

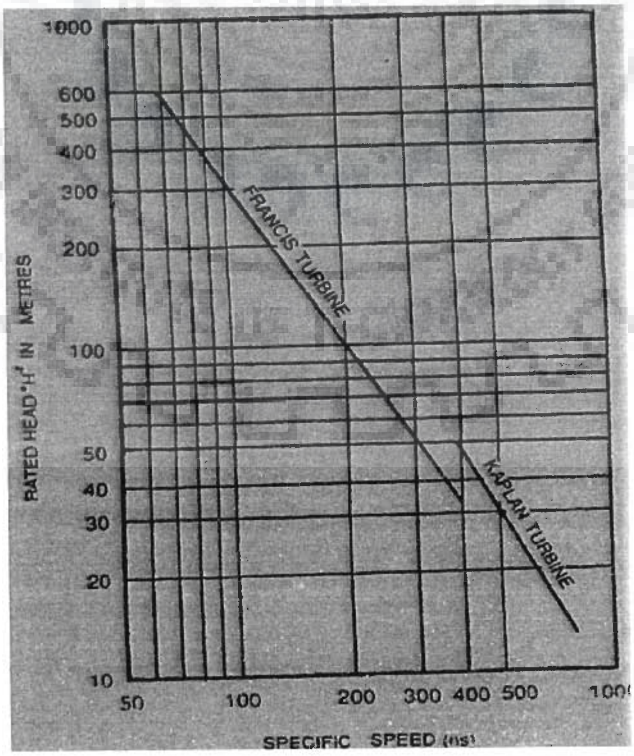


Fig. 3.20 Selection chart for different type of turbines [21]

Fig.3.21 shows the performance curves for different turbines at part load efficiency.

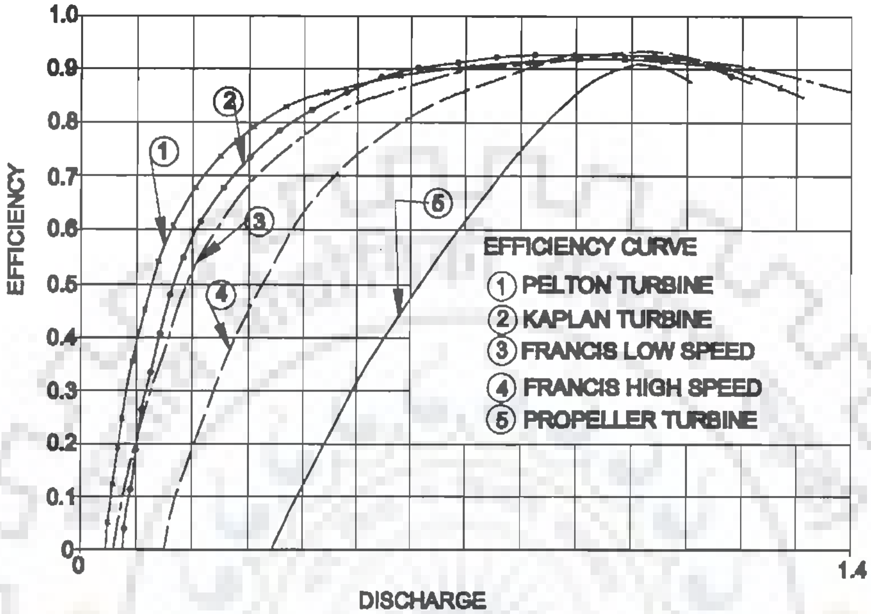


Fig. 3.21 Performance curves for different hydro turbines [21]

Under the present study a head range 3 to 20 m and unit size upto 5 MW capacity has been considered for low head SHP schemes. In this head range and unit size, the turbines are axial flow under reaction turbines. The various types of turbines considered under present study are as given in Table-3.2.

Out of the various types of turbines a suitable type has to be selected to match the specific conditions under which the turbine is to operate so as to attain the high order of efficiency. Francis, rim, open flume and cross flow turbines are not considered as these are not applicable for entire range of head and capacity considered. Tubular, vertical and bulb turbines with propeller, semi Kaplan and Kaplan runners are considered in the present study.

Table 3.2 Turbines applicable for low head range [69]

S. No.	Turbine type	Rated head (m)	Capacity (MW)
1	Tubular propeller (fixed blades and movable wickets gates)	2-18	0.25-15
2	Tubular semi Kaplan (Adjustable blades and fixed wickets gates)	2-18	0.25-15
3	Tubular Kaplan (Adjustable blades and movable wickets gates)	2-18	0.25-15
4	Vertical propeller (fixed blades and movable wickets gates)	2-20	0.25-15
5	Vertical Semi Kaplan (Adjustable blade and fixed wickets gates)	2-20	1-15
6	Vertical Kaplan (Adjustable blades and movable wickets gates)	2-20	1-15
7	Bulb propeller (fixed blades and movable wickets gates)	2-20	1-15
8	Bulb semi Kaplan (Adjustable blades and fixed wickets gates)	2-20	1-15
9	Bulb Kaplan (Adjustable blades and movable wickets gates)	2-20	1-15
10	Vertical Francis	8-20	1-15 and above
11	Horizontal Francis	8-20 and over	0.25-15
12	Rim	2-9	1-8
13	Right angle drive propeller	2-18	0.25-15
14	Open flume	2-11	0.25-2
15	Closed flume	2-20	0.25-3
16	Cross flow	6-20	0.25-2

The selection of turbine is governed by head, discharge, capacity, speed, part load efficiency, number of units and cavitation characteristics. The size of turbine is defined by its runner diameter. The criteria for computation of runner diameter, turbine layout and sizing of power house, based on different type of turbines, considered on similar lines as considered under sizing of power house building under civil works. The part load efficiency of various turbines considered for analysis is given in Table 3.3 [21]. In the analysis, governing system is considered alongwith turbine.

Table 3.3 Value of part load efficiency of different turbines

S. No.	Type of turbines	Efficiency at part load/discharge ratio						Maximum efficiency
		100%	90%	80%	70%	60%	50%	
1.	Tubular Semi:Kaplan	0.90	0.90	0.90	0.88	0.85	0.82	0.90
2.	Vertical Semi Kaplan	0.89	0.89	0.89	0.87	0.84	0.81	0.89
3.	Bulb Semi Kaplan	0.91	0.91	0.91	0.89	0.86	0.83	0.91
4.	Tubular Propeller	0.89	0.88	0.85	0.80	0.75	0.70	0.89
5.	Vertical Propeller	0.88	0.87	0.84	0.79	0.74	0.69	0.88
6.	Bulb Propeller	0.90	0.89	0.86	0.81	0.76	0.71	0.90
7.	Tubular Kaplan	0.92	0.92	0.92	0.91	0.90	0.89	0.92
8.	Vertical Kaplan	0.91	0.91	0.91	0.90	0.89	0.88	0.91
9.	Bulb Kaplan	0.93	0.93	0.93	0.92	0.91	0.90	0.93

The size of turbines is also related to the specific speed. In case of high specific speed i.e. smaller runner diameter requires a small positive or even a negative suction head and a deep excavation for the draft tube to avoid cavitation. Cavitation occurrence results in pitting and erosion of runner blades, noise and vibration. For any condition of speed or installed capacity, a propeller or Kaplan turbine has a safe limit of suction head (H_s). It is the distance between the runner and tail water level upto which operation will be free from cavitation. The values of suction head is worked out by using the following expression [69].

$$H_s = H_a - H_{\vartheta} - \sigma H \tag{3.13}$$

Where,

H_a is atmospheric pressure head at the elevation of the plant location, (m)

H_{ϑ} is vapour pressure at plant location temperature, (m)

σ is the Thoma coefficient

The safe value of plant sigma (σ) is given by the expression [69];

$$\sigma = \frac{N_s^{1.64}}{50327} \tag{3.14}$$

3.4.3 Generator and Excitation System

As discussed in chapter-2, there are two types of generator, synchronous and induction. Both types of generators along with their excitation system have been considered in the present study. The efficiency of both type of generators are different. The efficiencies considered in the study are 96% and 94% for synchronous and induction generator respectively. The size of generator is governed by its orientation (horizontal or vertical), capacity and speed. The orientation and speed is based on the type and speed of the turbine as similar speed for turbine and generator is considered in the present study. In India, frequency (f) is specified as 50 cycles/ sec. Thus number of poles changes with change in speed and the size of generator are determined based on number of poles. Based on speed, number of poles and the size of generator is worked out by the following expression [136].

$$N = \frac{120f}{p} \tag{3.15}$$

Where;

N is speed, (RPM)

f is frequency, (cycles/second)

p is number of poles

3.4.4 Auxiliaries

The electrical and mechanical auxiliary equipment have been discussed in chapter 2. The electrical auxiliaries are selected to with stand maximum stresses under the wrost conditions i.e. failure of protection device and time delayed fault clearing by the back-up protection device. The equipment should be suitable for the prevailing climatic conditions and insensitive to any signals emitted by wireless communication equipment. All mechanical auxiliaries should be capable to with stand corrosion, shocks and vibrations, heat, humidity and splash water.

3.4.5 Transformer and Switchyard

The transformer and switchyard equipment have also been discussed in chapter 2. The transformers are usually star/star, star/delta and delta/star type. The principal components and accessories of a transformer are steel tank, core, windings, transformer oil, tap changing switch, conservator, breather, pressure relief or explosion vent pipe, oil and winding temperature thermometer and buchholz relay. The selection of transformer is blade based on its capacity and rating. The capacity and ratings are based on the generation voltage and transmission line voltage level.

CHAPTER-4

COST ANALYSIS OF LOW HEAD SMALL HYDROPOWER SCHEMES

4.1 GENERAL

As discussed earlier that small hydropower (SHP) projects are site specific, accordingly the selection and sizing of various components under different schemes have been discussed and presented in previous Chapter-3. Further it has been found that head and capacity of the schemes are the basic parameters which affect the installation cost of a SHP project. These parameters are considered as the cost sensitive parameters and based on this consideration cost analysis of low head SHP schemes has been carried out and presented in this chapter. The cost of different SHP schemes consists of mainly cost of civil works and electro-mechanical equipment. Other indirect costs including land, survey and investigations, preparation of reports, designs, audit and accounts, tools and plant and communications have also been considered in the total installation costs of the schemes [152].

4.2 TYPE OF SCHEMES, ALTERNATIVES AND RANGE OF PARAMETERS CONSIDERED

As per the definition of small hydropower in India total plant capacity upto 25 MW and unit size upto 5 MW is considered. Accordingly, under the present study low head small hydropower schemes covering head range from 3 to 20 m with plant capacity upto 20 MW and having unit size of 5 MW have been considered. The unit sizes as 1 MW, 2MW, 3 MW, 4MW and 5MW have been taken for single generating unit installations. However, for the installations having more than one generating units, the unit sizes have been considered as 1MW, 2MW, 2.5MW, 4MW and 5MW.

Various alternatives such as location of power house, soil conditions, type of turbines, type of generators and number of generating units under different schemes have been considered for cost analysis. Alternatives under different schemes considered under present study are as given in Table 4.1.

Table 4.1 Various alternatives under different schemes considered for cost analysis

S. No.	Alternatives	Details	Type of scheme
1.	Location of powerhouse	Powerhouse in diversion channel and spillway in main canal	Canal based
		Powerhouse and spillway combined in main canal and diversion channel	
		Powerhouse and spillway combined in main canal and no diversion channel	
2.	Type of soil	Ordinary soil	Canal based, run of river and dam toe
		Soft rock	
		Hard rock	
3.	Number of generating units	One unit	
		Two units	
		Three units	
		Four units	
4.	Type of turbine	Tubular semi Kaplan	
		Vertical Semi Kaplan	
		Bulb Semi Kaplan	
		Tubular Propeller	
		Vertical Propeller	
		Bulb Propeller	
		Tubular Kaplan	
		Vertical Kaplan	
		Bulb Kaplan	
5.	Type of generator	Synchronous	
		Induction	

In order to compute the costs of various components under civil works major items considered are earthwork in excavation, concreting in M20 grade, reinforcement steel of f_e 415 grade and fabricated steel structures. The prices as per schedule of rates prevailing for the year 2007 taken for different items are considered as given in Table 4.2.

Table 4.2 Prices as per schedule of rates prevailing for the year 2007 of civil works items

S. No.	Items	Price (Rs.)
1.	Earthwork in excavation with all leads and lifts (a) In ordinary soil	90 per m^3
	(b) In soft rock, where blasting is not required	155 per m^3
	(c) In hard rock including blasting	210 per m^3
2.	M20 grade concrete work in plain cement concrete as well as in reinforced cement concrete including shuttering, mixing, placing in position, compacting and curing.	3400 per m^3
3.	Reinforcement steel bars of f_e 415 grade including cutting, bending, binding and placing in position.	30000 per MT
4.	Structural steel including fabrication, transportation to site and erection.	50000 per MT

4.3 METHODOLOGY FOR COST EVALUATION

In order to find out the overall installation cost for different alternatives under different schemes, cost of individual components has been determined. Civil works costs have been estimated based on quantities of different items and their prevailing prices. Cost of electromechanical equipment has been computed based on capacity and type of equipment taking the prevailing market prices obtained from different manufacturers.

Various steps involved for cost evaluation are discussed as;

Based on the selection and design criterion discussed in Chapeter-3 the sizes of different components under civil works have been determined for the given alternative under the considered scheme. For various combinations of layouts having different head and capacity, design discharge is worked out. Sizing of components such as intake, channel, desilting tank, forebay and spillway and penstock has been worked out based on discharge, as discussed in Chapter-3. For the given scheme, type and runner diameter of the turbine has been determined, based on specific speed as discussed in Chapter-3.

For a particular layout considered and worked out sizes of various components, quantities of different items such as earthwork in excavation, concreting, reinforcement steel, fabricated steel structures (gates, trash racks, rooffing, trusses, railings etc.) and other miscellaneous items such as masonary work, damp proofing treatment, dewatering, doors, widows, floor finishing, plastering, sanitary and water supply works, drainage, fencing and paintings are determined. Based on the determined quantities and prevailing prices of these items, the cost of civil works components has been worked out.

Based on type and sizes and prevailing prices of electro mechanical equipment, cost of electro mechanical equipment has been worked out.

Following the methodology discussed above, the cost of installation for different alternatives has been evaluated for three different schemes i.e. canal based, run of river and dam toe. Computation of various costs for some typical cases under all the three schemes are detailed and presented in this part of the Chapter. The cost of civil work depend on the layout and type of scheme. Accordingly the civil works costs have been discussed and presented for each schemes. However, cost of electromechanical equipments depend on the head and capacity. These costs are considered to be similar for all schemes and discussed accordingly in the following part of the chapter.

4.4 CANAL BASED SHP SCHEMES

In order to discuss a typical example for cost evaluation of an installation under canal based scheme, a layout for 2000 kW installed capacity at 10 m head has been considered. This layout has already been shown in Fig. 3.1 under Chapter-3. For the layout, powerhouse is considered in diversion channel. The main channel is used as spillway having tilting gates at the fall for regulation of flow. Soil is considered as ordinary soil. Two units of semi-Kaplan tubular turbines, coupled with synchronous generators have been considered.

4.4.1 Diversion Channel

The diversion channel is considered trapezoidal open channel lined with plain cement concrete (PCC) to minimise the loss due to seepage and also from the safety point of view as the water passes through sharp bends. For the given values of head (H) and capacity (P) as 10 m and 2000 kW respectively, discharge (Q) is determined as 23.70 m^3/s, using power equation given below;

$$P = gQH\eta \qquad (4.1)$$

Where, g is the acceleration due to gravity (m/s^2), and η is the combined efficiency of turbine and generator. The values of these efficiencies are taken as 0.90 and 0.96 respectively. The combined efficiency comes out to be as 0.86.

The size of diversion channel i.e. bed width (b) and water depth (h) is determined by using Manning's equation [149]. Manning's coefficient (n) is taken as 0.018 for plain cement concrete. Bed slope (S_1), is taken as 1:4000, which is generally taken for channels in plain area. Side slope of the channel (s) is taken as 1:1.5 being soil as ordinary soil in plain area.

The channel section has been worked out as hydraulically efficient section and the determined values are as given below.

Bed width (b) = 1.9 m
Water depth (h) = 3.10 m

Free board above full supply depth has been considered 0.60 m, thus width of channel at top is worked out as 11.20 m. The radius of curve of channel is provided six times the water surface width which comes out to be as 67 m [153, 154].

Based on this radius of curve, the off take angle of diversion channel is worked out as 55° and the length of the channel comes out to be 245 m. Thickness of lining has been considered 200 mm based on experience on such projects.

Based on the determined sizes of diversion channel for a layout of channel as shown in Fig. 4.1 and 4.2, the quantities of the major items i.e. earth work in excavation and concreting in lining of the channel has been worked out as given below.

Earthwork in excavation = 9700 m^3
PCC in lining = 510 m^3

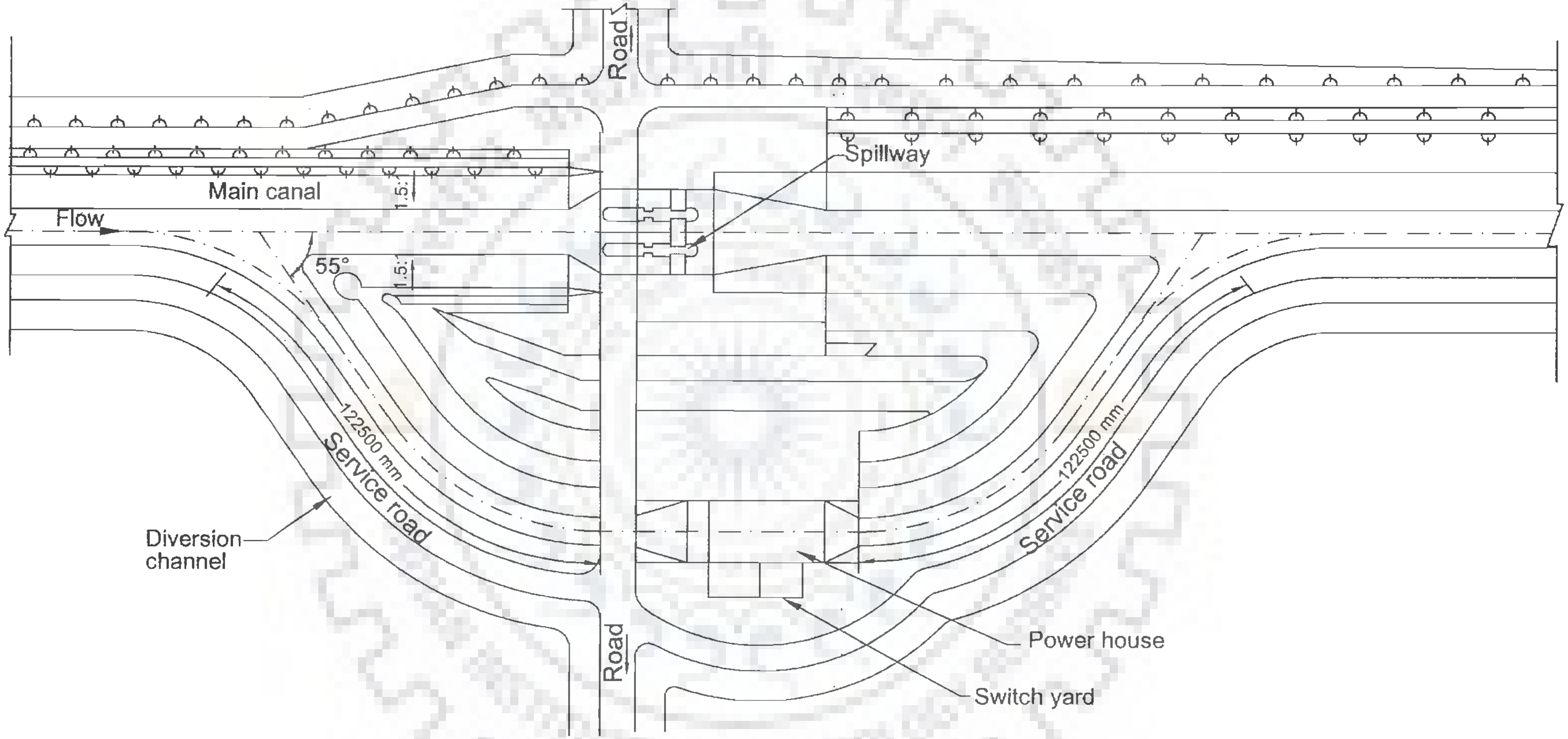
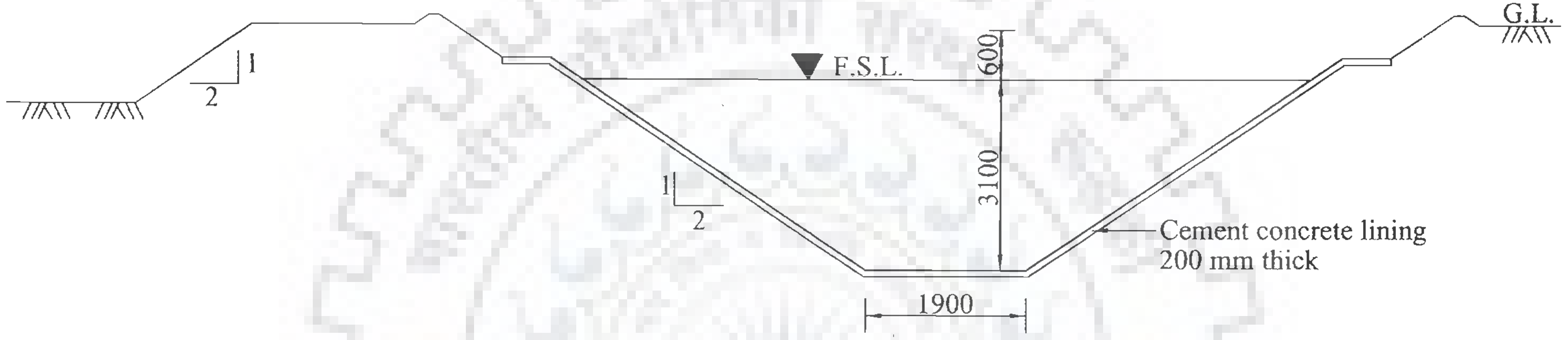


Fig. 4.1 Layout of diversion channel for a canal based scheme (H = 10 m, P = 2 x 1000 kW)



Notes:-

1. All dimensions are in mm.
2. F.S.L. - Full supply level.
3. G.L. - Ground level.

Fig. 4.2 Cross section of diversion channel for a canal based scheme (H = 10 m, P = 2 x 1000 kW)

For the worked out quantities and prevailing rates, the cost of these items and miscellaneous items such as protection works at the joining of diversion channel in upstream and downstream has been computed. A total cost of the diversion channel comes out to be Rs. 3.02 Millions. On similar lines quantities and cost of diversion channel for the considered layout for different combinations of head and capacity has been worked out and presented in Table 4.3.

4.4.2 Spillway

Spillway is provided in the main canal. Canal section is converted from trapezoidal to rectangular to provide spillway arrangement. The width (B) at spillway is provided as 11.20 m, which is equal to the top width of trapezoidal channel. Considering 1 pier of 1 m width, spillway arrangement is provided in 2 bays of 5.5 m each. Head over crest (H_s) is worked out as 1.17 m, using Eq. 3.1 (chapter-3). The scheme is having a head of 10 m, which need to be dissipated in the spillway. This is divided into 2 falls of 5m each. The difference in upstream full supply level (FSL) and down stream bed level, z is estimated as;

$$z = 5+3.1 \text{ (water depth)}$$

$$= 8.1 \text{ m}$$

The free fall velocity (V_1) has been worked out as 12.13 m/s, using the following expression [29];

$$V_1 = \sqrt{2g\left(z - \frac{H_s}{2}\right)} \qquad (4.2)$$

Discharge intensity (q) is worked out as 2.1 m^2/s, by using following expression;

$$q = Q / B \qquad (4.3)$$

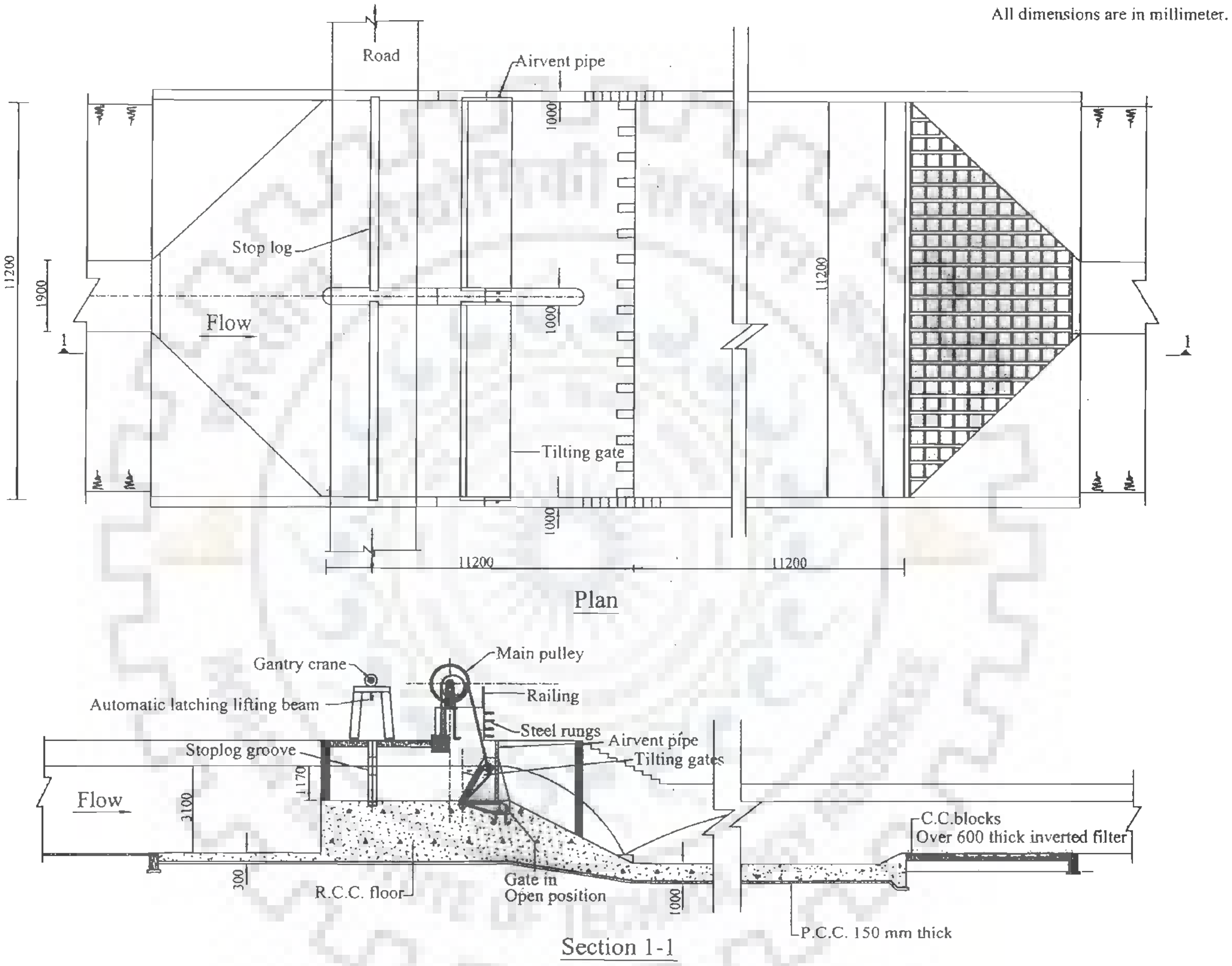


Fig. 4.3 Spillway for a canal based scheme (H = 10 m, P = 2x1000 kW)

Table 4.3 Quantities and cost of diversion channel for canal based schemes

S. No.	Head (m)	Capacity (kW)	Runner dia. (m)	Quantities (m^3)		Cost of items (Rs.)				
				Earth work in excavation	Concreting	Earth work	Concreting	Misc.	Total	Total per kW
1.	3	2 x 1000	3.03	10300	550	927000	1870000	447520	3244520	1622
2.	5	2 x 1000	2.08	10000	530	900000	1802000	432320	3134320	1567
3.	10	2 x 1000	1.28	9700	510	873000	1734000	417120	3024120	1512
4.	15	2 x 1000	0.93	9450	485	850500	1649000	399920	2899420	1450
5.	20	2 x 1000	0.77	9300	475	837000	1615000	392320	2844320	1422
6.	3	2 x 2000	4.27	17650	935	1588500	3179000	762800	5530300	1383
7.	5	2 x 2000	2.93	17100	900	1539000	3060000	735840	5334840	1334
8.	10	2 x 2000	1.75	16400	870	1476000	2958000	709440	5143440	1286
9.	15	2 x 2000	1.34	16100	840	1449000	2856000	688800	4993800	1248
10.	20	2 x 2000	1.06	15800	825	1422000	2805000	676320	4903320	1226
11.	3	2 x 2500	4.75	20900	1100	1881000	3740000	899360	6520360	1304
12.	5	2 x 2500	3.34	20000	1080	1800000	3672000	875520	6347520	1270
13.	10	2 x 2500	1.96	19500	1030	1755000	3502000	841120	6098120	1220
14.	15	2 x 2500	1.44	19200	1000	1728000	3400000	820480	5948480	1190
15.	20	2 x 2500	1.14	18750	990	1687500	3366000	808560	5862060	1172
16.	3	2 x 4000	6.21	30000	1590	2700000	5406000	1296960	9402960	1175
17.	5	2 x 4000	4.11	29000	1550	2610000	5270000	1260800	9140800	1143
18.	10	2 x 4000	2.5	27800	1480	2502000	5032000	1205440	8739440	1092
19.	15	2 x 4000	1.86	27100	1440	2439000	4896000	1173600	8508600	1064
20.	20	2 x 4000	1.44	26850	1400	2416500	4760000	1148240	8324740	1041
21.	3	2 x 5000	6.69	35600	1880	3204000	6392000	1535360	11131360	1113
22.	5	2 x 5000	4.62	34500	1825	3105000	6205000	1489600	10799600	1080
23.	10	2 x 5000	2.76	33100	1750	2979000	5950000	1428640	10357640	1036
24.	15	2 x 5000	2.08	32300	1700	2907000	5780000	1389920	10076920	1008
25.	20	2 x 5000	1.65	31850	1685	2866500	5729000	1375280	9970780	997

Length of basin depends upon the upstream and downstream water depth. Upstream water depth (d_1) and downstream depth (d_2) has been worked out as 0.17m and 2.20m respectively, using following expressions [29];

$$d_1 = \frac{q}{V_1} = 0.17 \tag{4.4}$$

$$\text{Upstream Froude number } F_1 = \frac{V_1}{\sqrt{gd_1}} \tag{4.5}$$

$$= \frac{12.13}{\sqrt{9.81 \times 0.17}} = 9.4$$

$$\frac{d_2}{d_1} = \frac{1}{2}\left(\sqrt{1+8F_1^2} - 1\right) \tag{4.6}$$

The length of basin (L) has been estimated as 11.2 m, using the expression given below;

$$L_1 = 5.5\,(d_2 - d_1) \tag{4.7}$$

2 numbers of tilting gates as shown in Fig. 4.3 are proposed to provide at the first fall. The second fall is also designed on similar line without gates, as gates are required for flow regulation on first fall only.

Based on the sizes worked out for spillway in Fig. 4.3, quantities of the major items i.e. earth work in excavation, concreting, rainforcement steel, fabricated steel structures (gates) has been worked out as given below.

Earthwork in excavation	= 3700 m^3
Concreting	= 1560 m^3
Reinforcement steel	= 94 MT
Structural steel	= 42 MT

For the worked out quantities and prevailing rates, the cost of these items and miscellaneous items such as dewatering, fencing and paintings has been computed. The quantities and cost of spillway for the layout at different combinations of head and capacity has also been worked on similar lines and presented in Table 4.4.

4.4.3 Power House Building

As discussed earlier that the size of power house building depends upon the turbine runner diameter. In order to find out the dimensions of power house building, runner diameter of the selected turbine is determined using different equations presented in Chapter-3. For the considered case of semi Kaplan turbine for two units of 1000 kW (P_u) each under 10 m head, the, speed of turbine is determined as 500 rpm corresponding to specific speed of 1000(metric). Corresponding to this speed of 500 rpm and 10 m head the runner diameter of turbine is worked out as 1.28 m. Based on this runner diameter, the dimensions of power house have been worked out as ;

Length of power house = 10.24 m
Width of power house = 9.54 m
Centre to centre distance between the machines = 3.48 m.

The plan and section of power house for two generating units are shown in Fig. 4.4 and Fig. 4.5 respectively. The quantities of the various items i.e. earth work in excavation, concreting, reinforcement steel and fabricated steel structures (gates, trash racks, roofing, trusses, railings) have been worked out as given below;

Earthwork in excavation = 6710 m^3
Concreting = 4000 m^3
Reinforcement steel = 251 MT
Structural steel = 133 MT

For the determined quantities and prevailing rates, the cost of these items and miscellaneous items such as masonry work, damp proofing treatment, dewatering, doors, widows, floor finishing, plastering, sanitary and water supply works, drainage, fencing, white/colour wash and paintings has been worked out as Rs.30.08 Millions. The quantities and cost of powerhouse for layouts at different combinations of head and capacity has also been determined on similar lines and presented in Table 4.5.

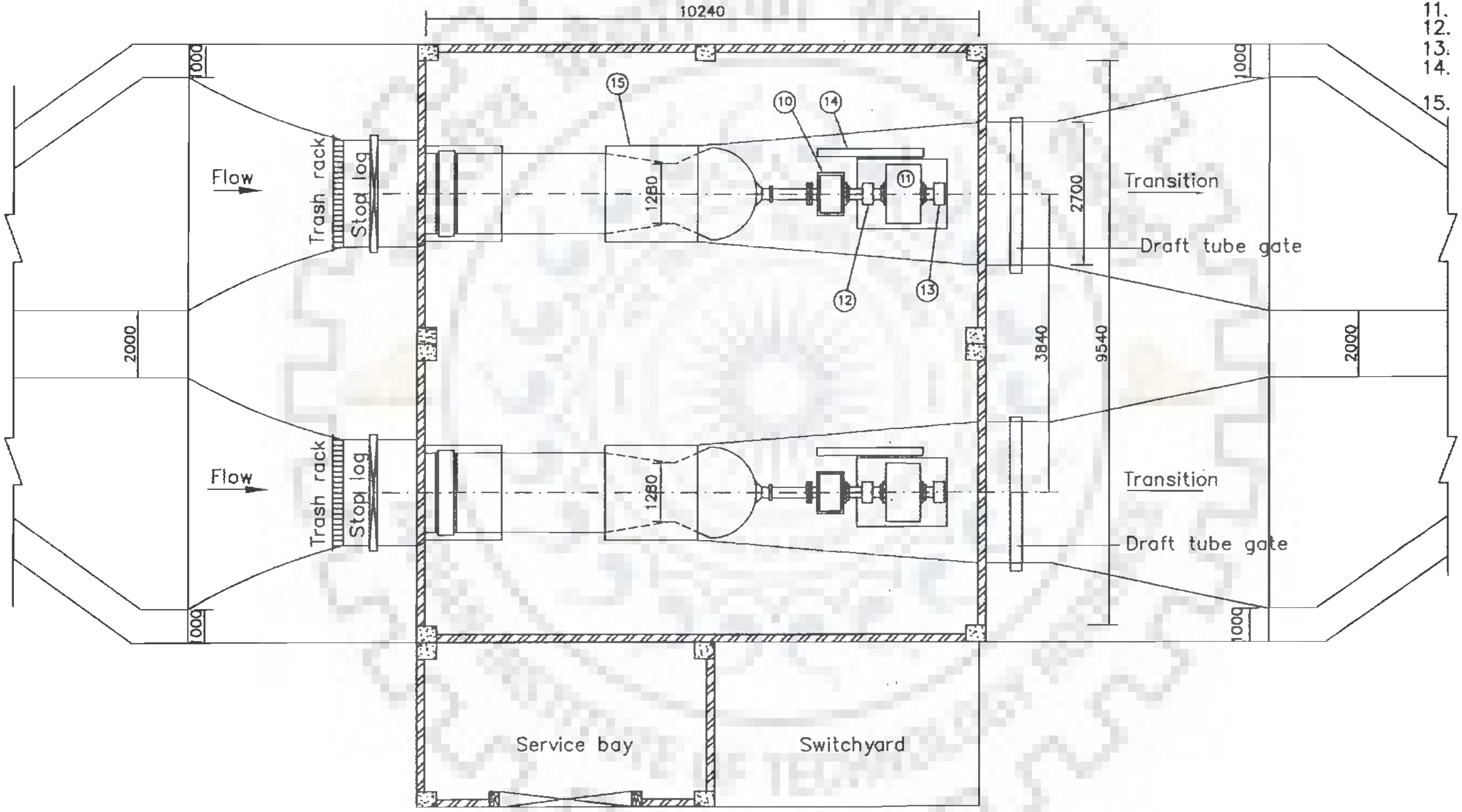
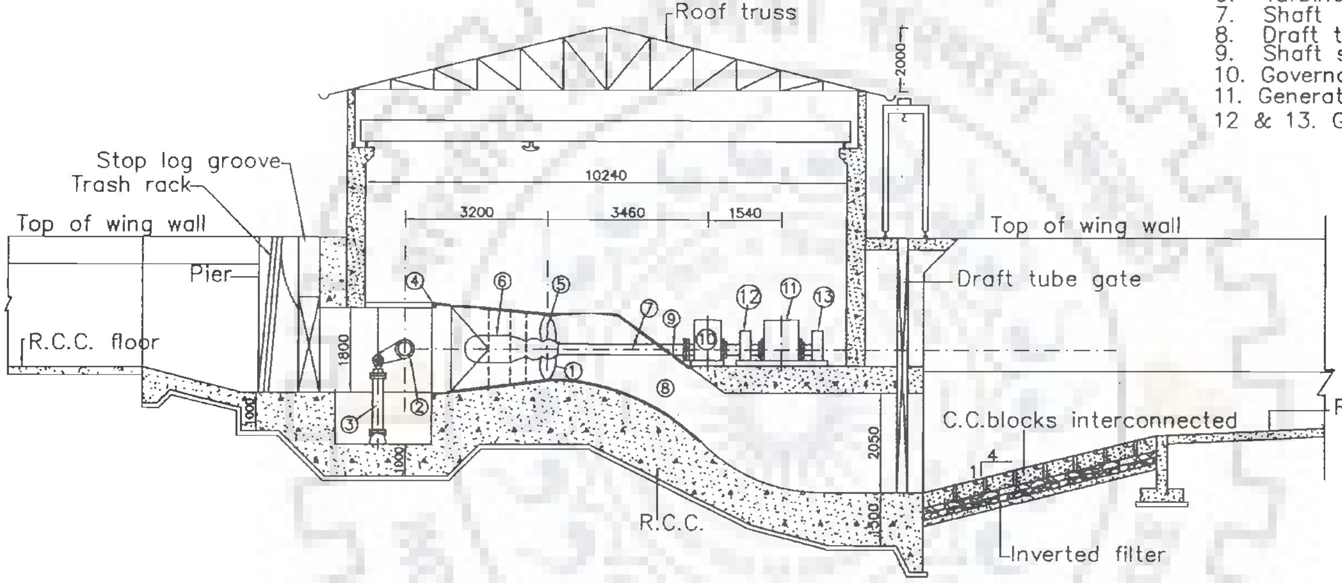


Fig. 4.4 Plan of power house building for a canal based scheme (H = 10 m, P = 2 x1000 kW)

Notes: –
1. All dimensions are in mm.

Equipments marked
1. Runner
2. Main inlet valve
3. Valve servo motor
4. Stay vane
5. Runner chamber
6. Turbine bearing
7. Shaft
8. Draft tube
9. Shaft seal
10. Governor
11. Generator
12. Generator bearing
13. Generator bearing
14. Control and protection cubicle
15. Turbine



Equipments marked

1. Runner
2. Main inlet valve
3. Valve servo motor
4. Stay vane
5. Runner chamber
6. Turbine bearing
7. Shaft
8. Draft tube
9. Shaft seal
10. Governor
11. Generator
12 & 13. Generator bearing

Notes: –

1. All dimensions are in mm.
2. R.C.C.– Reinforcement cement concrete.
3. C.C– Cement concrete.

Fig. 4.5 Longitudinal section of power house building (H = 10 m, P = 2x1000 kW)

Table 4.4 Quantities and cost of spillway for different combination of head and capacity

S. No.	Head (m)	Capacity (kW)	Runner dia (m)	Quantities				Cost of items (Rs.)						
				Earth work in excavation (m^3)	Concreting (m^3)	Reinforcement (MT)	Steel (MT)	Earth work in excavation	Concreting	Reinforcement	Steel	Misce-llaneous	Total	Total per kW
1.	3	2x1000	3.03	3975	1680	105	45	357750	5712000	3150000	2250000	458790	11928540	5964
2.	5	2x1000	2.08	3860	1630	100	44	347400	5542000	3000000	2200000	443576	11532976	5766
3.	10	2x1000	1.28	3700	1560	94	42	333000	5304000	2820000	2100000	422280	10979280	5490
4.	15	2x1000	0.93	3610	1525	91	41	324900	5185000	2730000	2050000	411596	10701496	5351
5.	20	2x1000	0.77	3550	1500	90	40	319500	5100000	2700000	2000000	404780	10524280	5262
6.	3	2x2000	4.27	6760	2860	175	77	608400	9724000	5250000	3850000	777296	20209696	5052
7.	5	2x2000	2.93	6550	2780	170	75	589500	9452000	5100000	3750000	755660	19647160	4912
8.	10	2x2000	1.75	6290	2660	163	68	566100	9044000	4890000	3400000	716004	18616104	4654
9.	15	2x2000	1.34	6140	2600	158	65	552600	8840000	4740000	3250000	695304	18077904	4519
10.	20	2x2000	1.06	6050	2560	155	63	544500	8704000	4650000	3150000	681940	17730440	4433
11.	3	2x2500	4.75	8012	3400	208	92	721085	11560000	6240000	4600000	924843	24045929	4809
12.	5	2x2500	3.34	7780	3290	202	90	700200	11186000	6060000	4500000	897848	23344048	4669
13.	10	2x2500	1.96	7460	3160	194	84	671400	10744000	5820000	4200000	857416	22292816	4459
14.	15	2x2500	1.44	7290	3090	188	82	656100	10506000	5640000	4100000	836084	21738184	4348
15.	20	2x2500	1.14	7180	3040	185	80	646200	10336000	5550000	4000000	821288	21353488	4271
16.	3	2x4000	6.21	11500	4860	300	130	1035000	16524000	9000000	6500000	1322360	34381360	4298
17.	5	2x4000	4.11	11140	4700	290	128	1002600	15980000	8700000	6400000	1283304	33365904	4171
18.	10	2x4000	2.5	10700	4530	277	122	963000	15402000	8310000	6100000	1231000	32006000	4001
19.	15	2x4000	1.86	10450	4425	271	118	940500	15045000	8130000	5900000	1200620	31216120	3902
20.	20	2x4000	1.44	10300	4350	265	115	927000	14790000	7950000	5750000	1176680	30593680	3824
21.	3	2x5000	6.69	13600	5770	355	155	1224000	19618000	10650000	7750000	1569680	40811680	4081
22.	5	2x5000	4.62	13200	5600	342	150	1188000	19040000	10260000	7500000	1519520	39507520	3951
23.	10	2x5000	2.76	12690	5370	330	145	1142100	18258000	9900000	7250000	1462004	38012104	3801
24.	15	2x5000	2.08	12390	5250	322	140	1115100	17850000	9660000	7000000	1425004	37050104	3705
25.	20	2x5000	1.65	12200	5160	315	137	1098000	17544000	9450000	6850000	1397680	36339680	3634

Table 4.5 Quantities and cost of power house building for different combination of head and capacity

S. No.	Head (m)	Capacity (kW)	Runner dia (m)	Quantities				Cost of items (Rs.)						
				Earth work in excavation (m^3)	Concreting (m^3)	Reinforcement (MT)	Steel (MT)	Earth work in excavation	Concreting	Reinfrocement	Steel	Misc	Total	Cost per kW
1.	3	2x1000	3.03	7210	4296	272	140	648900	14606400	8160000	7000000	1824918	32240218	16120
2.	5	2x1000	2.08	7000	4170	264	138	630000	14178000	7920000	6900000	1777680	31405680	15703
3.	10	2x1000	1.28	6710	4000	251	133	603900	13600000	7530000	6650000	1703000	30086900	15043
4.	15	2x1000	0.93	6560	3918	246	130	590400	13321200	7380000	6500000	1667496	29459096	14730
5.	20	2x1000	0.77	6400	3842	240	125	576000	13062800	7200000	6250000	1625328	28714128	14357
6.	3	2x2000	4.27	12200	7295	460	242	1098000	24803000	13800000	12100000	3108060	54909060	13727
7.	5	2x2000	2.93	11900	7080	445	236	1071000	24072000	13350000	11800000	3017580	53310580	13328
8.	10	2x2000	1.75	11400	6800	428	226	1026000	23120000	12840000	11300000	2897160	51183160	12796
9.	15	2x2000	1.34	11150	6640	418	220	1003500	22576000	12540000	11000000	2827170	49946670	12487
10.	20	2x2000	1.06	10900	6530	410	218	981000	22202000	12300000	10900000	2782980	49165980	12291
11.	3	2x2500	4.75	14500	8650	545	290	1305000	29410000	16350000	14500000	3693900	65258900	13052
12.	5	2x2500	3.34	14100	8400	528	280	1269000	28560000	15840000	14000000	3580140	63249140	12650
13.	10	2x2500	1.96	13540	8065	506	268	1218600	27421000	15180000	13400000	3433176	60652776	12131
14.	15	2x2500	1.44	13220	7875	495	262	1189800	26775000	14850000	13100000	3354888	59269688	11854
15.	20	2x2500	1.14	13000	7750	485	258	1170000	26350000	14550000	12900000	3298200	58268200	11654
16.	3	2x4000	6.21	20800	12400	780	412	1872000	42160000	23400000	20600000	5281920	93313920	11664
17.	5	2x4000	4.11	20200	12030	758	400	1818000	40902000	22740000	20000000	5127600	90587600	11323
18.	10	2x4000	2.5	19400	11550	728	284	1746000	39270000	21840000	14200000	4623360	81679360	10210
19.	15	2x4000	1.86	18940	11290	711	375	1704600	38386000	21330000	18750000	4810236	84980836	10623
20.	20	2x4000	1.44	18600	11100	700	365	1674000	37740000	21000000	18250000	4719840	83383840	10423
21.	3	2x5000	6.69	25000	14700	925	490	2250000	49980000	27750000	24500000	6268800	110748800	11075
22.	5	2x5000	4.62	24000	14270	900	475	2160000	48518000	27000000	23750000	6085680	107513680	10751
23.	10	2x5000	2.76	23020	13700	862	456	2071800	46580000	25860000	22800000	5838708	103150508	10315
24.	15	2x5000	2.08	22470	13380	840	445	2022300	45492000	25200000	22250000	5697858	100662158	10066
25.	20	2x5000	1.65	22000	13160	825	435	1980000	44744000	24750000	21750000	5593440	98817440	9882

4.5 RUN OF RIVER SCHEMES

As discussed in Chapter-3, the main components of civil works run of river schemes are diversion weir & intake, power channel, desilting tank, forebay & spillway, power house building and tail race channel. The size of the components has been worked out based on methodology presented in Chapter-3 considering various combinations of head and capacity. In order to compute the installation cost under this scheme, an example of 2000 kW installed capacity at 10 m head has been taken under similar conditions and alternatives as considered for canal based scheme. Schematic of a typical layout considered under this scheme is as shown in Fig. 4.6. Various costs of different components under this scheme are discussed as follows.

4.5.1 Design Discharge

The sizes of diversion, channels, desilting tank, forebay & spillway and penstock have been determined based on design discharge. The portion of channel between desilting tank and forbay known as head race channel is designed for 10% more than the discharge required for power generation considering evaporation and seepage losses. As determined for canal based scheme, the discharge for power generation also comes to be as 23.70 m^3/s. Thus design discharge for head race channel is worked out 26.35 m^3/s. The portion of channel between intake and desilting tank known as intake channel is designed for 15% more than the discharge required for head race channel considering flushing discharge for desilting. Thus design discharge for intake channel and desilting tank is worked out as 31 m^3/s.

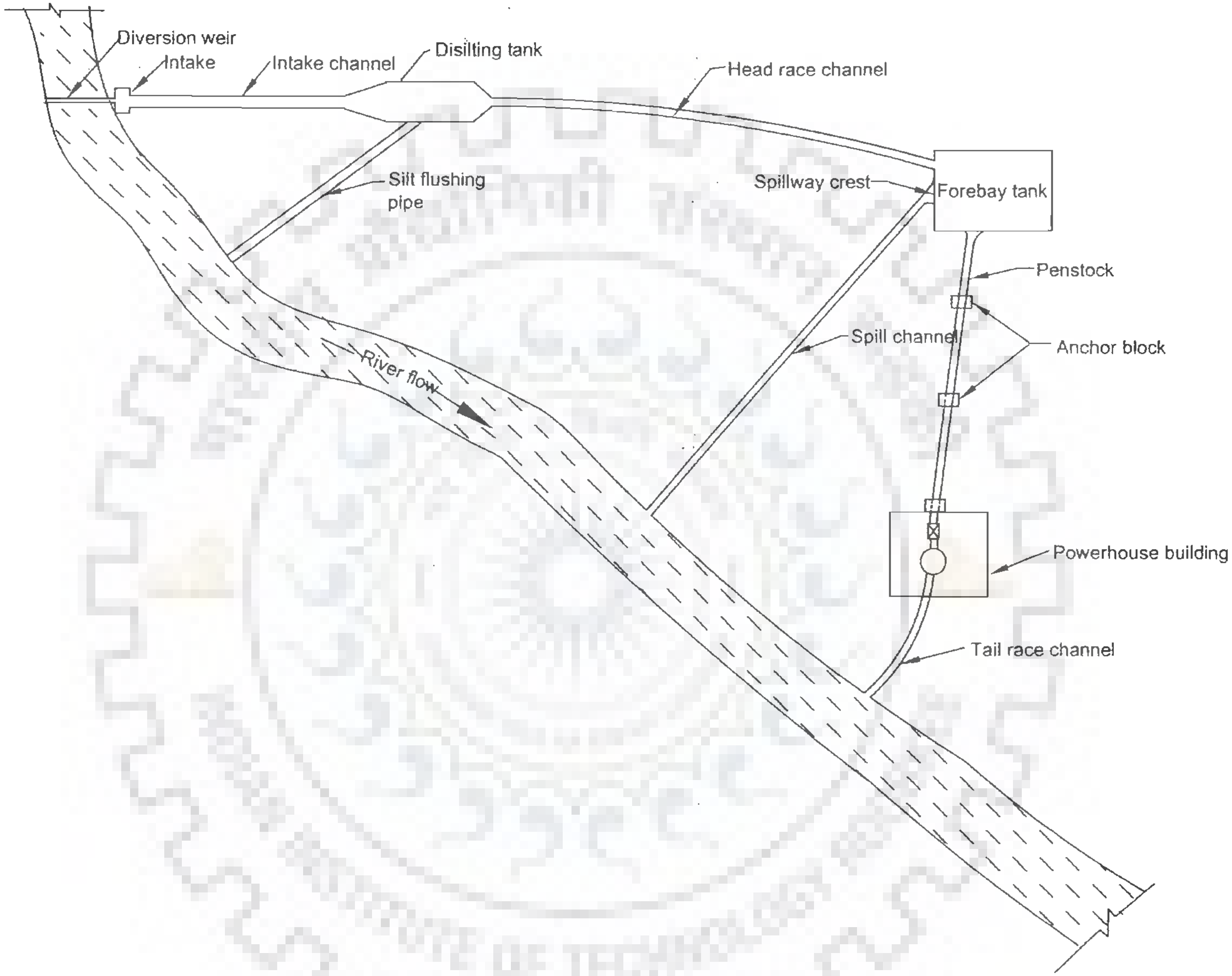


Fig. 4.6 Typical layout of run of river scheme considered for cost estimate

4.5.2 Diversion Weir and Intake

The size of weir is based on width of stream, high flood discharge and discharge needed to divert for power generation. The width of stream, slope of river and high flood discharge are site specific. In order to estimate the cost of intake, values of these parameters are considered as 25 m, 1 in 50 and 1000 m^3/s respectively which are generally observed in such projects.

Using manning's equation [23] given below, considering side slope of river as 1:1, the water depth at high flood discharge (Q_f) is determined.

$$Q_f = \left(1.7\ H_2^{3/2} + 3.544\ h_2 \sqrt{H_2}\right) B_e \tag{4.8}$$

Where;

H_2 is (upstream total energy level – downstream total energy level)

H_2 is (downstream total energy level – crest level)

B_e is (width of water way in weir)

The water depth (d_f) comes out to be as 4.5 m. The weir is divided in 3 bays to provide tilting gates for regulation of flow. The floor length of weir in determined on similar line as used for spillway is canal based scheme and found to be 32 m. The water way for intake is provided as 11 m in 2 bays of 4.5 m wide. The arrangement of diversion weir and intake is shown in Fig. 4.7.

The quantities of the major items i.e. earth work in excavation, concreting, reinforcement steel and fabricated steel structures (gates) have been worked out and are given below;

Earthwork in excavation = 3385 m^3

Concreting = 425 m^3

Reinforced steel = 18 MT

Structural steel = 11 MT

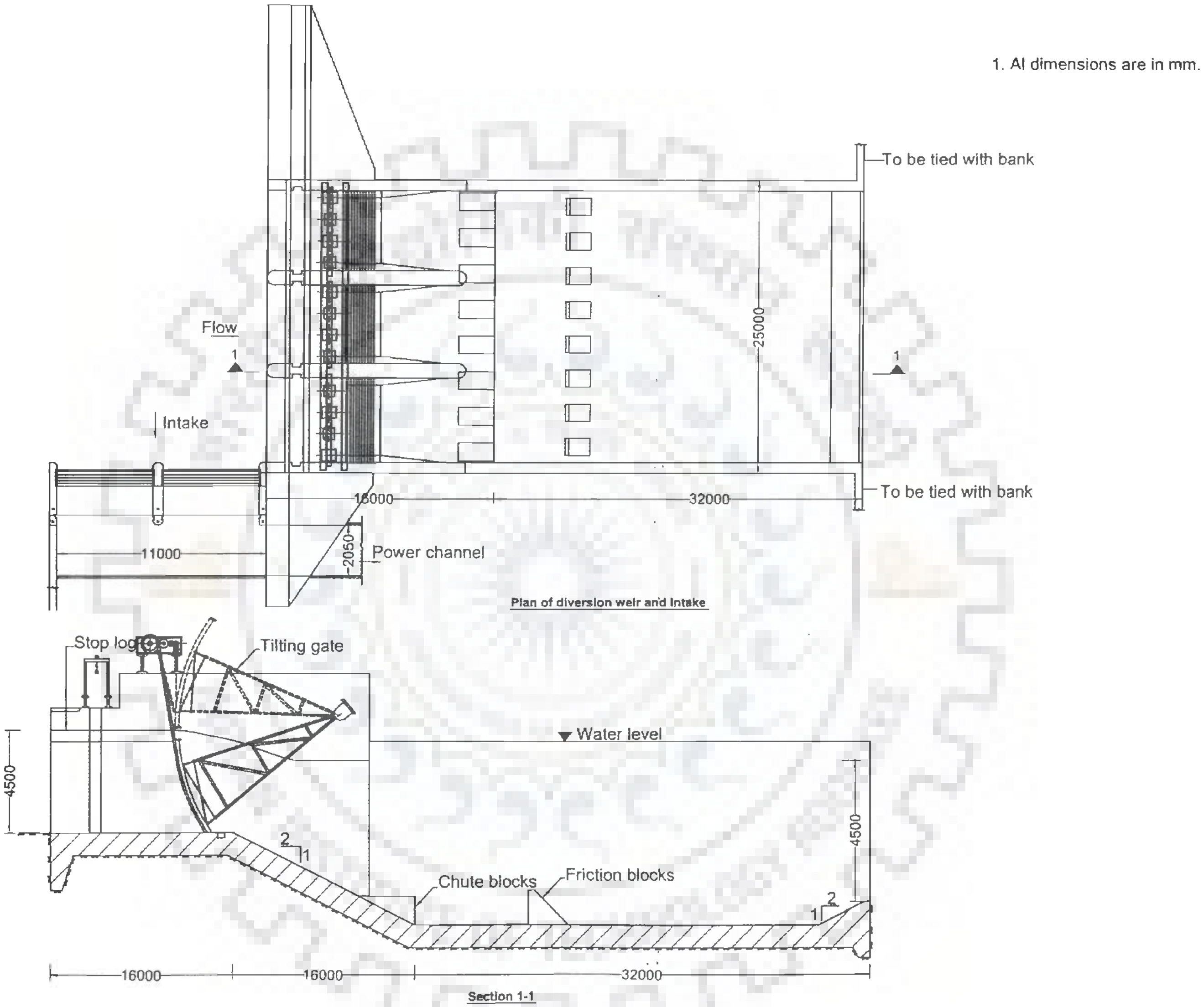


Fig. 4.7 Diversion weir and intake for run of river scheme [H = 10 m, P = 2 x 1000 kW)

Based on the determined quantities and prevailing rates, the cost of these items and miscellaneous items such as river protection, temporary diversion have been worked out. The sizing and cost of diversion weir and intake for layouts at different combinations of head and capacity has also been determined on similar lines and presented in Table 4.6.

4.5.3 Power Channel (Intake and Head Race Channel)

Low head sites under run of river scheme are found in foot hills. Bed slope and side slope of the channel (s) for such sites are taken as 1:500 and 1:1 respectively. The head race channel is designed as trapezoidal open channel lined with cement concrete on similar lines as for diversion channel. The bed width (b) and water depth (h) has been determined and are as given below.

Bed width (b) = 2.00 m
Water depth (h) = 2.30 m
Free board = 0.60 m

The size of intake channel has been worked out on similar lines as for head race channel. The bed width (b) and water depth (h) has been determined and their values are as given below.

Bed width (b) = 2.05 m
Water depth (h) = 2.45 m
Free board = 0.60 m

Total length of channel is considered as 50 times of the head i.e. 500 m. Out of this length, 100 m is considered for intake channel as desilting tank should be placed as near to the intake as possible.

Table 4.6 Quantities and cost of diversion weir and intake for run of river scheme at different combination of head and capacity

S. No.	Head (m)	Capacity (kW)	Runner dia (m)	Quantities				Cost of items (Rs.)						
				Earth work in excavation	Concreting	Rein	Steel	Earth work in excavation	Concreting	Rein	Steel	Misc	Total	Total per kW
1.	3	2x1000	3.03	3600	460	20	12	324000	1564000	600000	613073	775268	3876341	1938
2.	5	2x1000	2.08	3526	443	19	12	317346	1507391	555355	595023	743779	3718893	1859
3.	10	2x1000	1.28	3386	426	18	11	304735	1447491	533286	571378	714222	3571112	1786
4.	15	2x1000	0.93	3307	416	17	11	297592	1413561	520785	557984	697481	3487403	1744
5.	20	2x1000	0.77	3251	409	17	11	292625	1389970	512094	548672	685841	3429203	1715
6.	3	2x2000	4.27	6173	776	32	21	555608	2639138	972314	1041765	1302206	6511030	1628
7.	5	2x2000	2.93	5992	753	31	20	539250	2561438	943688	1011094	1263867	6319337	1580
8.	10	2x2000	1.75	5754	723	30	19	517821	2459652	906187	970915	1213644	6068220	1517
9.	15	2x2000	1.34	5619	706	29	19	505683	2401996	884946	948156	1185195	5925977	1481
10.	20	2x2000	1.06	5525	695	29	19	497244	2361910	870177	932333	1165416	5827081	1457
11.	3	2x2500	4.75	7322	921	38	25	659014	3130318	1153275	1235652	1544565	7722825	1545
12.	5	2x2500	3.34	7107	894	37	24	639612	3038158	1119321	1199273	1499091	7495455	1499
13.	10	2x2500	1.96	6824	858	36	23	614195	2917428	1074842	1151616	1439520	7197601	1440
14.	15	2x2500	1.44	6664	838	35	22	599798	2849041	1049647	1124622	1405777	7028885	1406
15.	20	2x2500	1.14	6553	824	34	22	589788	2801495	1032130	1105853	1382317	6911583	1382
16.	3	2x4000	6.21	10490	1319	55	35	944118	4484560	1652206	1770221	2212776	11063882	1383
17.	5	2x4000	4.11	10181	1280	53	34	916322	4352529	1603563	1718104	2147630	10738148	1342
18.	10	2x4000	2.5	9777	1229	51	33	879909	4179569	1539841	1649830	2062287	10311436	1289
19.	15	2x4000	1.86	9548	1200	50	32	859284	4081597	1503746	1611157	2013946	10069729	1259
20.	20	2x4000	1.44	9388	1180	49	32	844943	4013481	1478651	1584269	1980336	9901680	1238
21.	3	2x5000	6.69	12443	1564	65	42	1119832	5319200	1959705	2099684	2624605	13123027	1312
22.	5	2x5000	4.62	12076	1518	63	41	1086862	5162596	1902009	2037867	2547334	12736669	1274
23.	10	2x5000	2.76	11596	1458	61	39	1043673	4957445	1826427	1956886	2446108	12230539	1223
24.	15	2x5000	2.08	11325	1424	59	38	1019208	4841240	1783615	1911016	2388770	11943848	1194
25.	20	2x5000	1.65	11235	1400	57	38	1011150	4760446	1710000	1879124	2340180	11700900	1170

Based on the determined sizes of intake and head race channel, the quantities of the major items i.e. earth work in excavation and concreting in lining of the channel have been worked out as given below.

Earthwork in excavation = 32707 m^3

PCC in lining = 1732 m^3

Based on quantities as worked out and prevailing rates, the cost of these items and miscellaneous items such as cross drainage works has been computed. The quantities and cost of intake and head race channel for layouts of different combinations of head and capacity have also been worked on similar lines and presented in Table 4.7.

4.5.4 Desilting Tank

The desilting tank is designed for the design discharge (Q_s) of 31 m^3/s. Silt particle size coarser than 0.5 mm are considered to be removed. In order to achieve this a horizontal velocity (V_h) of 0.60 m/s and settling velocity (V_f) as 0.06 m/s are considered. Width and depth of the tank has been determined as given below [133].

$$\text{Cross-sectional area of the tank [width } (B_t) \text{ x depth } (d_t)] = \frac{Q_s}{V_h}$$

This comes out to be as 51.70 m^2. Providing depth as 4m, width of the desilting tank comes out to 13 m. The length of the tank has been worked out as 40 m by using following expression [133];

$$\text{Length of tank} = \frac{d_t V_h}{V_f}$$

Table 4.7 Quantities and cost of power channel

Sl. No.	Head	Capacity kW	Quantitites (M^3)			Cost of items (Rs.)				
			Runner dia	Earth work in excavation	Concreting	Earth work in excavation	Concreting	Misccellaneous	Total	Cost per kW
1.	3	2x1000	3.03	31199	1652	2807901	5615802	1347793	9771496	4886
2.	5	2x1000	2.08	31505	1668	2835409	5670818	1360996	9867223	4934
3.	10	2x1000	1.28	32708	1732	2943696	5887392	1412974	10244062	5122
4.	15	2x1000	0.93	33333	1765	2999931	5999863	1439967	10439761	5220
5.	20	2x1000	0.77	31835	1685	2865111	5730223	1375253	9970588	4985
6.	3	2x2000	4.27	48082	2546	4327375	8654750	2077140	15059265	3765
7.	5	2x2000	2.93	48553	2570	4369768	8739537	2097489	15206794	3802
8.	10	2x2000	1.75	50407	2669	4536654	9073309	2177594	15787557	3947
9.	15	2x2000	1.34	51370	2720	4623321	9246642	2219194	16089157	4022
10.	20	2x2000	1.06	49062	2597	4415544	8831088	2119461	15366093	3842
11.	3	2x2500	4.75	55265	2926	4973892	9947785	2387468	17309145	3462
12.	5	2x2500	3.34	55807	2954	5022619	10045239	2410857	17478715	3496
13.	10	2x2500	1.96	57938	3067	5214438	10428877	2502930	18146245	3629
14.	15	2x2500	1.44	59045	3126	5314053	10628106	2550746	18492905	3699
15.	20	2x2500	1.14	56391	2985	5075234	10150468	2436112	17661814	3532
16.	3	2x4000	6.21	67926	3596	6113342	12226684	2934404	21274430	2659
17.	5	2x4000	4.11	74827	3961	6734435	13468869	3232529	23435832	2929
18.	10	2x4000	2.5	77685	4113	6991629	13983259	3355982	24330870	3041
19.	15	2x4000	1.86	79169	4191	7125195	14250390	3420094	24795679	3099
20.	20	2x4000	1.44	75611	4003	6804981	13609963	3266391	23681335	2960
21.	3	2x5000	6.69	85172	4509	7665475	15330951	3679428	26675855	2668
22.	5	2x5000	4.62	86006	4553	7740571	15481141	3715474	26937186	2694
23.	10	2x5000	2.76	89291	4727	8036191	16072382	3857372	27965945	2797
24.	15	2x5000	2.08	90997	4817	8189712	16379423	3931062	28500197	2850
25.	20	2x5000	1.65	86907	4601	7821657	15643315	3754396	27219368	2722

Length of the tank is increased by 10% to improve the efficiency of silt removal. Thus 44 m length, 13 m width and 4 m depth is provided in desilting tank. Two rows of hoppers are provided to facilitate silt removal. The upstream and downstream transition lengths are determined based on the methodology given in chapter 3, and found to be 25 m and 10 m respectively.

The silt flushing shall be carried out by 200 mm diameter flushing pipes which will takeoff from the bottom of the hoppers and end into the nearby river. The layout of desilting tank has been shown in Fig. 4.8. The quantities of the major items i.e. earth work in excavation, concreting, reinforcement steel and fabricated steel structures (gates, silt flushing pipes and railings) have been worked out and are given below.

Earthwork in excavation	= 7980 m^3
Concreting	= 722 m^3
Reinforced steel	= 42 MT
Structural steel	= 13 MT

Based on the determined quantities and prevailing rates, the cost of these items and miscellaneous items such as fencing, paintings, protection works near joining of pipes with river has been worked. The quantities and cost of desilting tank for layouts at different combinations of head and capacity has also been worked on similar lines and presented in Table 4.8.

All dimensions are in millimetre.

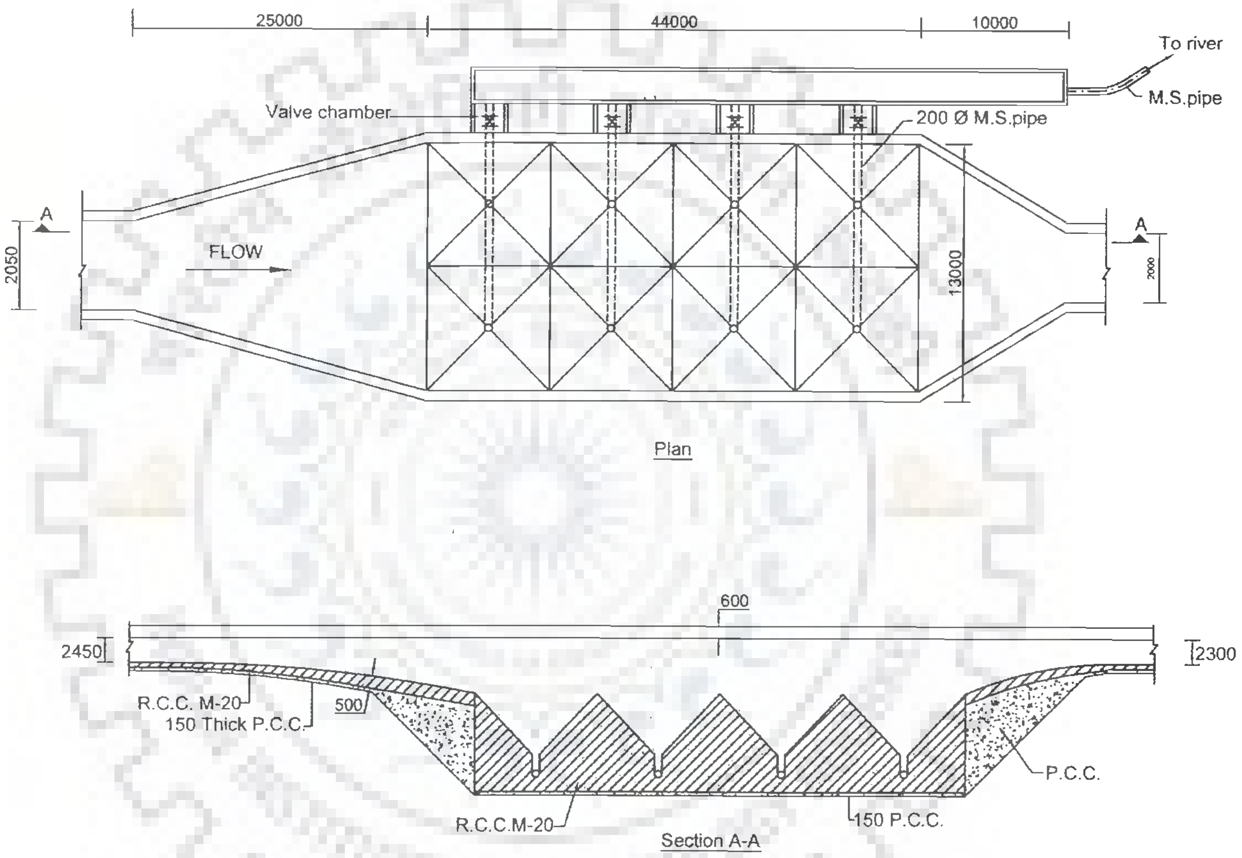


Fig. 4.8 Desilting tank for run of river scheme (H = 10 m, P = 2x1000 kW)

4.5.5 Forebay

Based on the criteria for sizing of forebay and spillway presented in Chapter-3, forebay is designed for design discharge (Q) of 23.70 m^3/s. Volume of forebay for 2 minutes storage has been considered which comes out to be 2844 m^3/s . Assuming a depth of 5.0 m and width as 10m, the length has been worked out as 57 m. A free board of 0.60 m has been provided above full supply level. Considering, spilling head of 0.75 m over the crest of the spillway, length of spillway crest (L) comes out to be as 21.50 m by using Eq. (3.9)

The crest of the spillway shall be kept at full supply level of the forebay tank so that at the time of tripping of the power house, the entire discharge entering into the forebay gets spilled over the crest.The spilled water is diverted into nearby drain, to reduce the length of spilling channel which is designed on similar lines as intake channel. Based on past experience the length of the spilling channel is considered 100 m. The layout of forebay including spillway is shown in Fig. 4.9. The quantities of the major items i.e. earth work in excavation, concreting, reinforcement steel and fabricated steel structures (gates, silt flushing pipes and railings) have been worked out and are given below;

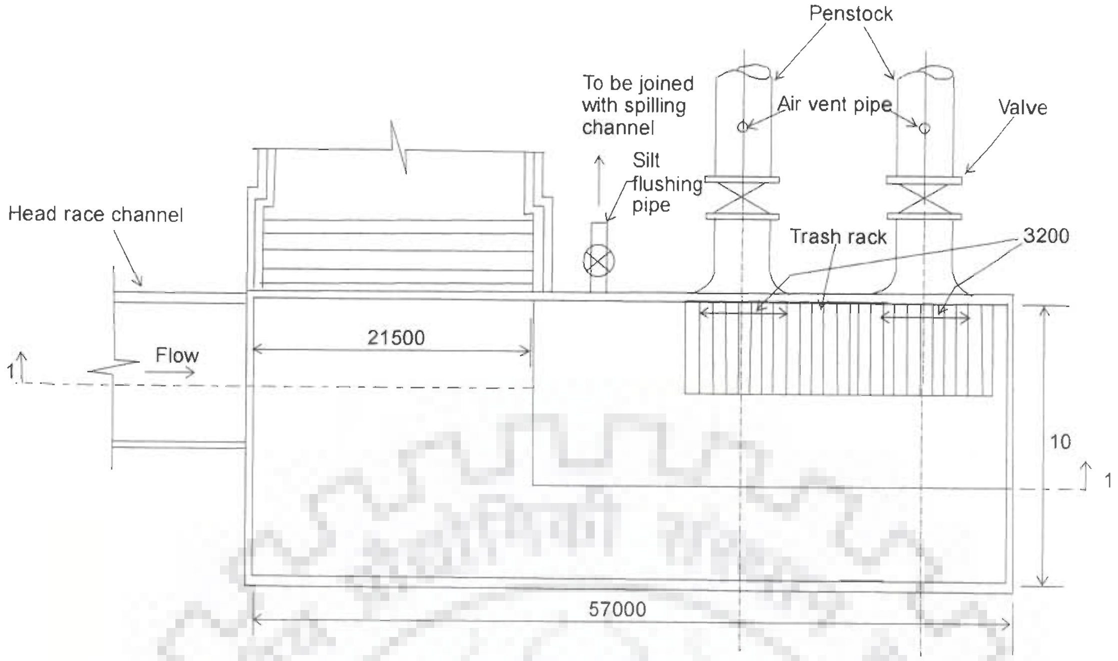
Earthwork in excavation = 6770 m^3

Concreting = 960 m^3

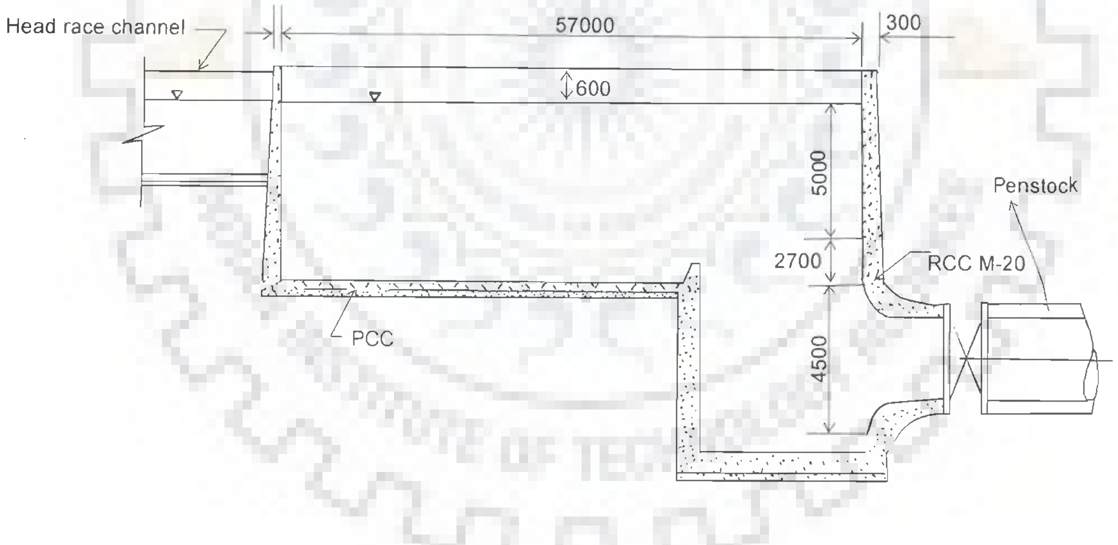
Reinforced steel = 50 MT

Structural steel = 18 MT

Based on the determined quantities and prevailing rates, the cost of these items and miscellaneous items such as fencing, paintings, railings has been worked out. The sizing and cost of forebay for layouts at different combinations of head and capacity have also been worked on similar lines and given in Table 4.9.



PLAN



SECTION 1-1

All dimension in mm

Fig. 4.9 Forbay for run of river scheme (H = 10 m, P = 2x1000 kW)

4.5.6 Penstock

The penstock has been designed for the design discharge (Q) of 23.70 m3/s. Considering flow velocity as 3 m/s, the area of pipe is worked out as 7.9 m^2. In case of 2 generating units and cross sectional area required for penstock, 2 pipes of 2.25 m diameter each are worked out. Thickness of pipe has been worked out as 3.44 mm by using the Eq. (3.11). The length of penstock has been taken as 25 m as discussed in Chapter-3.

Based on the sizing, the quantities of the major items i.e. earth work in excavation, concreting, reinforcement steel and fabricated steel structures (penstock pipe and fittings) have been worked out and are given below.

Earthwork in excavation = 940 m^3

Concreting = 50 m^3

Reinforced steel = 4 MT

Structural steel = 31 MT

The quantities and cost of penstock for layouts at different combinations of head and capacity have worked on similar lines are given in Table 4.10.

4.5.7 Power House Building

The sizing of power house building has been worked out on similar lines as worked out for canal based scheme. In this case, the difference is at the intake of power house, where penstock joins the turbine inlet in place of transitional casing from open channel to close conduit. The quantities of the major items i.e. earth work in excavation, concreting, rainforcement steel and fabricated steel structures (gates, trash racks, roofing trusses, railings) have been worked out on the similar lines as worked out for canal based scheme. Based on determined quantities and prevailing rates, the cost of these items and miscellaneous items such as masonary work, damp proofing treatment, dewatering, doors, widows, floor finishing, plastering, sanitary and water supply works, drainage, fencing, white/colour wash, paintings have been computed and presented in Table 4.11. The quantities and cost of powerhouse for layouts at different combinations of head and capacity have also been worked on similar lines and are given in Table 4.11.

4.5.8 Tail Race Channel

As the design discharge for tail race channel is 23.70 m^3/s. The tail race channel is designed on the similar lines as for head race channel. The bed width (b) and water depth (h) has been determined and are given as follows;

Bed width (b) = 1.80 m
Water depth (h) = 2.25 m
Free board = 0.60 m

As per the criterion discussed in Chapter-3, the length of channel is considered as 30 m. Based on the determined sizes of tail race channel, the quantities of the major items i.e. earth work in excavation and concreting in lining of the channel has been computed as given below.

Earthwork in excavation = 2453 m^3
PCC in lining = 130 m^3

Based on worked out quantities and prevailing rates, the cost of these items and miscellaneous items such as protection works at the joining with the stream have been computed. The quantities and cost of tail race channel for layouts at different combinations of head and capacity has also been worked on similar lines and are given in Table 4.12.

Table 4.8 Quantities and cost of desilting tank for run of river scheme at different combination of head and capacity

S. No.	Head (m)	Capacity (kW)	Runner dia (m)	Quantities				Cost of items (Rs.)						
				Earth work in excavation	Concretin	Reinforcement	Steel	Earth work in excavation	Concreting	Reinforcement	Steel	Misc	Total	Total per kW
1.	3	2x1000	3.03	9000	790	46	14	810000	2686000	1380000	706493	837374	6419867	3210
2.	5	2x1000	2.08	8311	752	44	14	748029	2555765	1309050	685693	794781	6093318	3047
3.	10	2x1000	1.28	7981	722	42	13	718304	2454204	1257031	658445	763198	5851182	2926
4.	15	2x1000	0.93	7794	705	41	13	701466	2396676	1227566	643011	745308	5714026	2857
5.	20	2x1000	0.77	7664	693	40	13	689760	2356679	1207079	632280	732870	5618667	2809
6.	3	2x2000	4.27	14552	1316	76	24	1309647	4474628	2291883	1200510	1391500	10668168	2667
7.	5	2x2000	2.93	14123	1277	74	23	1271090	4342889	2224407	1165165	1350533	10354084	2589
8.	10	2x2000	1.75	13562	1227	71	22	1220579	4170312	2136013	1118864	1296865	9942633	2486
9.	15	2x2000	1.34	13244	1198	70	22	1191968	4072557	2085944	1092637	1266466	9709572	2427
10.	20	2x2000	1.06	13023	1178	68	21	1172076	4004592	2051132	1074403	1245330	9547533	2387
11.	3	2x2500	4.75	17260	1561	91	28	1553391	5307419	2718434	1423942	1650478	12653664	2531
12.	5	2x2500	3.34	16752	1515	88	28	1507657	5151162	2638400	1382019	1601886	12281125	2456
13.	10	2x2500	1.96	16086	1455	84	27	1447746	4946466	2533556	1327101	1538230	11793098	2359
14.	15	2x2500	1.44	15709	1421	82	26	1413810	4830517	2474167	1295992	1502173	11516660	2303
15.	20	2x2500	1.14	15447	1397	81	25	1390215	4749903	2432877	1274364	1477104	11324464	2265
16.	3	2x4000	6.21	24727	2236	130	41	2225421	7603521	3894487	2039969	2364510	18127907	2266
17.	5	2x4000	4.11	23999	2170	126	40	2159902	7379664	3779828	1979910	2294896	17594200	2199
18.	10	2x4000	2.5	23045	2084	121	38	2074072	7086411	3629625	1901232	2203701	16895042	2112
19.	15	2x4000	1.86	22505	2035	118	37	2025454	6920302	3544545	1856666	2152045	16499012	2062
20.	20	2x4000	1.44	22129	2001	116	37	1991652	6804812	3485391	1825681	2116130	16223667	2028
21.	3	2x5000	6.69	29329	2653	154	48	2639603	9018644	4619305	2419636	2804578	21501767	2150
22.	5	2x5000	4.62	28465	2574	149	47	2561890	8753124	4483307	2348399	2722008	20868729	2087
23.	10	2x5000	2.76	27334	2472	144	45	2460086	8405292	4305150	2255078	2613841	20039447	2004
24.	15	2x5000	2.08	26694	2414	140	44	2402420	8208267	4204234	2202218	2552571	19569710	1957
25.	20	2x5000	1.65	26000	2350	136	43	2340000	7990000	4080000	2165466	2486320	19061786	1906

Table 4.9 Quantities and cost of forebay for run of river scheme at different combination of head and capacity

S. No.	Head (m)	Capacity (kW)	Runner Dia (m)	Quantities				Cost of items (Rs.)						
				Earth work in excavation	Spiil Conc	Spill rein	Spill Steel	Earth work in excavation	Spiil Conc	Spill rein	Spill Steel	Misc	Total	Total per kW
1.	3	2x1000	3.03	7266	1034	55	20	653944	3514949	1650000	980916	1155968	7955777	3978
2.	5	2x1000	2.08	7052	1003	53	19	634691	3411465	1586728	952037	1119436	7704357	3852
3.	10	2x1000	1.28	6772	963	51	18	609470	3275900	1523674	914205	1074952	7398201	3699
4.	15	2x1000	0.93	6613	941	50	18	595183	3199111	1487959	892775	1049755	7224783	3612
5.	20	2x1000	0.77	6503	925	49	18	585251	3145722	1463127	877876	1032236	7104211	3552
6.	3	2x2000	4.27	12347	1757	93	33	1111216	5972785	2778039	1666824	1959907	13488771	3372
7.	5	2x2000	2.93	11983	1705	90	32	1078500	5796939	2696251	1617750	1902205	13091645	3273
8.	10	2x2000	1.75	11507	1637	86	31	1035643	5566580	2589107	1553464	1826615	12571409	3143
9.	15	2x2000	1.34	11237	1599	84	30	1011367	5436096	2528417	1517050	1783798	12276728	3069
10.	20	2x2000	1.06	11050	1572	83	30	994488	5345375	2486221	1491733	1754029	12071847	3018
11.	3	2x2500	4.75	14645	2084	110	40	1318029	7084404	3295072	1977043	2324673	15999221	3200
12.	5	2x2500	3.34	14214	2022	107	38	1279224	6875831	3198061	1918837	2256232	15528185	3106
13.	10	2x2500	1.96	13649	1942	102	37	1228391	6602599	3070976	1842586	2166574	14911126	2982
14.	15	2x2500	1.44	13329	1896	100	36	1199596	6447830	2998991	1799394	2115788	14561600	2912
15.	20	2x2500	1.14	13106	1865	98	35	1179577	6340225	2948942	1769365	2080479	14318588	2864
16.	3	2x4000	6.21	20980	2985	157	57	1888236	10149268	4720590	2832354	3330376	22920823	2865
17.	5	2x4000	4.11	20363	2897	153	55	1832644	9850461	4581610	2748966	3232326	22246007	2781
18.	10	2x4000	2.5	19554	2782	147	53	1759818	9459024	4399546	2639728	3103880	21361995	2670
19.	15	2x4000	1.86	19095	2717	143	52	1718567	9237298	4296418	2577851	3031123	20861257	2608
20.	20	2x4000	1.44	18777	2672	141	51	1689887	9083141	4224717	2534830	2980538	20513112	2564
21.	3	2x5000	6.69	24885	3541	187	67	2239663	12038190	5599158	3359495	3950206	27186712	2719
22.	5	2x5000	4.62	24152	3436	181	65	2173725	11683771	5434312	3260587	3833907	26386302	2639
23.	10	2x5000	2.76	23193	3300	174	63	2087345	11219481	5218363	3131018	3681555	25337763	2534
24.	15	2x5000	2.08	22649	3222	170	61	2038417	10956490	5096042	3057625	3595257	24743831	2474
25.	20	2x5000	1.65	22271	3169	165	60	2004398	10773642	4950000	3006598	3524888	24259526	2426

Table 4.10 Quantities and cost of penstock for run of river scheme at different combination of head and capacity

S. No.	Head (m)	Capacity (kW)	Runner dia (m)	Quantities				Cost of items (Rs.)						
				Earth work in excavation	Conc	Rein	Steel	Earth work in excavation	Conc	Rein	Steel	Misc	Total	Total per kW
1.	3	2x1000	3.03	605	32	2	19	54450	107342	67089	966075	131445	1326400	663
2.	5	2x1000	2.08	724	38	3	23	65186	130371	81482	1173341	159542	1609922	805
3.	10	2x1000	1.28	943	50	4	31	84858	169716	106073	1527447	207690	2095785	1048
4.	15	2x1000	0.93	1100	58	4	36	99014	198028	123767	1782251	242337	2445397	1223
5.	20	2x1000	0.77	1227	65	5	40	110468	220936	138085	1988420	270370	2728278	1364
6.	3	2x2000	4.27	916	49	3	30	82457	164914	103071	1484222	201813	2036476	509
7.	5	2x2000	2.93	1113	59	4	36	100147	200295	125184	1802654	245111	2473391	618
8.	10	2x2000	1.75	1449	77	5	47	130371	260742	162964	2346682	319084	3219843	805
9.	15	2x2000	1.34	1690	89	6	55	152119	304239	190149	2738148	372312	3756968	939
10.	20	2x2000	1.06	1886	100	7	61	169716	339433	212145	3054894	415381	4191569	1048
11.	3	2x2500	4.75	1052	56	4	34	94681	189362	118351	1704255	231731	2338380	468
12.	5	2x2500	3.34	1278	68	5	41	114994	229988	143743	2069894	281448	2840067	568
13.	10	2x2500	1.96	1663	88	6	54	149699	299397	187123	2694573	366387	3697179	739
14.	15	2x2500	1.44	1941	103	7	63	174671	349342	218338	3144074	427507	4313931	863
15.	20	2x2500	1.14	2165	115	8	70	194876	389753	243596	3507777	476960	4812962	963
16.	3	2x4000	6.21	1408	75	5	46	126682	253364	158352	2280274	310054	3128726	391
17.	5	2x4000	4.11	1710	91	6	55	153861	307722	192326	2769494	376574	3799977	475
18.	10	2x4000	2.5	2225	118	8	72	200295	400590	250369	3605308	490222	4946783	618
19.	15	2x4000	1.86	2597	137	10	84	233707	467415	292134	4206734	571999	5771990	721
20.	20	2x4000	1.44	2897	153	11	94	260742	521485	325928	4693364	638167	6439687	805
21.	3	2x5000	6.69	1616	86	6	52	145462	290924	181828	2618320	356019	3592553	359
22.	5	2x5000	4.62	1963	104	7	64	176670	353341	220838	3180066	432401	4363316	436
23.	10	2x5000	2.76	2555	135	10	83	229988	459976	287485	4139788	562896	5680134	568
24.	15	2x5000	2.08	2982	158	11	97	268354	536708	335443	4830375	656797	6627677	663
25.	20	2x5000	1.65	3327	176	12	108	299397	598794	374246	5389147	732774	7394358	739

Table 4.11 Quantities and cost of powerhouse building for run of river at different combination of head and capacity

S. No.	Head (m)	Capacity (m)	Runner dia (m)	Quantities				Cost of items (Rs.)						
				Earth work in excavation	Conc	Rein	Steel	Earth work in excavation	Conc	Rein	Steel	Misc	Total	Total per kW
1.	3	2x1000	3.03	6488	3864	243	128	583879	13137268	7298482	6422664	1646538	29088830	14544
2.	5	2x1000	2.08	6297	3750	236	125	566688	12750491	7083606	6233573	1598062	28232420	14116
3.	10	2x1000	1.28	6046	3601	227	120	544169	12243812	6802118	5985864	1534558	27110520	13555
4.	15	2x1000	0.93	5905	3517	221	117	531414	11956810	6642672	5845551	1498587	26475033	13238
5.	20	2x1000	0.77	5806	3458	218	115	522545	11757267	6531815	5747997	1473578	26033203	13017
6.	3	2x2000	4.27	11024	6566	413	218	992157	22323531	12401962	10913727	2797883	49429260	12357
7.	5	2x2000	2.93	10699	6372	401	212	962947	21666300	12036833	10592413	2715510	47974002	11994
8.	10	2x2000	1.75	10274	6119	385	203	924681	20805324	11558514	10171492	2607601	46067612	11517
9.	15	2x2000	1.34	10033	5976	376	199	903006	20317635	11287575	9933066	2546477	44987759	11247
10.	20	2x2000	1.06	9866	5876	370	195	887936	19978563	11099201	9767297	2503980	44236977	11059
11.	3	2x2500	4.75	13076	7788	490	259	1176811	26478255	14710142	12944925	3318608	58628742	11726
12.	5	2x2500	3.34	12691	7558	476	251	1142165	25698704	14277058	12563811	3220904	56902641	11381
13.	10	2x2500	1.96	12186	7258	457	241	1096777	24677489	13709716	12064550	3092912	54641444	10928
14.	15	2x2500	1.44	11901	7088	446	236	1071068	24099033	13388352	11781750	3020412	53360615	10672
15.	20	2x2500	1.14	11702	6970	439	232	1053194	23696855	13164919	11585129	2970006	52470102	10494
16.	3	2x4000	6.21	18732	11157	702	371	1685925	37933310	21074061	18545174	4754308	83992779	10499
17.	5	2x4000	4.11	18181	10828	682	360	1636289	36816508	20453615	17999182	4614336	81519930	10190
18.	10	2x4000	2.5	17459	10398	655	346	1571266	35353494	19640830	17283930	4430971	78280491	9785
19.	15	2x4000	1.86	17049	10154	639	338	1534435	34524786	19180437	16878784	4327107	76445549	9556
20.	20	2x4000	1.44	16765	9985	629	332	1508827	33948617	18860343	16597101	4254893	75169781	9396
21.	3	2x5000	6.69	22219	13233	833	440	1999699	44993234	24996241	21996692	5639152	99625019	9963
22.	5	2x5000	4.62	21565	12844	809	427	1940826	43668579	24260322	21349083	5473129	96691938	9669
23.	10	2x5000	2.76	20708	12333	777	410	1863701	41933277	23296265	20500713	5255637	92849594	9285
24.	15	2x5000	2.08	20222	12044	758	400	1820015	40950336	22750187	20020164	5132442	90673143	9067
25.	20	2x5000	1.65	19885	11843	746	394	1789641	40266933	22370518	19686056	5046789	89159938	8916

Table 4.12 Quantities and cost of tailrace channel for run of river scheme at different combination of head and capacity

S. No.	Head (m)	Capacity (kW)	Runner dia (m)	Quantities		Cost of items (Rs.)				
				Earth work in excavation	Concreting	Earth work in excavation	Concreting	Miscellaneous	Total	Total per kW
1.	3	2x1000	3.03	5200	275	467984	935967	224632	1628583	814
2.	5	2x1000	2.08	3781	200	340249	680498	163320	1184067	592
3.	10	2x1000	1.28	2453	130	220777	441554	105973	768305	384
4.	15	2x1000	0.93	1905	101	171425	342849	82284	596558	298
5.	20	2x1000	0.77	1592	84	143256	286511	68763	498529	249
6.	3	2x2000	4.27	8014	424	721229	1442458	346190	2509878	627
7.	5	2x2000	2.93	5826	308	524372	1048744	251699	1824815	456
8.	10	2x2000	1.75	3781	200	340249	680498	163320	1184067	296
9.	15	2x2000	1.34	2935	155	264190	528380	126811	919380	230
10.	20	2x2000	1.06	2453	130	220777	441554	105973	768305	192
11.	3	2x2500	4.75	9211	488	828982	1657964	397911	2884858	577
12.	5	2x2500	3.34	6697	355	602714	1205429	289303	2097446	419
13.	10	2x2500	1.96	4345	230	391083	782166	187720	1360968	272
14.	15	2x2500	1.44	3374	179	303660	607320	145757	1056737	211
15.	20	2x2500	1.14	2820	149	253762	507523	121806	883091	177
16.	3	2x4000	6.21	12350	654	1111517	2223033	533528	3868078	484
17.	5	2x4000	4.11	8979	475	808132	1616264	387903	2812300	352
18.	10	2x4000	2.5	5826	308	524372	1048744	251699	1824815	228
19.	15	2x4000	1.86	4524	240	407154	814308	195434	1416896	177
20.	20	2x4000	1.44	3781	200	340249	680498	163320	1184067	148
21.	3	2x5000	6.69	14195	752	1277579	2555158	613238	4445976	445
22.	5	2x5000	4.62	10321	546	928868	1857737	445857	3232462	323
23.	10	2x5000	2.76	6697	355	602714	1205429	289303	2097446	210
24.	15	2x5000	2.08	5200	275	467984	935967	224632	1628583	163
25.	20	2x5000	1.65	4345	230	391083	782166	187720	1360968	136

4.6 DAM TOE SCHEME

It is found that the sizes, thus cost of penstock, power house building and tail race channel are similar as in case of run of river schemes under similar conditions. However, the sizing of intake structure is based on size of bell mouth entry, which has been designed as per methodology given in chapter 3, having 2 number of penstock of 2.25 m diameter each. Based on sizing worked out, the quanities and cost determined for intake structure has been given in Table 4.13.

4.7 ELECTRO-MECHANICAL EQUIPMENT

The criteria for selection and sizing of the components under electro-mechanical equipment have been discussed in Chapter-3. These components are similar in all three types of SHP schemes considered for analysis. In order to estimate the cost of electromechanical equipment, all components under electro-mechanical equipment are categorised as follows;

i. Turbines with governing system
ii. Generator with excitation system
iii. Electrical and mechanical auxiliary
iv. Transformer and switchyard

Type of turbines and generators considered under present study have been discussed in chapter-3 and given in Table-4.1. By carrying out an extensive market survey, the cost of these items was obtained from different manufacturers/suppliers. As a typical example, having two units of different capacity at different heads, costs of various items for one type of turbine (tubular semi Kaplan) and synchronous generator are as given in Table 4.14.

Table 4.13 Quantities and cost of intake in dam toe schemes at different combination of head and capacity

S. No.	Head (m)	Capacity (kW)	Runner dia (m)	Quantities				Cost of items (Rs.)						
				Earth work in excavation	Concreting	Rein	Steel	Earth work in excavation	Concreting	Rein	Steel	Misc	Total	Total per kW
1.	3	2000	3.03	1600	630	55	11	144000	2142000	1650000	560523	1124131	5620654	2810
2.	5	2000	2.08	1511	600	53	11	136005	2040079	1586728	544021	1076708	5383541	2692
3.	10	2000	1.28	1451	576	51	10	130601	1959010	1523674	522403	1033922	5169609	2585
4.	15	2000	0.93	1417	563	50	10	127539	1913090	1487959	510157	1009686	5048431	2524
5.	20	2000	0.77	1393	553	49	10	125411	1881163	1463127	501643	992835.9	4964180	2482
6.	3	4000	4.27	2646	1051	93	19	238118	3571765	2778039	952471	1885098	9425491	2356
7.	5	4000	2.93	2568	1020	90	18	231107	3466608	2696251	924429	1829599	9147993	2287
8.	10	4000	1.75	2466	979	86	18	221923	3328852	2589107	887694	1756894	8784470	2196
9.	15	4000	1.34	2408	956	84	17	216721	3250822	2528417	866886	1715711	8578557	2145
10.	20	4000	1.06	2368	940	83	17	213105	3196570	2486221	852419	1687079	8435393	2109
11.	3	5000	4.75	3138	1246	110	23	282435	4236521	3295072	1129739	2235942	11179708	2236
12.	5	5000	3.34	3046	1209	107	22	274120	4111793	3198061	1096478	2170113	10850564	2170
13.	10	5000	1.96	2925	1161	102	21	263227	3948398	3070976	1052906	2083877	10419384	2084
14.	15	5000	1.44	2856	1134	100	21	257056	3855845	2998991	1028225	2035029	10175147	2035
15.	20	5000	1.14	2809	1115	98	20	252766	3791497	2948942	1011066	2001068	10005339	2001
16.	3	8000	6.21	4496	1785	157	32	404622	6069330	4720590	1618488	3203257	16016287	2002
17.	5	8000	4.11	4363	1733	153	31	392709	5890641	4581610	1570838	3108950	15544748	1943
18.	10	8000	2.5	4190	1664	147	30	377104	5656559	4399546	1508416	2985406	14927031	1866
19.	15	8000	1.86	4092	1625	143	29	368264	5523966	4296418	1473058	2915426	14577132	1822
20.	20	8000	1.44	4024	1598	141	29	362119	5431779	4224717	1448474	2866772	14333860	1792
21.	3	10000	6.69	5333	2117	187	38	479928	7198917	5599158	1919711	3799429	18997143	1900
22.	5	10000	4.62	5176	2055	181	37	465798	6986973	5434312	1863193	3687569	18437844	1844
23.	10	10000	2.76	4970	1973	174	36	447288	6709324	5218363	1789153	3541032	17705162	1771
24.	15	10000	2.08	4853	1927	170	35	436804	6552054	5096042	1747214	3458028	17290142	1729
25.	20	10000	1.65	4772	1895	167	34	429514	6442709	5010996	1718056	3400319	17001594	1700

Table 4.14 Analysed cost of electro-mechanical equipment at different combination of head and capacity

S. No.	Head (m)	Capacity (kW)	Runner dia (m)	Cost (Rs)							
				Turbine		Generator		Auxiliary		Transformer	
				Total Cost	Cost per kW	Total Cost	Cost per kW	Total Cost	Cost per kW	Total Cost	Cost per kW
1.	3	2x1000	3.03	23180000	11590	30400000	15200	15276000	7638	7448000	3724
2.	5	2x1000	2.08	20400000	10200	27336000	13668	13600000	6800	6800000	3400
3.	10	2x1000	1.28	17995000	8998	23541000	11771	11918000	5959	5841000	2921
4.	15	2x1000	0.93	15930000	7965	21708000	10854	10854000	5427	5400000	2700
5.	20	2x1000	0.77	15808000	7904	20956000	10478	10504000	5252	5200000	2600
6.	3	2x2000	4.27	44588960	11147	54350400	13588	27040000	6760	13520000	3380
7.	5	2x2000	2.93	35520000	8880	47760000	11940	24240000	6060	12000000	3000
8.	10	2x2000	1.75	31200000	7800	41600000	10400	20800000	5200	10400000	2600
9.	15	2x2000	1.34	28896000	7224	38208000	9552	19008000	4752	9600000	2400
10.	20	2x2000	1.06	27421600	6855	36501600	9125	17887600	4472	9080000	2270
11.	3	2x2500	4.75	48425000	9685	65650000	13130	32500000	6500	16250000	3250
12.	5	2x2500	3.34	43645000	8729	57710000	11542	29145000	5829	14500000	2900
13.	10	2x2500	1.96	37875000	7575	50000000	10000	24875000	4975	12500000	2500
14.	15	2x2500	1.44	34040000	6808	46230000	9246	23115000	4623	11500000	2300
15.	20	2x2500	1.14	32482000	6496	43600000	8720	22018000	4404	10900000	2180
16.	3	2x4000	6.21	72480000	9060	96480000	12060	47760000	5970	24000000	3000
17.	5	2x4000	4.11	62964000	7871	84800000	10600	42612000	5327	21200000	2650
18.	10	2x4000	2.5	55384000	6923	72864000	9108	37168000	4646	18400000	2300
19.	15	2x4000	1.86	50568000	6321	67368000	8421	33264000	4158	16800000	2100
20.	20	2x4000	1.44	48320000	6040	64320000	8040	32160000	4020	16000000	2000
21.	3	2x5000	6.69	85215000	8522	112860000	11286	57000000	5700	28500000	2850
22.	5	2x5000	4.62	74500000	7450	100500000	10050	50250000	5025	25000000	2500
23.	10	2x5000	2.76	65560000	6556	88110000	8811	43560000	4356	22000000	2200
24.	15	2x5000	2.08	60400000	6040	79800000	7980	40200000	4020	20000000	2000
25.	20	2x5000	1.65	56832000	5683	77184000	7718	37248000	3725	19200000	1920

CHAPTER–5

DEVELOPMENT OF CORRELATIONS FOR COSTS OF DIFFERENT COMPONENTS

5.1 GENERAL

Cost of different components of various schemes for different alternatives have been determined and presented in Chapter-4. It was observed that these costs strongly depend on the installed capacity and head of the scheme. In order to predict the cost of various components of low head SHP scheme, correlations for cost as function of installed capacity and head are required to be developed from the determined values of cost. Saini and Saini [155] mentioned that it is feasible to adopt a statistical approach for the development of correlations from the determined values.

In the present chapter correlations for cost from the determined values have been developed by following the procedure given by Saini and Saini [155]. Microsoft Excel software has been employed for carrying out the regression analysis. Different plots are shown on linear scale, however in order to have the best curve fitting, data on log scales have been employed while carrying out the regression analysis. It has been found that the regression of data deals with first order.

5.2 DEVELOPMENT OF CORRELATIONS

For a range of capacity, head and other related parameters considered under the present study, cost values determined in the previous chapter, have been used to develop the correlations. It is revealed from the determined values that the cost is found to be the strong function of capacity (P) and head (H) of a scheme. Therefore the functional relationship for cost per kW (C) can be written as;

$$C = f(P, H) \qquad (5.1)$$

Based on this relationship the correlations for cost components of different alternatives and schemes are developed and discussed as follows;

5.2.1 Canal Based Scheme

Various alternatives such as location of power house, soil conditions, type of turbines, type of generators and number of generating units have been considered for cost estimation. Under canal based schemes, main components considered are as discussed below;

5.2.1.1 Diversion channel

Data of cost obtained for diversion channel as determined in Chapter-4 for different alternatives as function of head and capacity have been used for development of correlation for cost. For a typical case these data is given in Table 4.1. First order regression of the data has been shown in Fig. 5.1 and an average value of exponent, x_1 (average slope of lines) has been found as - 0.2295. Therefore the following first order equation similar to Eq. (5.1) can be represented as;

$$C = a_0 P^{-0.2295} \tag{5.2}$$

The coefficient 'a_0' will be a function of other parameter i.e. head.

In order to induce the effect of head (H) parameter, the values of $\frac{C}{P^{-0.2295}}$ are calculated from the determined cost data. These values have been plotted against respective head values as shown in Fig. 5.2. From the first order regression of the data values of constant a_1 and exponent y_1 are obtained equal to 9904 and -0.0623 respectively. By putting these values in the Eq. (5.3), Correlation has been obtained for cost per kW of diversion channel (C_1) as given below;

$$C_1 = a_1 \; P^{x_1} \;\; H^{y_1} \tag{5.3}$$

Where,

$a_1 = 9904$, $x_1 = -0.2295$ and $y_1 = -0.0623$

Correlation developed above for channel was obtained for one type of soil condition i.e ordinary soil. In order to induce the effect of other soils, similar approach of first order regression has been employed. The values of coefficients obtained for soft rock and hard rock conditions are as given below:

$a_1 = 12376$, $x_1 = -0.2305$, $y_1 = -0.0612$ for soft rock

$a_1 = 14466$, $x_1 = -0.2311$, $y_1 = -0.0605$ for hard rock.

5.2.1.2 Spillway

In case of spillway, all other alternatives are similar as in case of diversion channel except the location of power house i.e. (i) power house in diversion channel and spillway in main canal and (ii) power house and spillway combined in main canal. Accordingly, first order regression has been carried out to determine the values of constants and exponents for these cases also, as shown in Figs. 5.3 and 5.4. The developed correlations for cost per kW are given in Eq 5.4 and different values of constants and exponents obtained are as given in Table 5.1.

$$C_2 = a_2 \; P^{x_2} \;\; H^{y_2} \tag{5.4}$$

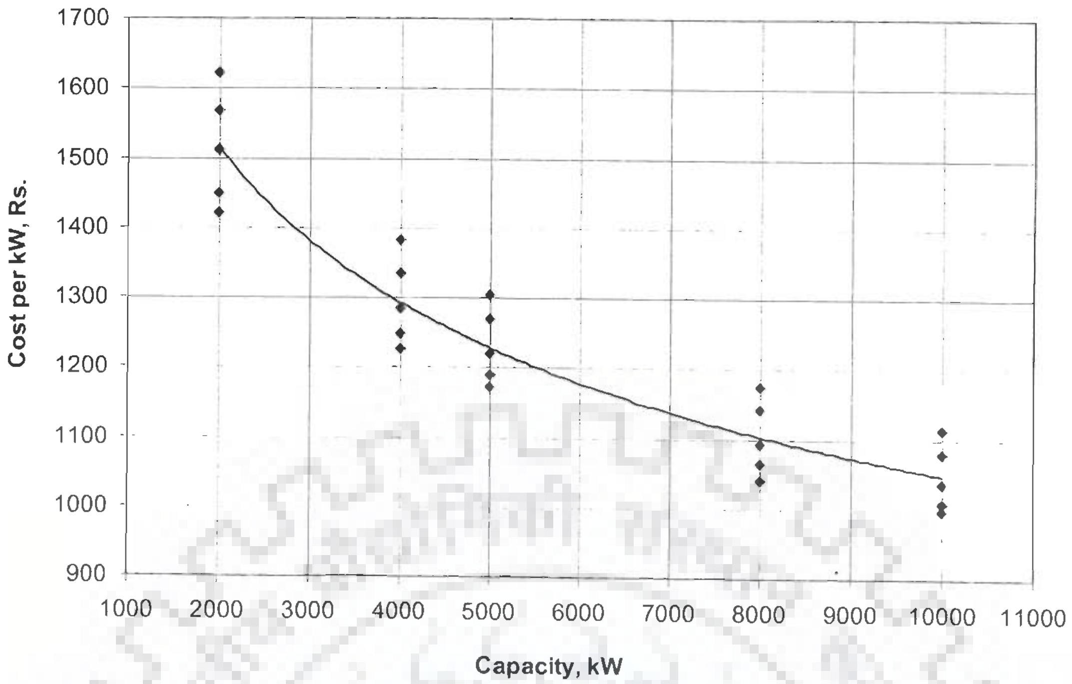


Fig. 5.1 Plot of cost per kW of diversion channel with capacity

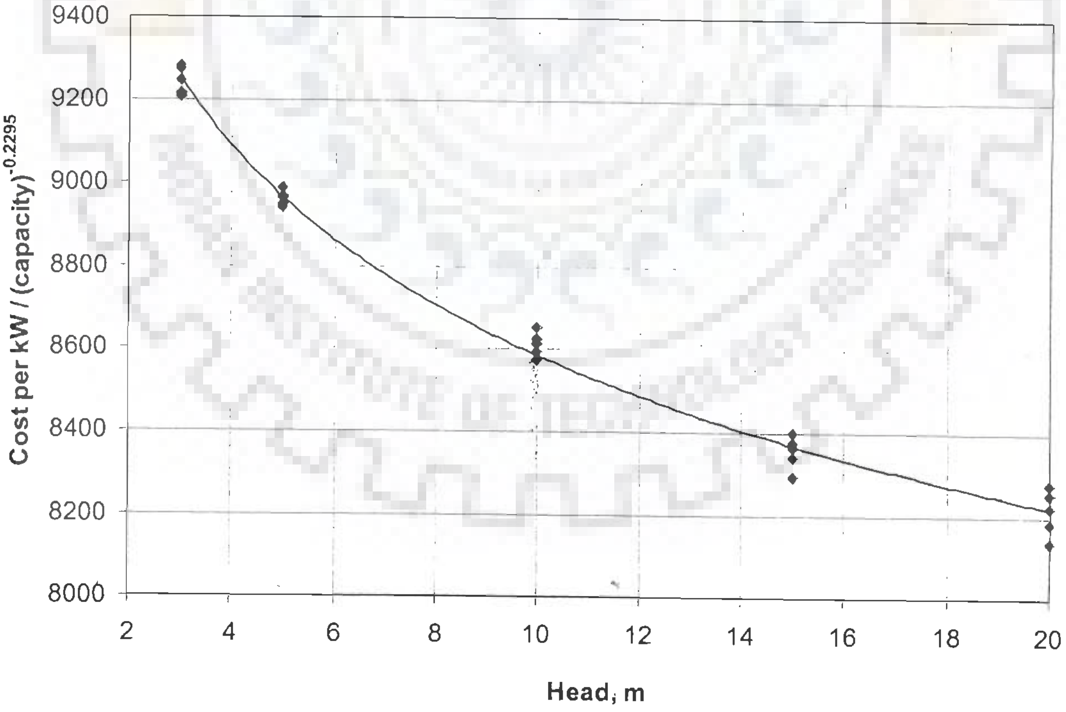


Fig. 5.2 Plot of cost per kW of diversion channel $(\text{capacity})^{-0.2295}$ with head

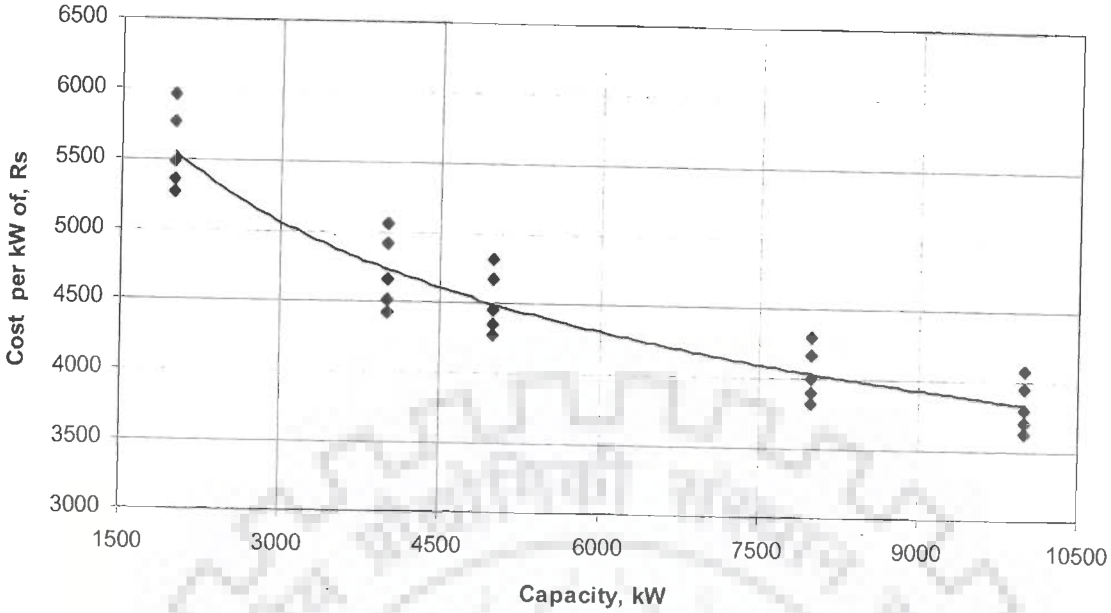


Fig. 5.3 Plot of cost per kW of spillway with capacity

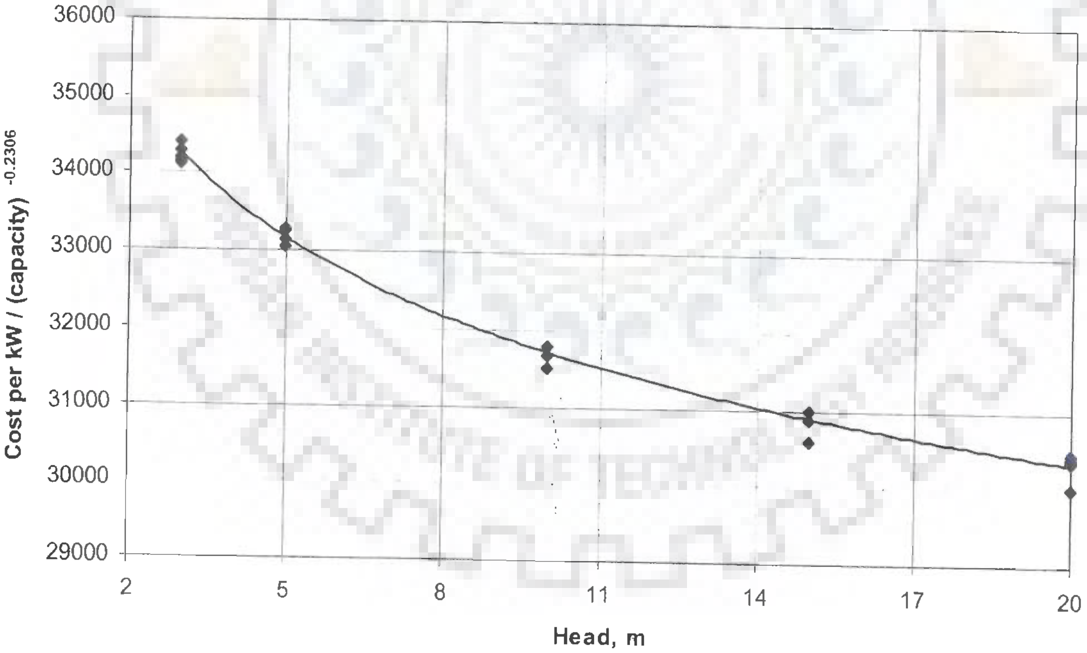


Fig. 5.4 Plot of cost per kW of spillway (capacity)$^{-0.2306}$ with head

Table 5.1 Values of coefficients in cost correlation for spillway

S. No.	Layout	Soil condition	Coefficients in cost correlation		
			a_2	x_2	y_2
1	Power house in diversion channel and spillway in main canal	Ordinary soil	36778	-0.2306	- 0.0644
2		Soft rock	37415	-0.2306	- 0.0624
3		Hard rock	37984	-0.2307	- 0.0607
4	Power house and spillway combined in main canal	Ordinary soil	32982	-0.2319	-0.0652
5		Soft rock	33747	-0.2320	-0.0650
6		Hard rock	34370	-0.2320	-0.0649

5.2.1.3 Power house building

In order to develop correlations for the cost of power house the influencing parameters/alternatives are considered as; (i) location of powerhouse (ii) soil conditions (iii) type of turbines and (iii) number of generating units. Data for costs, determined for these conditions in Chapter-4 have been used for development of correlations by following the method discussed above. The steps involved for a typical case are shown in Figs. 5.5 and 5.6. The developed correlations for cost per kW of powerhouse (C_3) are given in Eq. 5.5 and different values of constants and exponents obtained are given in Tables 5.2-5.25.

$$C_3 = a_3 \, P^{x_3} \, H^{y_3} \qquad (5.5)$$

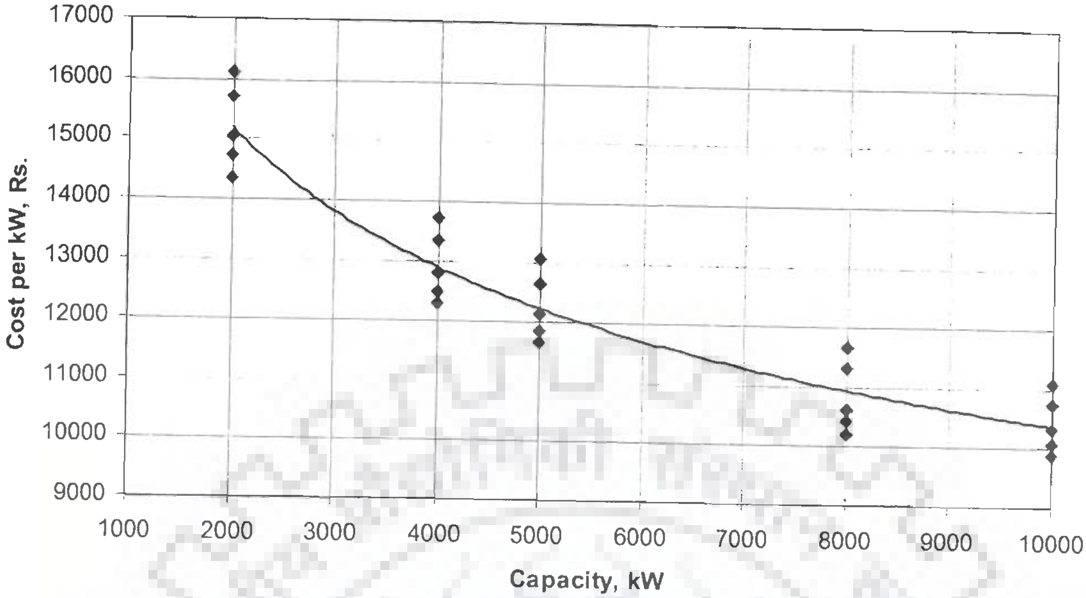


Fig. 5.5 Plot of cost per kW of powerhouse building with capacity

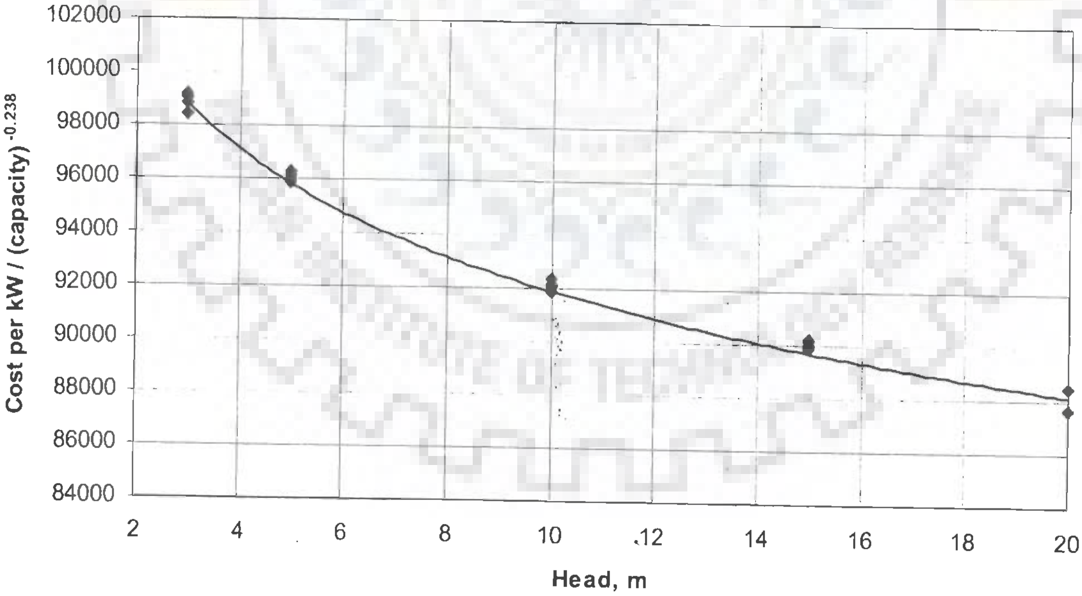


Fig. 5.6 Plot of cost per kW of powerhouse building $(capacity)^{-0.238}$ with head

Table 5.2 Coefficients in cost correlation of power house (Power house in bye pass channel in ordinary soil having 2 generating units)

S. No.	Type of turbine	Coefficient in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	105555	-0.238	-0.0602
2.	Vertical Semi Kaplan	94594	-0.2377	-0.0622
3.	Bulb Semi Kaplan	85805	-0.2371	-0.0599
4.	Tubular Propeller	103890	-0.2386	-0.0604
5.	Vertical Propeller	93133	-0.2382	-0.0624
6.	Bulb Propeller	82122	-0.2384	-0.0604
7.	Tubular Kaplan	111756	-0.2389	-0.0605
8.	Vertical Kaplan	100998	-0.2387	-0.0607
9.	Bulb Kaplan	91039	-0.2383	-0.0603

Table 5.3 Coefficients in cost correlation of power house (Power house in bye pass channel in soft rock having 2 generating units)

S. No.	Type of turbine	Coefficient in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	107182	-0.238	-0.0602
2.	Vertical Semi Kaplan	95969	-0.2376	-0.0621
3.	Bulb Semi Kaplan	87127	-0.2371	-0.0599
4.	Tubular Propeller	105389	-0.2385	-0.0599
5.	Vertical Propeller	94486	-0.2381	-0.0624
6.	Bulb Propeller	82538	-0.2383	-0.0604
7.	Tubular Kaplan	113478	-0.2389	-0.0605
8.	Vertical Kaplan	102464	-0.2386	-0.0607
9.	Bulb Kaplan	92359	-0.2382	-0.0603

Table 5.4 Coefficients in cost correlation of power house (Power house in bye pass channel in hard rock having 2 generating units)

S. No.	Type of turbine	Coefficient in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	108467	-0.2379	-0.0602
2.	Vertical Semi Kaplan	97201	-0.2376	-0.0621
3.	Bulb Semi Kaplan	88171	-0.237	-0.0599
4.	Tubular Propeller	106551	-0.2383	-0.0603
5.	Vertical Propeller	95617	-0.238	-0.0623
6.	Bulb Propeller	84312	-0.2382	-0.0604
7.	Tubular Kaplan	114837	-0.2388	-0.0605
8.	Vertical Kaplan	103688	-0.2385	-0.0607
9.	Bulb Kaplan	93461	-0.2381	-0.0603

Table 5.5 Coefficients in cost correlation of power house (Power house in by pass channel in ordinary soil having 1 generating unit)

S. No.	Type of turbine	Coefficient in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	71010	-0.2384	-0.0605
2.	Vertical Semi Kaplan	63582	-0.238	-0.0624
3.	Bulb Semi Kaplan	57610	-0.2373	-0.0601
4.	Tubular Propeller	69816	-0.2389	-0.0606
5.	Vertical Propeller	62597	-0.2385	-0.0627
6.	Bulb Propeller	55139	-0.2386	-0.0606
7.	Tubular Kaplan	75191	-0.2393	-0.0608
8.	Vertical Kaplan	67884	-0.239	-0.0609
9.	Bulb Kaplan	61064	-0.2384	-0.0604

Table 5.6 Coefficients in cost correlation of power house (Power house in by pass channel in soft rock having 1 generating unit)

S. No.	Type of turbine	Coefficient in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	71820	-0.2380	-0.0603
2.	Vertical Semi Kaplan	64635	-0.2381	-0.0625
3.	Bulb Semi Kaplan	58616	-0.2375	-0.0602
4.	Tubular Propeller	70763	-0.2387	-0.0606
5.	Vertical Propeller	63506	-0.2384	-0.0626
6.	Bulb Propeller	55939	-0.2385	-0.0606
7.	Tubular Kaplan	75518	-0.2395	-0.0610
8.	Vertical Kaplan	68868	-0.2389	-0.0609
9.	Bulb Kaplan	61949	-0.2383	-0.0604

Table 5.7 Coefficients in cost correlation of power house (Power house in by pass channel in hard rock having 1 generating unit)

S. No.	Type of turbine	Coefficient in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	72905	-0.2382	-0.0605
2.	Vertical Semi Kaplan	65333	-0.2379	-0.0623
3.	Bulb Semi Kaplan	59198	-0.2372	-0.0601
4.	Tubular Propeller	71543	-0.2385	-0.0605
5.	Vertical Propeller	64266	-0.2383	-0.0626
6.	Bulb Propeller	56608	-0.2384	-0.0606
7.	Tubular Kaplan	77262	-0.2392	-0.0608
8.	Vertical Kaplan	69750	-0.2389	-0.0609
9.	Bulb Kaplan	62878	-0.2385	-0.0606

Table 5.8 Coefficients in cost correlation of power house (Power house in by pass channel in ordinary soil having 3 generating units)

S. No.	Type of turbine	Coefficient in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	137066	-0.2379	-0.0601
2.	Vertical Semi Kaplan	123229	-0.2379	-0.0623
3.	Bulb Semi Kaplan	111761	-0.2373	-0.0600
4.	Tubular Propeller	135325	-0.2388	-0.0605
5.	Vertical Propeller	121214	-0.2383	-0.0625
6.	Bulb Propeller	106986	-0.2386	-0.0606
7.	Tubular Kaplan	145113	-0.2388	-0.0604
8.	Vertical Kaplan	130893	-0.2384	-0.0605
9.	Bulb Kaplan	118712	-0.2386	-0.0605

Table 5.9 Coefficients in cost correlation of power house (Power house in by pass channel in soft rock having 3 generating units)

S. No.	Type of turbine	Coefficient in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	139061	-0.2378	-0.0601
2.	Vertical Semi Kaplan	124900	-0.2377	-0.0622
3.	Bulb Semi Kaplan	113282	-0.2371	-0.0599
4.	Tubular Propeller	137161	-0.2386	-0.0605
5.	Vertical Propeller	123596	-0.2387	-0.0628
6.	Bulb Propeller	108988	-0.2389	-0.0609
7.	Tubular Kaplan	147224	-0.2387	-0.0604
8.	Vertical Kaplan	132793	-0.2383	-0.0605
9.	Bulb Kaplan	120328	-0.2384	-0.0605

Table 5.10 Coefficients in cost correlation of power house (Power house in by pass channel in hard rock having 3 generating units)

S. No.	Type of turbine	Coefficient in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	140848	-0.2378	-0.0601
2.	Vertical Semi Kaplan	126515	-0.2377	-0.0622
3.	Bulb Semi Kaplan	114744	-0.2371	-0.0600
4.	Tubular Propeller	138673	-0.2384	-0.0604
5.	Vertical Propeller	124552	-0.2382	-0.0624
6.	Bulb Propeller	109932	-0.2385	-0.0606
7.	Tubular Kaplan	149609	-0.2390	-0.0607
8.	Vertical Kaplan	134782	-0.2385	-0.0606
9.	Bulb Kaplan	121764	-0.2383	-0.0605

Table 5.11 Coefficients in cost correlation of power house (Power house in by pass channel in ordinary soil having 4 generating units)

S. No.	Type of turbine	Coefficient in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	165011	-0.2376	-0.0599
2.	Vertical Semi Kaplan	148812	-0.2379	-0.0623
3.	Bulb Semi Kaplan	135127	-0.2374	-0.0601
4.	Tubular Propeller	163763	-0.2390	-0.0607
5.	Vertical Propeller	146543	-0.2384	-0.0626
6.	Bulb Propeller	129206	-0.2389	-0.0608
7.	Tubular Kaplan	175825	-0.2391	-0.0607
8.	Vertical Kaplan	158193	-0.2391	-0.0609
9.	Bulb Kaplan	144279	-0.2386	-0.0605

Table 5.12 Coefficients in cost correlation of power house (Power house in by pass channel in soft rock having 4 generating units)

S. No.	Type of turbine	Coefficient in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	167414	-0.2375	-0.0599
2.	Vertical Semi Kaplan	150975	-0.2378	-0.0622
3.	Bulb Semi Kaplan	137364	-0.2375	-0.0602
4.	Tubular Propeller	165984	-0.2388	-0.0606
5.	Vertical Propeller	149129	-0.2386	-0.0606
6.	Bulb Propeller	131495	-0.2391	-0.0610
7.	Tubular Kaplan	178572	-0.2392	-0.0608
8.	Vertical Kaplan	160349	-0.2389	-0.0609
9.	Bulb Kaplan	146244	-0.2384	-0.0605

Table 5.13 Coefficients in cost correlation of power house (Power house in by pass channel in hard rock having 4 generating units)

S. No.	Type of turbine	Coefficient in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	170998	-0.2383	-0.0605
2.	Vertical Semi Kaplan	153249	-0.2380	-0.0624
3.	Bulb Semi Kaplan	139283	-0.2376	-0.0603
4.	Tubular Propeller	168175	-0.2388	-0.0607
5.	Vertical Propeller	150911	-0.2388	-0.0627
6.	Bulb Propeller	132648	-0.2387	-0.0608
7.	Tubular Kaplan	181249	-0.2393	-0.0609
8.	Vertical Kaplan	162756	-0.2391	-0.0611
9.	Bulb Kaplan	147988	-0.2383	-0.0605

Table 5.14 Coefficients in cost correlation of power house (Layout with spillway and power house combined in main canal in ordinary soil having 1 generating unit)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	69664	-0.2396	-0.0608
2.	Vertical Semi Kaplan	62951	-0.2390	-0.0631
3.	Bulb Semi Kaplan	56830	-0.2377	-0.0604
4.	Tubular Propeller	69144	-0.2399	-0.0614
5.	Vertical Propeller	62255	-0.2392	-0.0632
6.	Bulb Propeller	54705	-0.2403	-0.0617
7.	Tubular Kaplan	74228	-0.2405	-0.0617
8.	Vertical Kaplan	66389	-0.2393	-0.0611
9.	Bulb Kaplan	61497	-0.2396	-0.0613

Table 5.15 Coefficients in cost correlations of power house (Layout with spillway and power house combined in main canal in soft rock having 1 generating unit)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	70457	-0.2392	-0.0606
2.	Vertical Semi Kaplan	63598	-0.2385	-0.0628
3.	Bulb Semi Kaplan	57421	-0.2372	-0.0601
4.	Tubular Propeller	70083	-0.2397	-0.0613
5.	Vertical Propeller	63158	-0.2391	-0.0631
6.	Bulb Propeller	55044	-0.2394	-0.0611
7.	Tubular Kaplan	74914	-0.2399	-0.0613
8.	Vertical Kaplan	67640	-0.2396	-0.0614
9.	Bulb Kaplan	62784	-0.2401	-0.0617

Table 5.16 Coefficients in cost correlations of power house (Layout with spillway and power house combined in main canal in hard rock having 1 generating unit)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	71523	-0.2394	-0.0608
2.	Vertical Semi Kaplan	64629	-0.2388	-0.0630
3.	Bulb Semi Kaplan	58159	-0.2372	-0.0601
4.	Tubular Propeller	70916	-0.2396	-0.0613
5.	Vertical Propeller	63912	-0.2390	-0.0631
6.	Bulb Propeller	55932	-0.2397	-0.0614
7.	Tubular Kaplan	76204	-0.2403	-0.0616
8.	Vertical Kaplan	67867	-0.2387	-0.0608
9.	Bulb Kaplan	63130	-0.2394	-0.0612

Table 5.17 Coefficients in cost correlations of power house (Layout with spillway and power house combined in main canal in ordinary soil having 2 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	103971	-0.2396	-0.0608
2.	Vertical Semi Kaplan	93770	-0.2388	-0.063
3.	Bulb Semi Kaplan	84909	-0.2385	-0.061
4.	Tubular Propeller	103295	-0.24	-0.0614
5.	Vertical Propeller	92807	-0.2398	-0.0636
6.	Bulb Propeller	81489	-0.2401	-0.0616
7.	Tubular Kaplan	110552	-0.2403	-0.0615
8.	Vertical Kaplan	98885	-0.2391	-0.061
9.	Bulb Kaplan	90723	-0.2399	-0.0615

Table 5.18 Coefficients in cost correlations of power house (Layout with spillway and power house combined in main canal in soft rock having 2 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	105482	-0.2395	-0.0608
2.	Vertical Semi Kaplan	95131	-0.2387	-0.0629
3.	Bulb Semi Kaplan	86141	-0.2384	-0.061
4.	Tubular Propeller	104697	-0.2384	-0.0614
5.	Vertical Propeller	94152	-0.2397	-0.0635
6.	Bulb Propeller	82672	-0.24	-0.0616
7.	Tubular Kaplan	112156	-0.2402	-0.0615
8.	Vertical Kaplan	100319	-0.239	-0.061
9.	Bulb Kaplan	92035	-0.2398	-0.0615

Table 5.19 Coefficients in cost correlations of power house (Layout with spillway and power house combined in main canal in hard rock having 2 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	106744	-0.2394	-0.0608
2.	Vertical Semi Kaplan	96269	-0.2386	-0.0629
3.	Bulb Semi Kaplan	87244	-0.2384	-0.061
4.	Tubular Propeller	105851	-0.2396	-0.0613
5.	Vertical Propeller	95275	-0.2396	-0.0635
6.	Bulb Propeller	83731	-0.24	-0.0616
7.	Tubular Kaplan	113496	-0.2401	-0.0615
8.	Vertical Kaplan	100828	-0.2389	-0.0609
9.	Bulb Kaplan	93131	-0.2397	-0.0615

Table 5.20 Coefficients in cost correlations of power house (Layout with spillway and power house combined in main canal in ordinary soil having 3 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	135037	-0.2395	-0.0608
2.	Vertical Semi Kaplan	121510	-0.2385	-0.0628
3.	Bulb Semi Kaplan	109311	-0.2383	-0.0609
4.	Tubular Propeller	133497	-0.2398	-0.0613
5.	Vertical Propeller	119765	-0.2391	-0.0631
6.	Bulb Propeller	106033	-0.2402	-0.0616
7.	Tubular Kaplan	143315	-0.2404	-0.0616
8.	Vertical Kaplan	128419	-0.2390	-0.0609
9.	Bulb Kaplan	116419	-0.2394	-0.0611

Table 5.21 Coefficients in cost correlations of power house (Layout with spillway and power house combined in main canal in soft rock having 3 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	137561	-0.2398	-0.0610
2.	Vertical Semi Kaplan	123276	-0.2384	-0.0627
3.	Bulb Semi Kaplan	110084	-0.2375	-0.0604
4.	Tubular Propeller	135309	-0.2396	-0.0612
5.	Vertical Propeller	121503	-0.2390	-0.0630
6.	Bulb Propeller	107350	-0.2399	-0.0615
7.	Tubular Kaplan	145108	-0.2401	-0.0615
8.	Vertical Kaplan	129877	-0.2386	-0.0607
9.	Bulb Kaplan	118605	-0.2397	-0.0614

Table 5.22 Coefficients in cost correlations of power house (Layout with spillway and power house combined in main canal in hard rock having 3 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	138473	-0.2392	-0.0606
2.	Vertical Semi Kaplan	124751	-0.2383	-0.0627
3.	Bulb Semi Kaplan	111725	-0.2377	-0.0605
4.	Tubular Propeller	136801	-0.2394	-0.0612
5.	Vertical Propeller	122954	-0.2389	-0.0630
6.	Bulb Propeller	108409	-0.2396	-0.0613
7.	Tubular Kaplan	147296	-0.2403	-0.0617
8.	Vertical Kaplan	132384	-0.2392	-0.0612
9.	Bulb Kaplan	119900	-0.2395	-0.0614

Table 5.23 Coefficients in cost correlations of power house (Layout with spillway and power house combined in main canal in ordinary soil having 4 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	163423	-0.2397	-0.0609
2.	Vertical Semi Kaplan	147365	-0.2389	-0.0631
3.	Bulb Semi Kaplan	132047	-0.2382	-0.0608
4.	Tubular Propeller	162368	-0.2401	-0.0615
5.	Vertical Propeller	143990	-0.2396	-0.0635
6.	Bulb Propeller	127119	-0.2398	-0.0613
7.	Tubular Kaplan	172111	-0.2401	-0.0614
8.	Vertical Kaplan	155560	-0.2393	-0.0611
9.	Bulb Kaplan	141389	-0.2395	-0.0612

Table 5.24 Coefficients in cost correlations of power house (Layout with spillway and power house combined in main canal in soft rock having 4 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	166490	-0.2400	-0.0612
2.	Vertical Semi Kaplan	149504	-0.2388	-0.0630
3.	Bulb Semi Kaplan	133529	-0.2378	-0.06066
4.	Tubular Propeller	164890	-0.2401	-0.0616
5.	Vertical Propeller	146576	-0.2395	-0.0634
6.	Bulb Propeller	128553	-0.2394	-0.0611
7.	Tubular Kaplan	174806	-0.2401	-0.0615
8.	Vertical Kaplan	157508	-0.2390	-0.0610
9.	Bulb Kaplan	143881	-0.2397	-0.0614

Table 5.25 Coefficients in cost correlations of power house (Layout with spillway and power house combined in main canal in hard rock having 4 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_3	x_3	y_3
1.	Tubular Semi Kaplan	168297	-0.2398	-0.0611
2.	Vertical Semi Kaplan	151292	-0.2387	-0.0611
3.	Bulb Semi Kaplan	135126	-0.2377	-0.0605
4.	Tubular Propeller	166526	-0.2398	-0.0614
5.	Vertical Propeller	148325	-0.2394	-0.0633
6.	Bulb Propeller	130777	-0.2398	-0.0615
7.	Tubular Kaplan	176886	0.2400	-0.0615
8.	Vertical Kaplan	160050	-0.2393	-0.0612
9.	Bulb Kaplan	145920	-0.2398	-0.0616

5.2.2 Run of River Schemes

As discussed earlier, the main components of civil works in run-of-river schemes are diversion weir and intake, power channel, desilting tank, forebay & spillway, power house building and tail race channel. Various alternatives such as type of soil, type of turbines and number of generating units have been considered for cost estimation of the components under the scheme.

5.2.2.1 Diversion weir and intake

In order to develop correlations for the cost of diversion weir & intake, data for costs, determined in Chapter-4 have been used. The methodology discussed above for canal based scheme has been used for development of correlations. For a typical case the regression analysis used for correlation development are shown in Figs. 5.7-5.8. The developed correlations for cost per kW of diversion weir & intake (C_4) are expressed by Eq. 5.6 and different values of constants and exponents obtained are given in Table 5.26.

$$C_4 = a_4 \; P^{x_4} \;\; H^{y_4} \qquad (5.6)$$

Table 5.26 Values of coefficients in cost correlation for diversion weir and intake

S. No.	Type of soil	Coefficients in cost correlation		
		a_4	x_4	y_4
1.	Ordinary soil	12415	-0.2368	-0.0597
2.	Soft rock	13331	-0.2365	-0.0596
3.	Hard rock	14110	-0.2363	-0.0594

5.2.2.2 Power channel

On the similar lines the regression analysis steps for development of correlation for a typical case are shown in Fig. 5.9 and Fig. 5.10. The developed correlation for cost per kW of power channel (C_5), is expressed by Eq. 5.7 and different values of constants and exponents obtained are given in Table 5.27.

$$C_5 = a_5 \; P^{x_5} \;\; H^{y_5} \qquad (5.7)$$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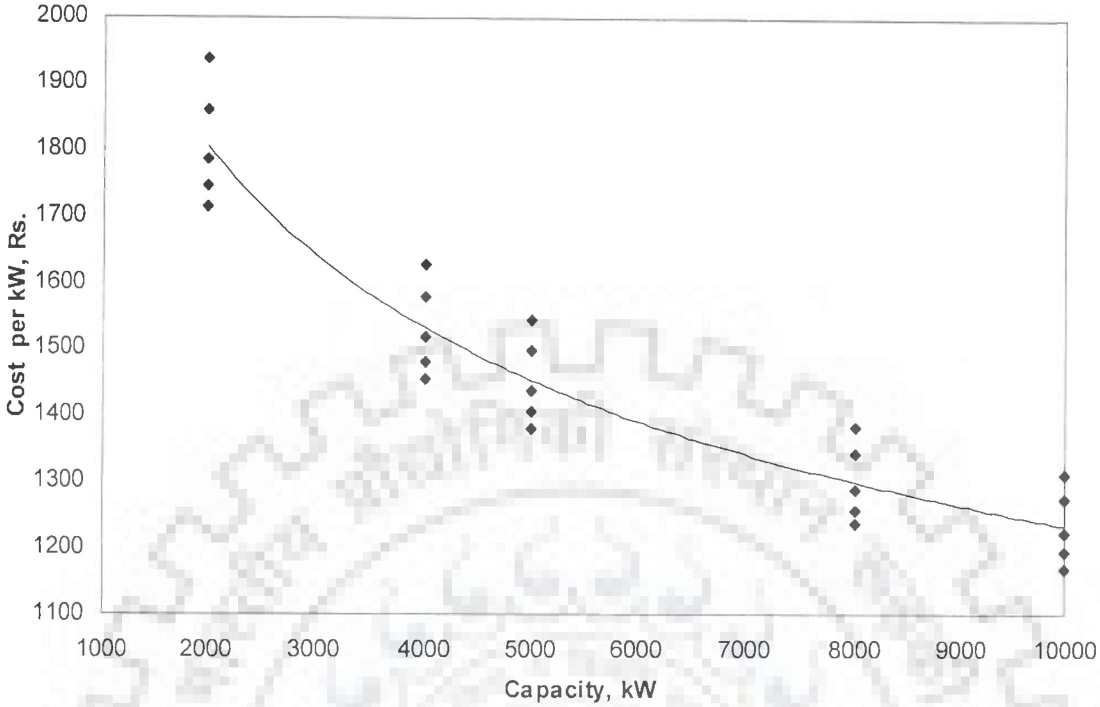


Fig. 5.7 Plot of cost per kW of diversion weir intake with capacity

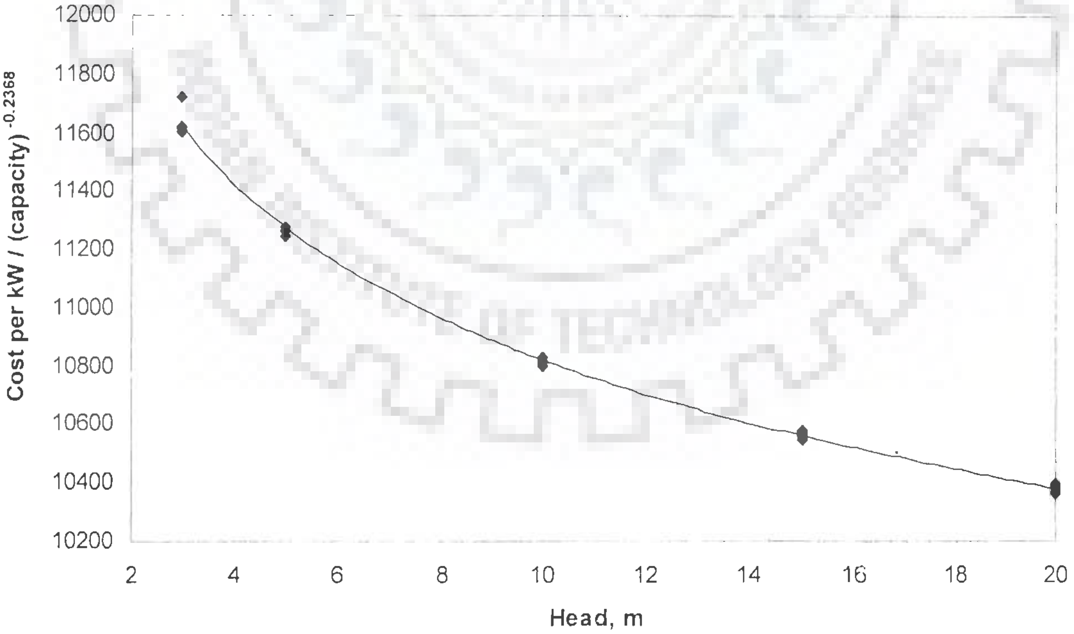


Fig. 5.8 Plot of cost per kW of intake $(\text{capacity})^{-0.2368}$ with head

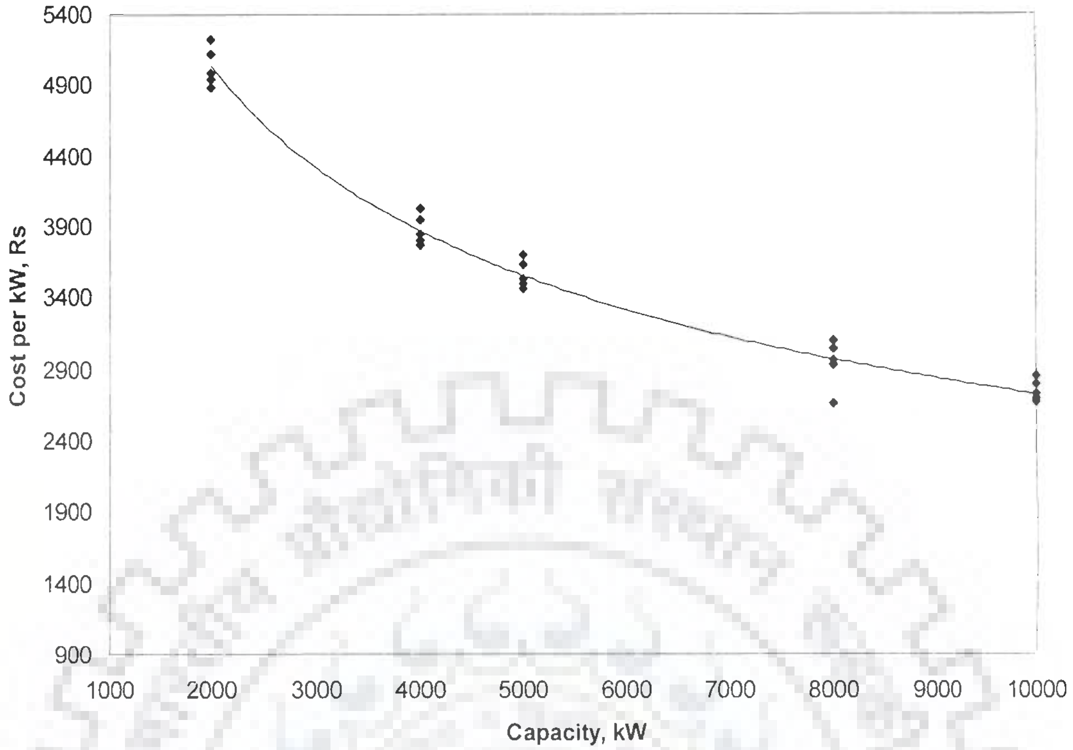


Fig. 5.9 Plot of cost per kW of power channel with capacity

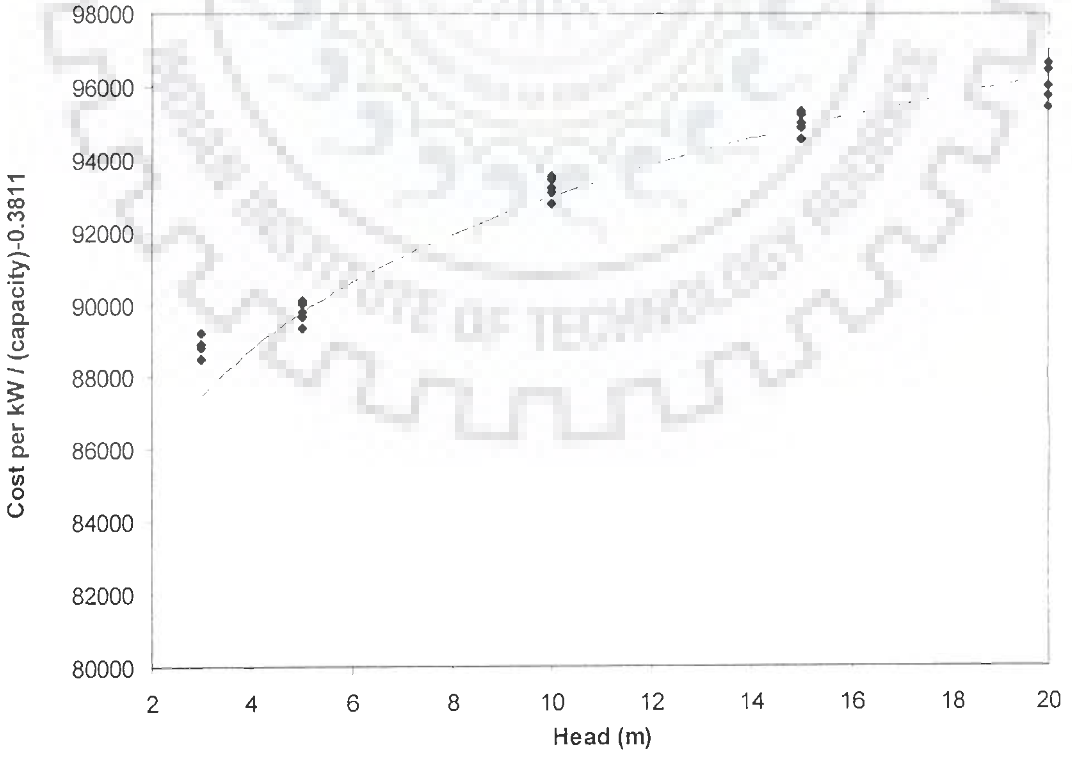


Fig. 5.10 Plot of cost per kW of power channel $(\text{capacity})^{-0.3811}$ with head

Table 5.27 Values of coefficients in cost correlation for power channel

S. No.	Type of soil	Coefficients in cost correlation		
		a_5	x_5	y_5
1.	Ordinary soil	85383	-0.3811	0.0307
2.	Soft rock	107056	-0.3821	0.0299
3.	Hard rock	123589	-0.3813	0.0305

5.2.2.3 Desilting tank

Considering the same alternatives for disilting tank and using the cost data for these alternatives determined in Chapter-4, correlations for the cost of desilting tank has been developed. Figs 5.11-5.12 show the steps involved in regression analysis for a typical case. Correlation for cost per kW of desilting tank (C_6) is expressed by Eq. 5.8 and different values of constants and exponents obtained are given in Table 5.28.

$$C_6 = a_6 \; P^{x_6} \;\; H^{y_6} \tag{5.8}$$

Table 5.28 Values of coefficients in cost correlation for desilting tank

S. No.	Type of soil	Coefficients in cost correlation		
		a_6	x_6	y_6
1.	Ordinary soil	20700	-0.2385	-0.0611
2.	Soft rock	22883	-0.2388	-0.0613
3.	Hard rock	24726	-0.2390	-0.0614

5.2.2.4 Forebay

In case of forebay, in addition of other alternatives considered above, number of generating units has also been considered. Cost for theses alternatives has also been determined in Chapter-4. In order to develop correlations for the cost of forebay, data for costs, determined in Chapter-4. Figs. 5.13-5.14 show the regression analysis steps for development of correlations for a typical case. Table 5.29 gives the values of constants and exponents obtained for different alternatives.

$$C_7 = a_7 \; P^{x_7} \;\; H^{y_7} \tag{5.9}$$

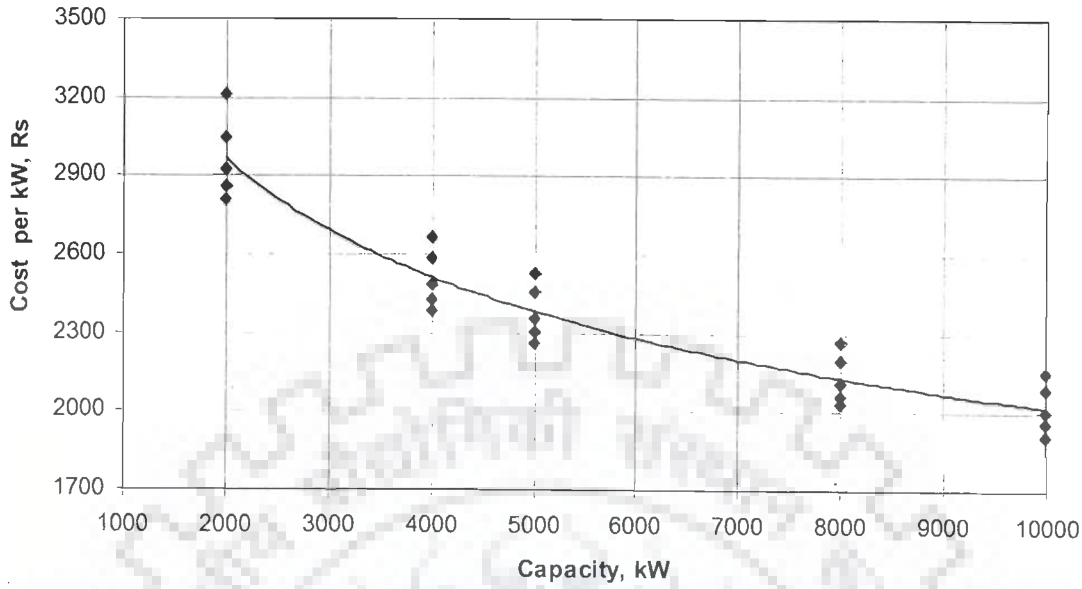


Fig. 5.11 Plot of cost per kW of desilting tank with capacity

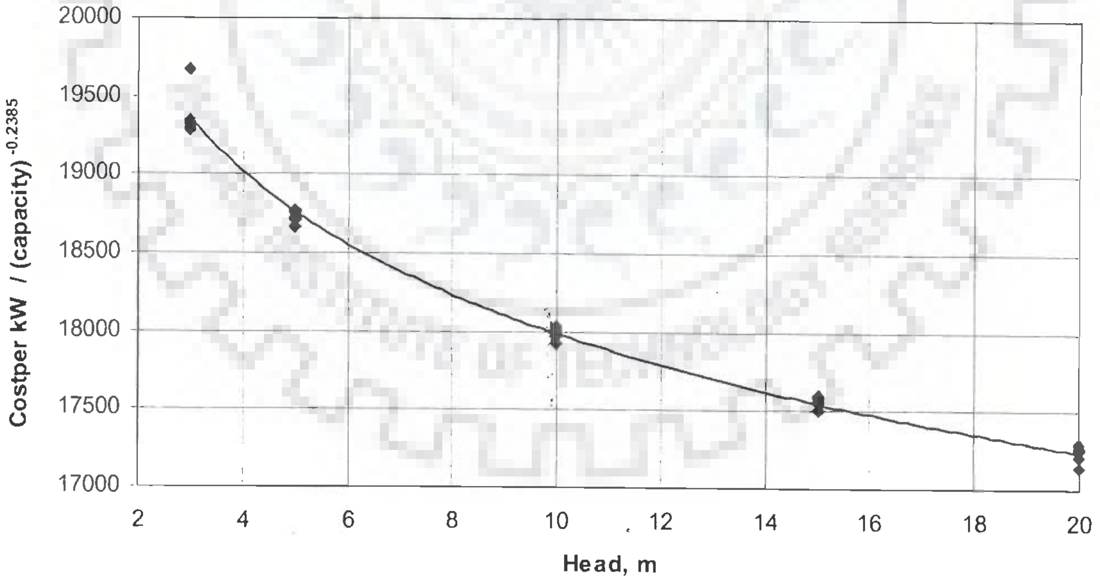


Fig. 5.12 Plot of cost per kW of desilting tank (capacity)$^{-0.2385}$ with head

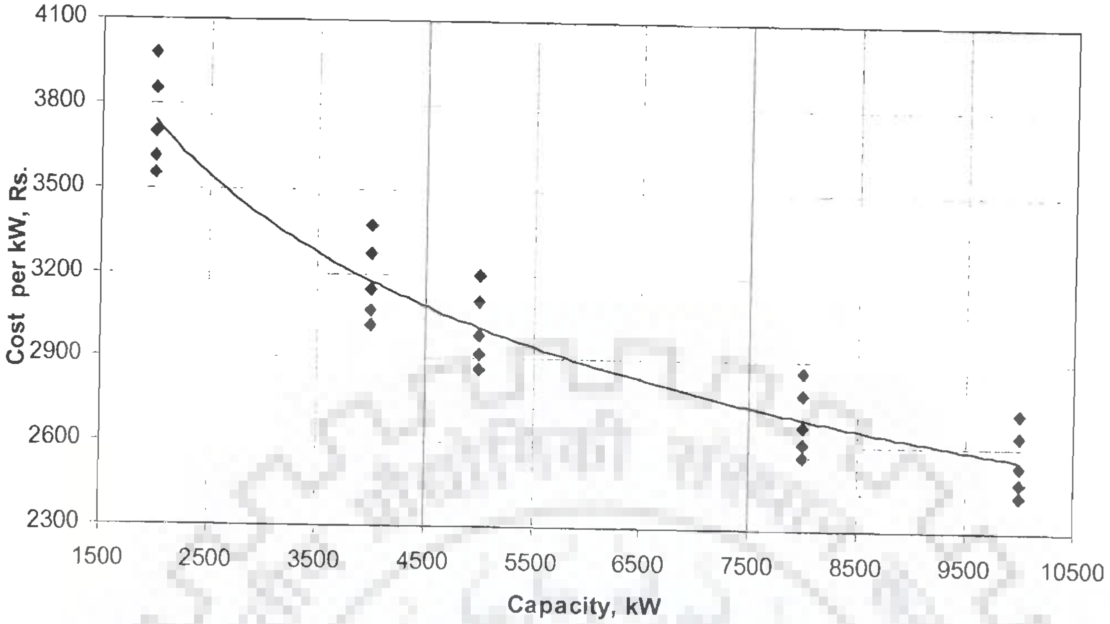


Fig. 5.13 Plot of cost per kW of forebay with capacity

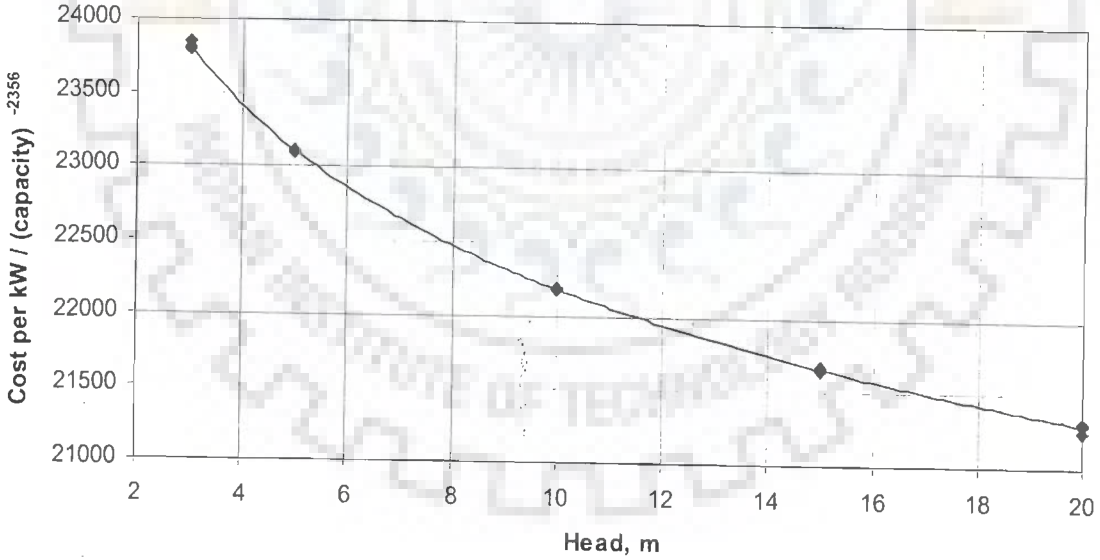


Fig. 5.14 Plot of cost per kW of forebay $(\text{capacity})^{-0.2356}$ with head

Table 5.29 Values of Coefficients in cost correlation for forebay & spillway

S. No.	Alternatives	Coefficients in cost correlation		
		a_7	x_7	y_7
1.	Ordinary soil having one generating unit	23830	-0.2354	-0.0588
2.	Soft rock having one generating unit	25081	-0.3725	0.3864
3.	Hard rock having one generating unit	26891	-0.2354	-0.0587
4.	Ordinary soil having two generating unit	25402	-0.2356	-0.0589
5.	Soft rock having two generating unit	27198	-0.2357	-0.0590
6.	Hard rock having two generating unit	28721	-0.2358	-0.0590
7.	Ordinary soil rock having three generating units	26726	-0.2358	-0.059
8.	Soft rock having three generating units	28707	-0.2362	-0.0593
9.	Hard rock having three generating units	30259	-0.2361	-0.0593
10.	Ordinary soil having four generating units	27753	-0.2359	-0.0592
11.	Soft rock having four generating units	29677	-0.2358	-0.0591
12.	Hard rock having four generating units	31244	-0.2356	-0.0589

5.2.2.5 Penstock

Similarly, regression analysis steps for development of correlations for a typical case are shown in Figs. 5.15-5.16 and the developed correlations for cost per kW of penstock (C_8) is given in Eq. 5.10. Different values of constants and exponents obtained are given in Table 5.30.

$$C_8 = a_8 \, P^{x_8} \, H^{y_8} \qquad (5.10)$$

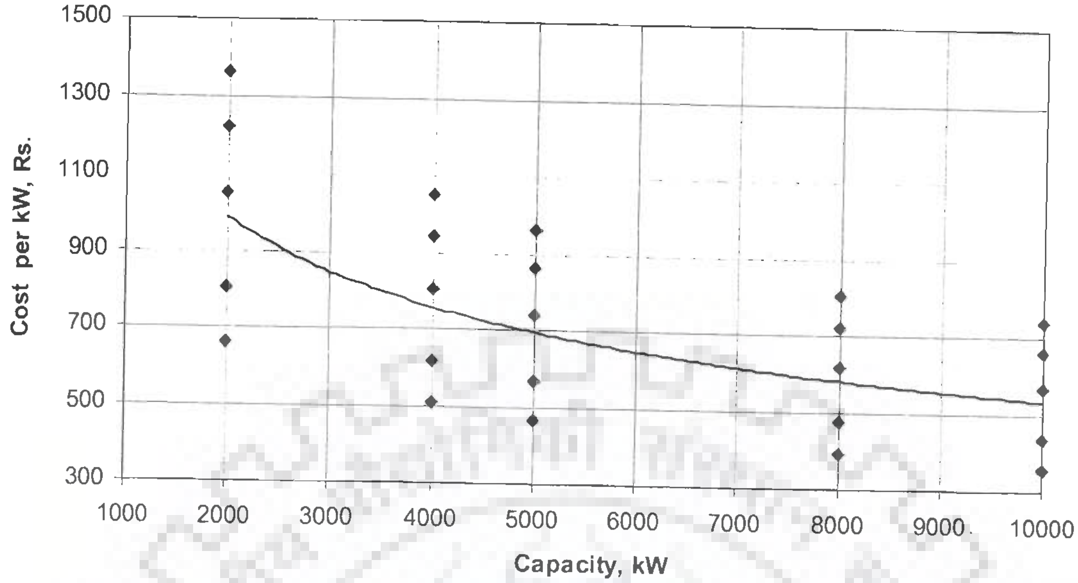


Fig. 5.15 Plot of cost per kW of Penstock with capacity

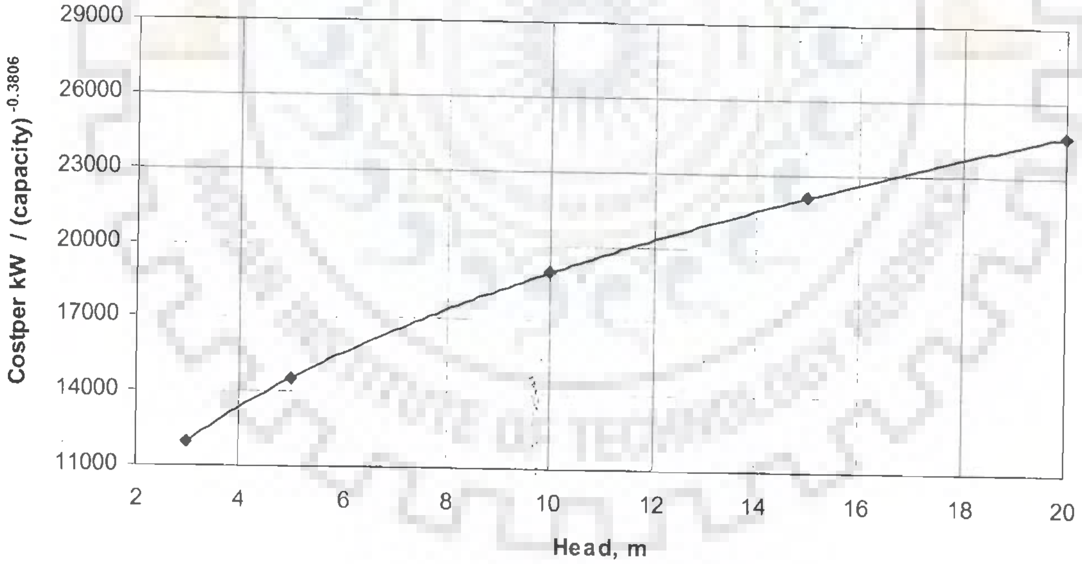


Fig. 5.16 Plot of cost per kW of Penstock $(\text{capacity})^{-0.3806}$ with head

Table 5.30 Values of coefficients in cost correlation for penstock

S. No.	Alternatives	Coefficients in cost correlation for penstock		
		a_8	x_8	y_8
1.	Ordinary soil having one generating unit	4906	-0.3722	0.3866
2.	Soft rock having one generating unit	5081	-0.3725	0.3864
3.	Hard rock having one generating unit	5232	-0.3728	0.3862
4.	Ordinary soil having two generating unit	7875	-0.3806	0.3804
5.	Soft rock having two generating unit	8140	-0.3807	0.3804
6.	Hard rock having two generating unit	8381	-0.3810	0.3801
7.	Ordinary soil rock having three generating units	9001	-0.369	0.389
8.	Soft rock having three generating units	9341	-0.3695	0.3886
9.	Hard rock having three generating units	9620	-0.3698	0.3884
10.	Ordinary soil having four generating units	10649	-0.3669	0.3905
11.	Soft rock having four generating units	11053	-0.3674	0.3901
12.	Hard rock having four generating units	11404	-0.3679	0.3898

5.2.2.6 Power house building

In order to develop correlations for the cost of powerhouse building, data for costs, determined in Chapter-4. Soil conditions, types of turbines and number of generating units have been used. Considering a typical case under these conditions the regression analysis is shown in Figs. 5.17-5.18. The developed correlations for cost per kW of powerhouse building (C_9) are given in Eq. 5.11 and different values of constants and exponents obtained are given in Table 5.31 to Table 5.42.

$$C_9 = a_9 \, P^{x_9} \, H^{y_9} \tag{5.11}$$

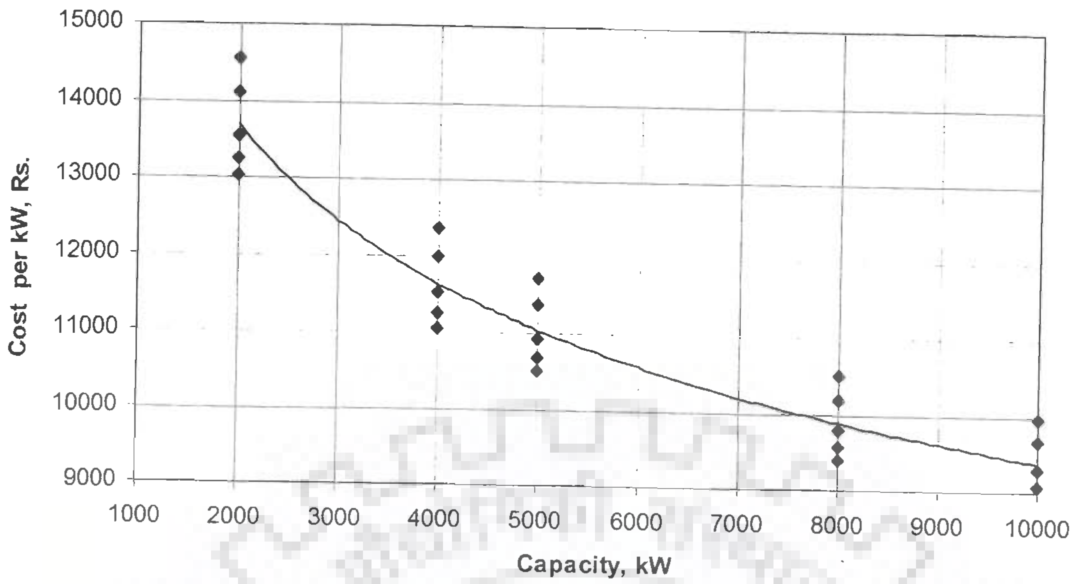


Fig. 5.17 Plot of cost per kW of power house building with capacity

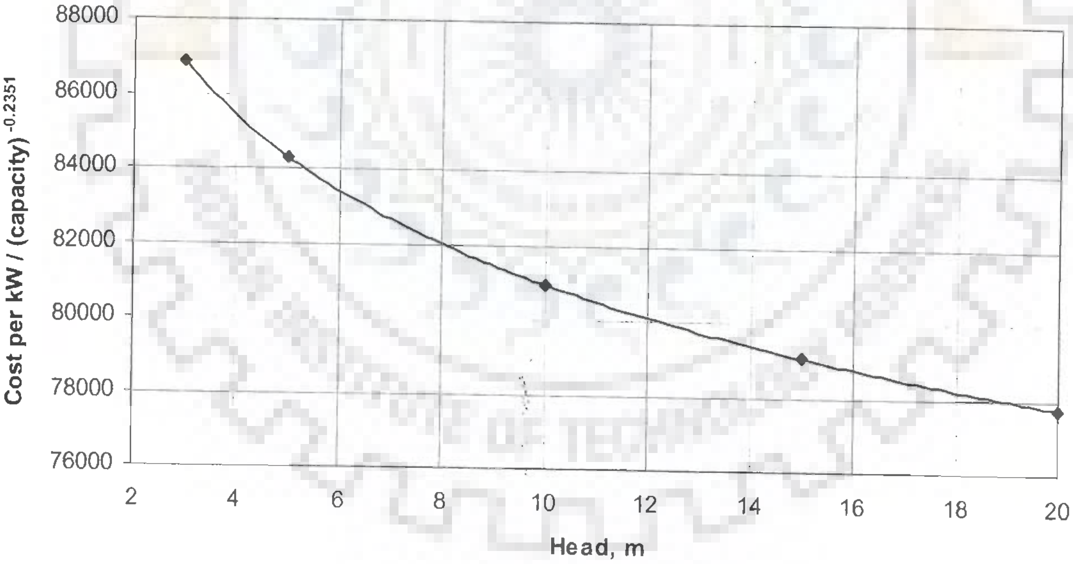


Fig. 5.18 Plot of cost per kW of power house building (capacity)$^{-0.2351}$ with head

Table 5.31 Coefficients in cost correlation of power house for run of river scheme in ordinary soil having 2 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_9	x_9	y_9
1.	Tubular Semi Kaplan	92615	-0.2351	-0.0585
2.	Vertical Semi Kaplan	83406	-0.2353	-0.0588
3.	Bulb Semi Kaplan	76103	-0.2353	-0.0586
4.	Tubular Propeller	91231	-0.2356	-0.0588
5.	Vertical Propeller	89664	-0.2359	-0.0591
6.	Bulb Propeller	72076	-0.2355	-0.0588
7.	Tubular Kaplan	97764	-0.2356	-0.0589
8.	Vertical Kaplan	88631	-0.2357	-0.059
9.	Bulb Kaplan	79962	-0.2355	-0.0588

Table 5.32 Coefficients in cost correlation of power house for run of river scheme in soft rock having 2 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_9	x_9	y_9
1.	Tubular Semi Kaplan	94127	-0.2352	-0.0586
2.	Vertical Semi Kaplan	84894	-0.2354	-0.0587
3.	Bulb Semi Kaplan	77187	-0.2352	-0.0586
4.	Tubular Propeller	92350	-0.2352	-0.0586
5.	Vertical Propeller	91040	-0.2359	-0.0591
6.	Bulb Propeller	73101	-0.2354	-0.0587
7.	Tubular Kaplan	98268	-0.2346	-0.0583
8.	Vertical Kaplan	89436	-0.2352	-0.056
9.	Bulb Kaplan	81088	-0.2353	-0.0589

Table 5.33 Coefficients in cost correlation of power house for run of river scheme in hard rock having 2 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_9	x_9	y_9
1.	Tubular Semi Kaplan	95430	-0.2353	-0.0586
2.	Vertical Semi Kaplan	85890	-0.2353	-0.0586
3.	Bulb Semi Kaplan	77533	-0.2344	-0.0588
4.	Tubular Propeller	93436	-0.2352	-0.0586
5.	Vertical Propeller	91626	-0.2353	-0.0587
6.	Bulb Propeller	73890	-0.2352	-0.0587
7.	Tubular Kaplan	100308	-0.2354	-0.0587
8.	Vertical Kaplan	90194	-0.2348	-0.0583
9.	Bulb Kaplan	81998	-0.2352	-0.0586

Table 5.34 Coefficients in cost correlation of power house for run of river scheme in ordinary soil having 1 generating unit)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_9	x_9	y_9
1.	Tubular Semi Kaplan	62246	-0.2354	-0.0587
2.	Vertical Semi Kaplan	56013	-0.2356	-0.0589
3.	Bulb Semi Kaplan	51092	-0.2355	-0.0588
4.	Tubular Propeller	60862	-0.2359	-0.0591
5.	Vertical Propeller	60192	-0.2361	-0.0592
6.	Bulb Propeller	48142	-0.2352	-0.0586
7.	Tubular Kaplan	65637	-0.2358	-0.0590
8.	Vertical Kaplan	59503	-0.2360	-0.0592
9.	Bulb Kaplan	54196	-0.2359	-0.0591

Table 5.35 Coefficients in cost correlations of power house for run of river scheme in soft rock having 1 generating unit)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_9	x_9	y_9
1.	Tubular Semi Kaplan	63267	-0.2355	-0.0588
2.	Vertical Semi Kaplan	57050	-0.2357	-0.0590
3.	Bulb Semi Kaplan	52047	-0.2358	-0.0590
4.	Tubular Propeller	61991	-0.2362	-0.0593
5.	Vertical Propeller	61120	-0.2361	-0.0592
6.	Bulb Propeller	48930	-0.2353	-0.0587
7.	Tubular Kaplan	66707	-0.2359	-0.0591
8.	Vertical Kaplan	60475	-0.2361	-0.0593
9.	Bulb Kaplan	55261	-0.2363	-0.0594

Table 5.36 Coefficients in cost correlation of power house for run of river scheme in ordinary soil having 1 generating unit)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_9	x_9	y_9
1.	Tubular Semi Kaplan	64212	-0.2357	-0.0589
2.	Vertical Semi Kaplan	57843	-0.2358	-0.0590
3.	Bulb Semi Kaplan	52983	-0.2363	-0.0594
4.	Tubular Propeller	62662	-0.2360	-0.0592
5.	Vertical Propeller	62289	-0.2367	-0.0597
6.	Bulb Propeller	49302	-0.2348	-0.0583
7.	Tubular Kaplan	67707	-0.2361	-0.0592
8.	Vertical Kaplan	61442	-0.2364	-0.0595
9.	Bulb Kaplan	55505	-0.2355	-0.0588

Table 5.37 Coefficients in cost correlation of power house for run of river scheme in ordinary soil having 3 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_9	x_9	y_9
1.	Tubular Semi Kaplan	121027	-0.2356	-0.0589
2.	Vertical Semi Kaplan	109020	-0.2357	-0.0590
3.	Bulb Semi Kaplan	98550	-0.2353	-0.0587
4.	Tubular Propeller	119185	-0.2357	-0.0589
5.	Vertical Propeller	116926	-0.2362	-0.0593
6.	Bulb Propeller	92758	-0.2349	-0.0584
7.	Tubular Kaplan	126622	-0.2360	-0.0591
8.	Vertical Kaplan	114686	-0.2361	-0.0593
9.	Bulb Kaplan	103690	-0.2360	-0.0592

Tabled 5.38 Coefficients in cost correlation of power house for run of river scheme in soft rock having 3 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_9	x_9	y_9
1.	Tubular Semi Kaplan	123140	-0.2358	-0.059
2.	Vertical Semi Kaplan	110477	-0.2355	-0.0589
3.	Bulb Semi Kaplan	100280	-0.2355	-0.0588
4.	Tubular Propeller	121155	-0.2358	-0.0590
5.	Vertical Propeller	118959	-0.2364	-0.0590
6.	Bulb Propeller	93978	-0.2347	-0.0582
7.	Tubular Kaplan	128711	-0.2361	-0.0592
8.	Vertical Kaplan	116567	-0.2362	-0.0593
9.	Bulb Kaplan	105281	-0.2360	-0.0592

Table 5.39 Coefficients in cost correlation of power house for run of river scheme in hard rock having 3 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_9	x_9	y_9
1.	Tubular Semi Kaplan	124457	-0.2356	-0.0588
2.	Vertical Semi Kaplan	112338	-0.2359	-0.0591
3.	Bulb Semi Kaplan	101345	-0.2353	-0.0586
4.	Tubular Propeller	122705	-0.2358	-0.0590
5.	Vertical Propeller	120619	-0.2365	-0.0595
6.	Bulb Propeller	95183	-0.2347	-0.0582
7.	Tubular Kaplan	130357	-0.2361	-0.0592
8.	Vertical Kaplan	118292	-0.2364	-0.0594
9.	Bulb Kaplan	106847	-0.2362	-0.0593

Table 5.40 Coefficients in cost correlation of power house for run of river scheme in ordinary soil having 4 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_9	x_9	y_9
1.	Tubular semi Kaplan	146311	-0.2357	-0.0589
2.	Vertical Semi Kaplan	131381	-0.2355	-0.0588
3.	Bulb Semi Kaplan	119845	-0.2356	-0.0588
4.	Tubular Propeller	143688	-0.2359	-0.0591
5.	Vertical Propeller	141492	-0.2361	-0.0592
6.	Bulb Propeller	112812	-0.2352	-0.0586
7.	Tubular Kaplan	153461	-0.2362	-0.0593
8.	Vertical Kaplan	138977	-0.2363	-0.0594
9.	Bulb Kaplan	125536	-0.2358	-0.0591

Table 5.41 Coefficients in cost correlation of power house for run of river scheme in soft rock having 4 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_9	x_9	y_9
1.	Tubular Semi Kaplan	148103	-0.2354	-0.0587
2.	Vertical Semi Kaplan	133525	-0.2356	-0.0589
3.	Bulb Semi Kaplan	121937	-0.2356	-0.0589
4.	Tubular Propeller	146055	-0.2360	-0.0592
5.	Vertical Propeller	143983	-0.2363	-0.0594
6.	Bulb Propeller	114778	-0.2354	-0.0587
7.	Tubular Kaplan	155481	-0.2360	-0.0591
8.	Vertical Kaplan	141266	-0.2364	-0.0595
9.	Bulb Kaplan	127062	-0.2355	-0.0588

Table 5.42 Coefficients in cost correlations of power house for run of river scheme in hard rock having 4 generating units)

S. No.	Type of turbine	Coefficients in cost correlation		
		a_9	x_9	y_9
1.	Tubular Semi Kaplan	150790	-0.2359	-0.0591
2.	Vertical Semi Kaplan	134839	-0.2353	-0.0587
3.	Bulb Semi Kaplan	122747	-0.2352	-0.0586
4.	Tubular Propeller	147992	-0.2360	-0.0592
5.	Vertical Propeller	145822	-0.2363	-0.0594
6.	Bulb Propeller	116483	-0.2356	-0.0588
7.	Tubular Kaplan	158149	-0.2364	-0.0595
8.	Vertical Kaplan	143352	-0.2366	-0.0596
9.	Bulb Kaplan	129500	-0.2361	-0.0593

5.2.2.7 Tail race channel

In case of tail race channel only soil condition is considered as different alternative. Using the cost data generated in Chapter-4, the regression analysis steps for development of correlations for a typical case are shown in Figs. 5.19-5.20. The developed correlations for cost per kW of tail race channel (C_{10}) are given in Eq. 5.12 and different values of constants and exponents obtained are given in Table 5.43.

$$C_{10} = a_{10}\, P^{x_{10}}\, H^{y_{10}} \tag{5.12}$$

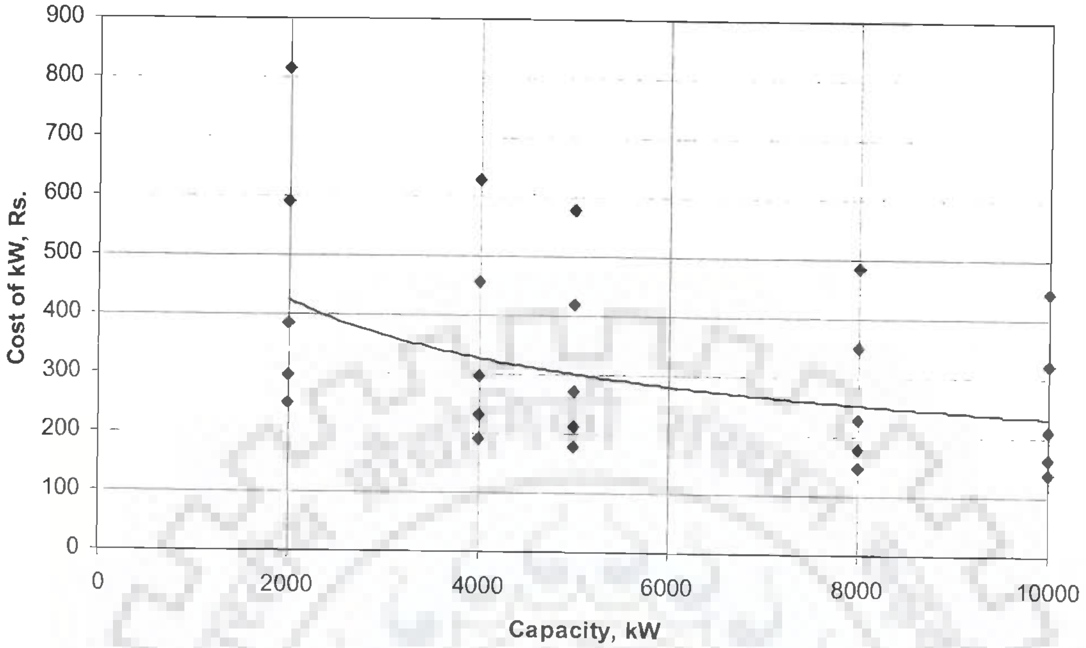


Fig. 5.19 Plot of cost per kW of tail race channel with capacity

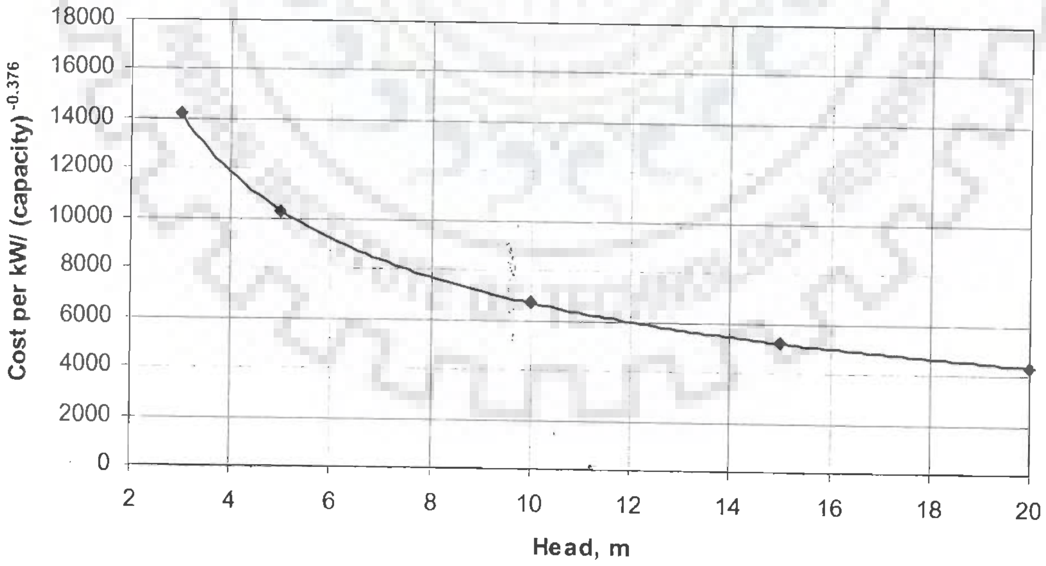


Fig. 5.20 Plot of cost per kW of tail race channel $(\text{capacity})^{-0.376}$ with head

Table 5.43 Values of coefficients in cost correlation for tail race channel

S. No.	Type of Soil	Coefficients in cost correlation		
		a_{10}	x_{10}	y_{10}
1.	Ordinary soil	28164	-0.376	-0.6240
2.	Soft rock	34773	-0.3755	-0.6236
3.	Hard rock	40880	-0.3765	-0.6244

5.2.3 Dam Toe Scheme

As discussed earlier, the main components under civil works are intake, penstock, power house building and tail race channel under dam toe scheme. Various alternatives such as type of soil, type of turbines and number of generating units have been considered for cost estimation of the components of the scheme. as discussed below.

Based on the methodology as discussed above, correlations for cost of components of civil works has been developed. It has been found that the values of coefficients in the correlation of cost for penstock, power house building and tail race channel are same as in case of run of river schemes under different conditions. The steps involved for development of correlation for cost per kW of intake (C_{11}) are shown in Figs. 5.21-5.22. The developed correlation is represented by Eq. 5.13 and different values of constants and exponents obtained are given in Table 5.44.

$$C_{11} = a_{11}\ P^{x_{11}}\ H^{y_{11}} \qquad (5.13)$$

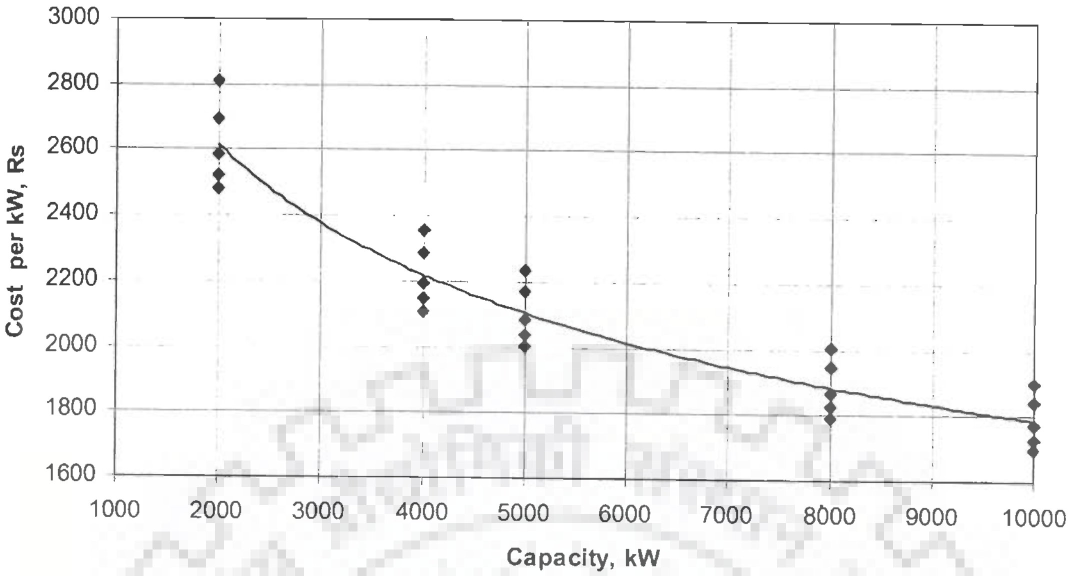


Fig. 5.21 Plot of cost per kW of intake with capacity

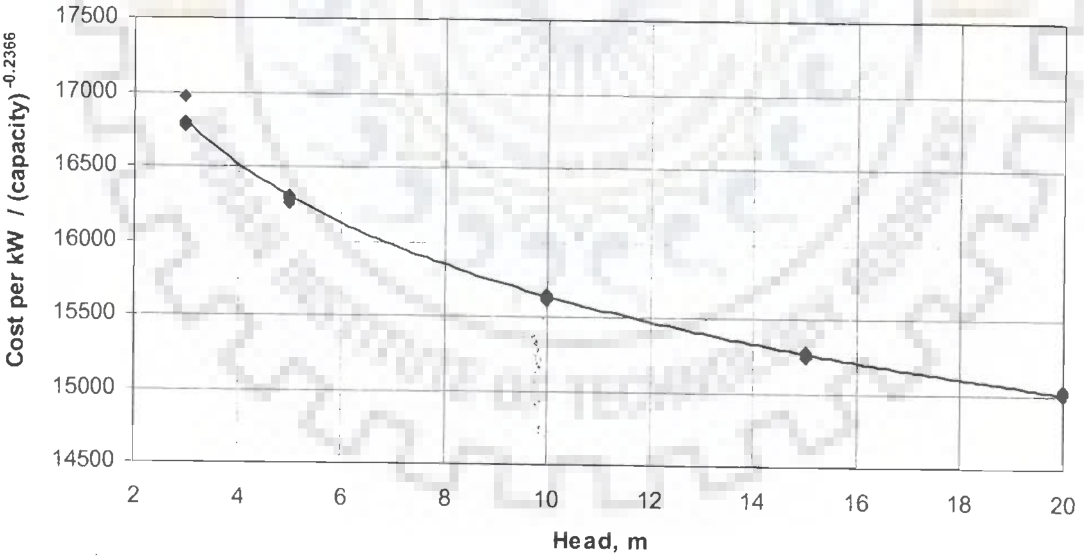


Fig. 5.22 Plot of cost per kW of intake $(capacity)^{-0.2366}$ with head

Table 5.44 Values of coefficients in cost correlation for intake

S. No.	Alternatives	Coefficients in cost correlation for intake		
		a_{11}	x_{11}	y_{11}
1.	Ordinary soil having one generating unit	14382	-0.2368	-0.0598
2.	Soft rock having one generating unit	14724	-0.2369	-0.0598
3.	Hard rock having one generating unit	15003	-0.2369	-0.0598
4.	Ordinary soil rock having two generating units	17940	-0.2366	-0.0596
5.	Soft rock having two generating units	18351	-0.2367	-0.0597
6.	Hard rock having two generating units	18698	-0.2367	-0.0597
7.	Ordinary soil rock having three generating units	21191	-0.2367	-0.0597
8.	Soft rock having three generating units	21740	-0.237	-0.0599
9.	Hard rock having three generating units	22128	-0.237	-0.0599
10.	Ordinary soil having four generating units	24164	-0.2371	-0.0600
11.	Soft rock having four generating units	24742	-0.2372	-0.0601
12.	Hard rock having four generating units	25235	-0.2373	-0.0601

5.2.4 Electro-Mechanical Equipment

As discussed earlier, the electro-mechanical equipments depend on the head and unit capacity. Therefore, components under equipment are similar for all three types of SHP schemes. Various alternatives such as type of turbines, type of generator and numbers of generating units have been considered for cost estimates of the components.

Correlations have been developed by regression analysis considering head and capacity as cost sensitive parameters. A similar methodology as used for development of the correlations for cost of civil works has been used to develop the correlations for cost of different components of electro-mechanical equipment and shown in Fig. 5.23 and Fig 5.30. The developed correlations for the cost per kW of turbines with governing system (C_{12}), generator with excitation system (C_{13}), electrical and mechanical auxiliary (C_{14}) and transformer & switchyard equipment (C_{15}) as a function of head and capacity are represented as follows;

$$C_{12} = a_{12}\, P^{x_{12}}\, H^{y_{12}} \tag{5.14}$$

$$C_{13} = a_{13}\, P^{x_{13}}\, H^{y_{13}} \tag{5.15}$$

$$C_{14} = a_{14}\, P^{x_{14}}\, H^{y_{14}} \tag{5.16}$$

$$C_{15} = a_{15}\, P^{x_{15}}\, H^{y_{15}} \tag{5.17}$$

Values of constants and exponents for different alternatives obtained are given in Tables 5.45-5.49.

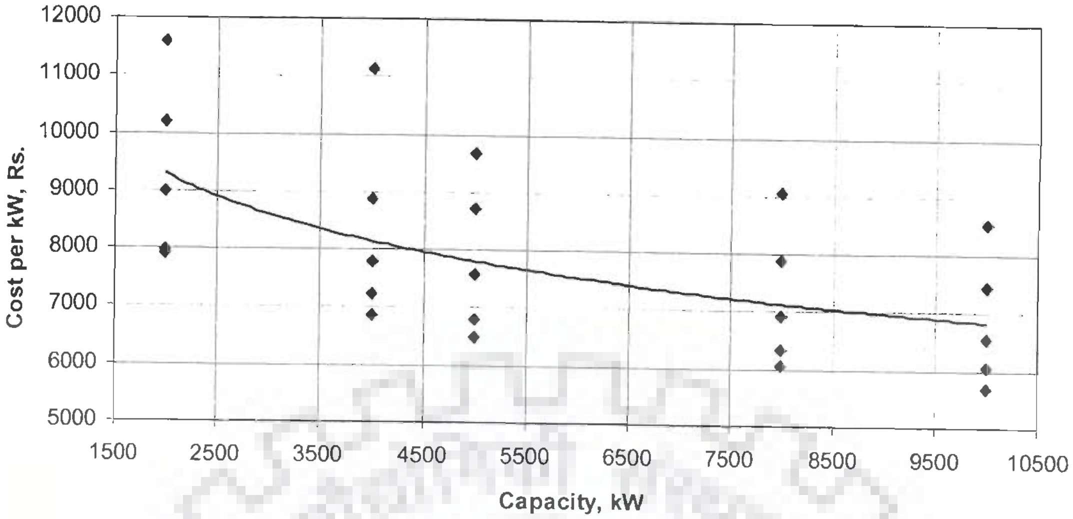


Fig. 5.23 Plot of cost per kW of turbine with capacity

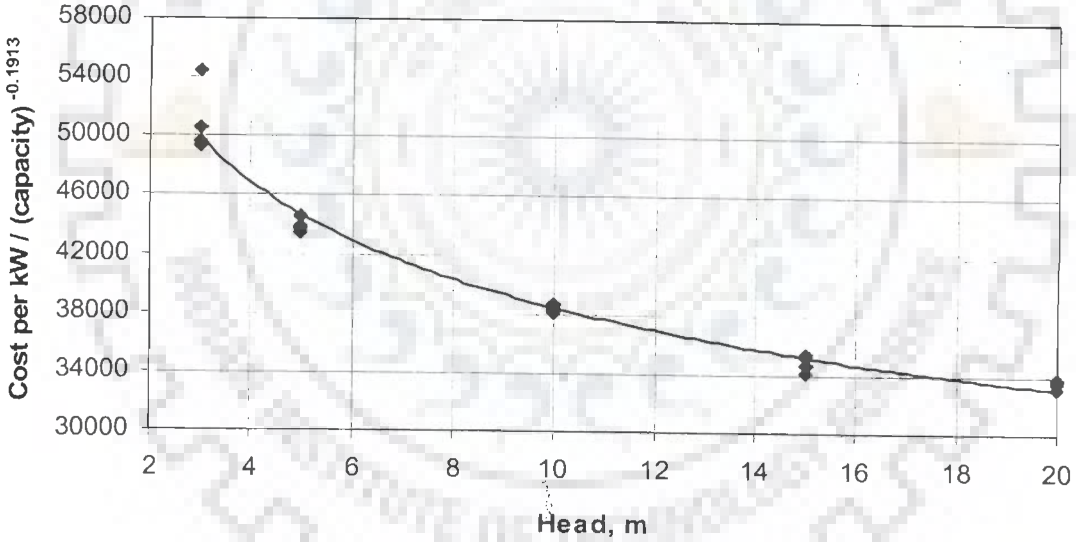


Fig. 5.24 Plot of cost per kW of turbine $(\text{capacity})^{-0.1913}$ with head

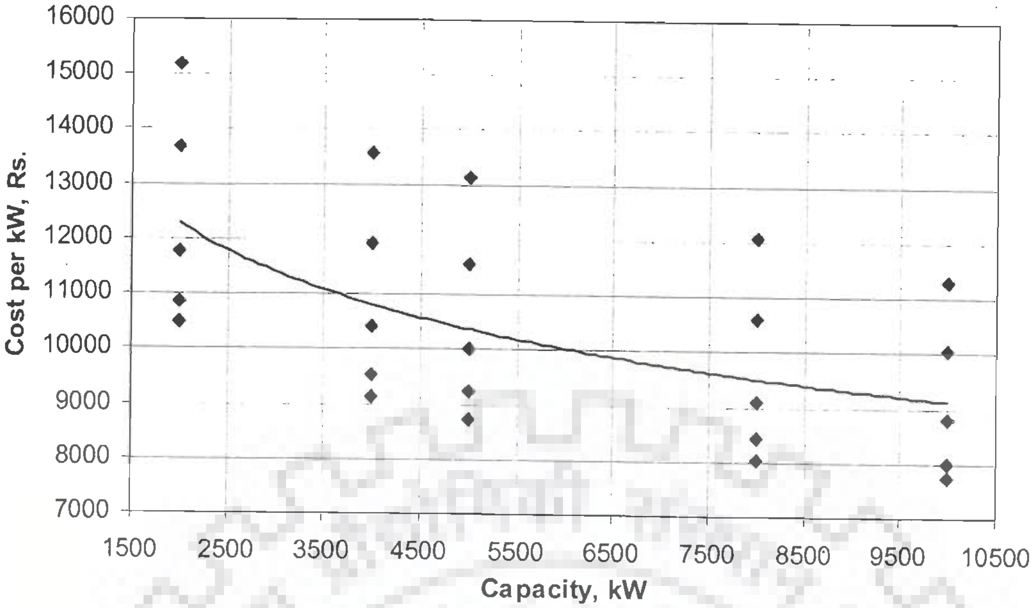


Fig. 5.25 Plot of cost per kW of generator with capacity

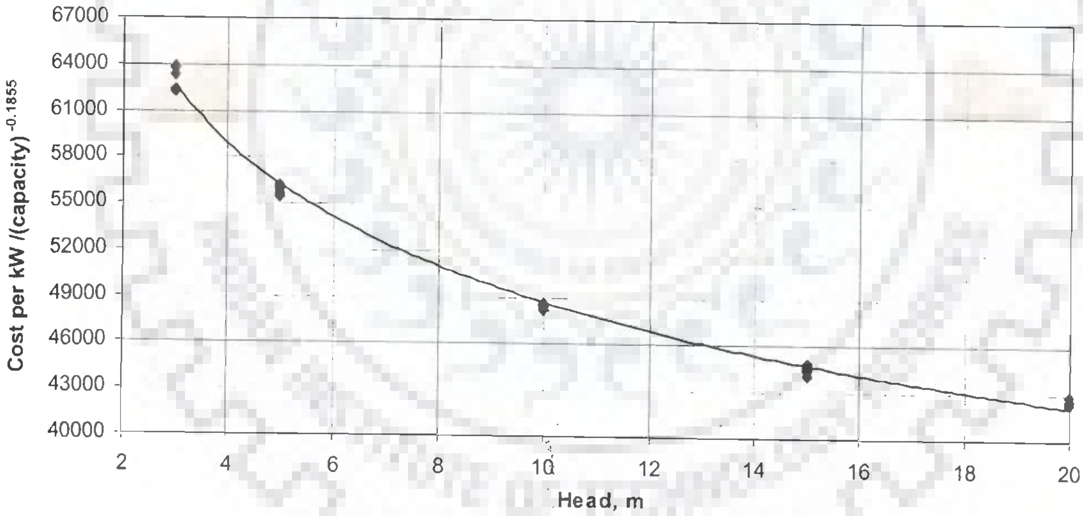


Fig. 5.26 Plot of cost per kW of Generator $(\text{capacity})^{-0.1855}$ with head

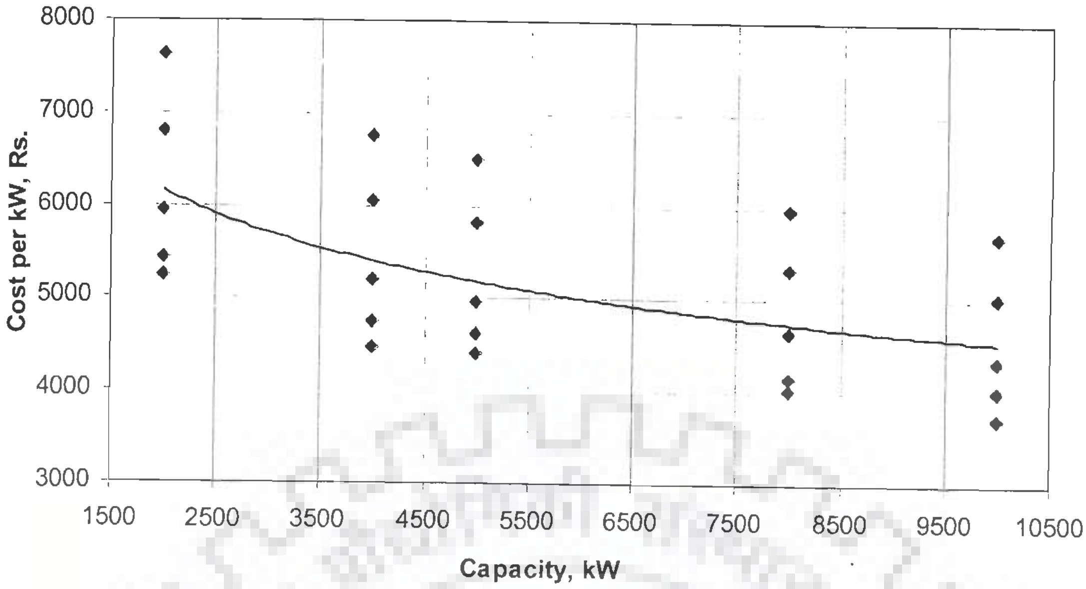


Fig. 5.27 Plot of cost per kW of auxiliary with capacity

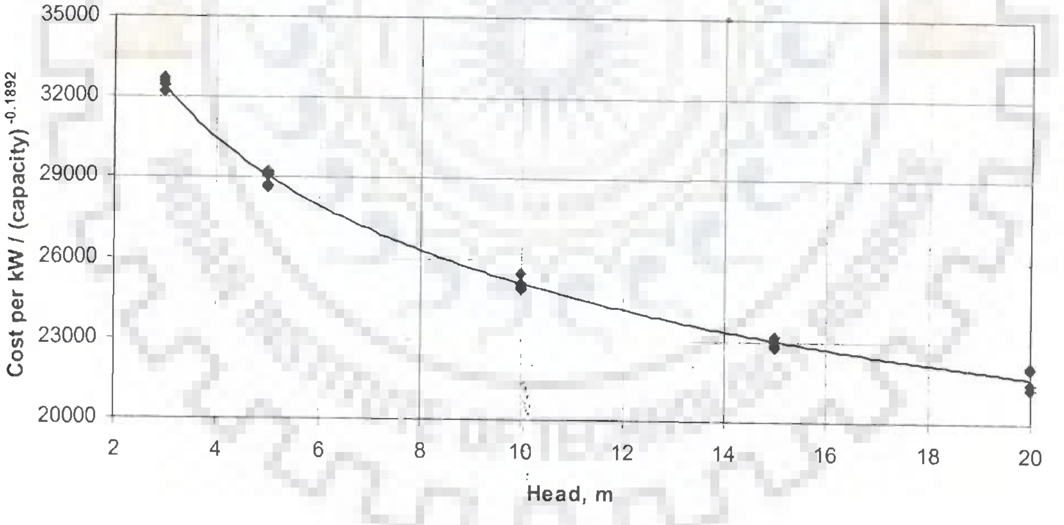


Fig. 5.28 Plot of cost per kW of auxiliary $(\text{capacity})^{-0.1892}$ with head

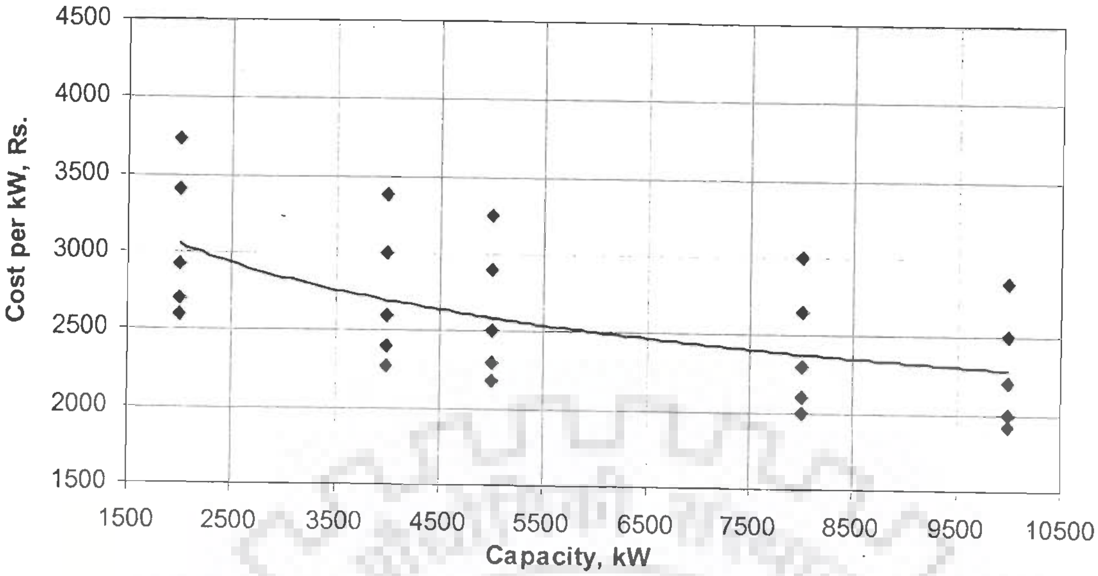


Fig. 5.29 Plot of cost per kW of transformer & switchyard with capacity

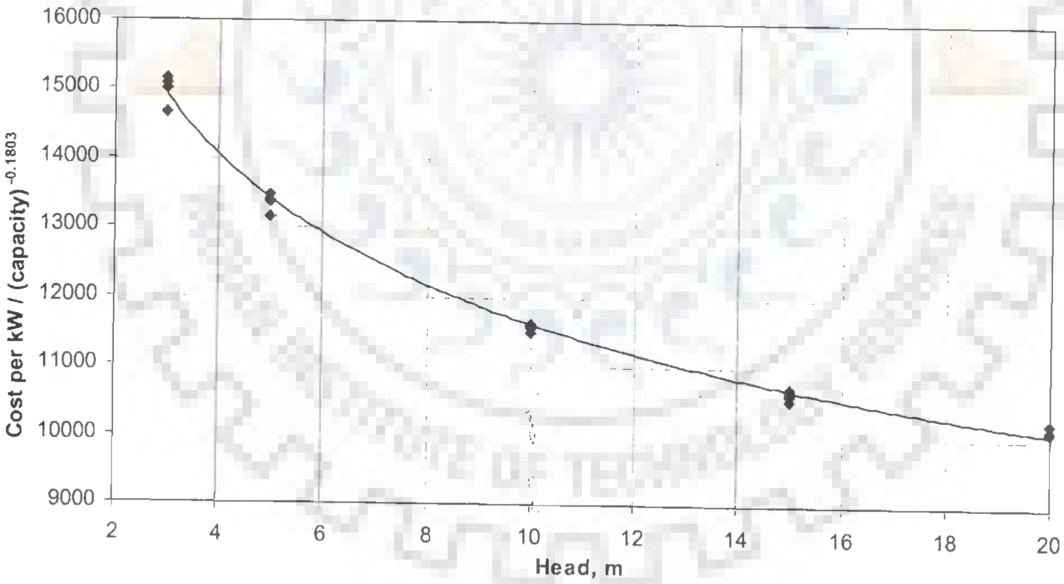


Fig. 5.30 Plot of cost per kW of transformer & switchyard (capacity)$^{-0.1803}$ with head

Table 5.45 Coefficients in cost correlation for electro-mechanical equipment having two generating units

S. No.	Type of turbine	Type of generator	Coefficient for cost of electro-mechanical								
			Turbine			Generator			Auxiliary		
			a_{12}	x_{12}	y_{12}	a_{13}	x_{13}	y_{13}	a_{14}	x_{14}	y_{14}
1.	Tubular semi Kaplan	Synchronous	63346	-0.1913	-0.2171	78661	-0.1855	-0.2083	40860	-0.1892	-0.2118
2.	Tubular semi Kaplan	Induction	63346	-0.1913	-0.2171	66268	-0.1882	-0.207	35930	-0.1831	-0.2098
3.	Vertical Semi Kaplan	Synchronous	62902	-0.1835	-0.2092	83091	-0.1827	-0.2097	42332	-0.1859	-0.2084
4.	Vertical Semi Kaplan	Induction	62902	-0.1835	-0.2092	70299	-0.1826	-0.2125	37171	-0.1848	-0.2094
5.	Bulb Semi Kaplan	Synchronous	67015	-0.1824	-0.2092	91696	-0.1893	-0.2137	44044	-0.1858	-0.2141
6.	Bulb Semi Kaplan	Induction	67015	-0.1824	-0.2092	78258	-0.1833	-0.2091	39223	-0.18	-0.1986
7.	Tubular Propeller	Synchronous	61153	-0.1961	-0.2111	78661	-0.1855	-0.2083	38328	-0.1902	-0.2134
8.	Tubular Propeller	Induction	61153	-0.1961	-0.2111	66268	-0.1882	-0.207	34124	-0.1897	-0.2196
9.	Vertical Propeller	Synchronous	59264	-0.1817	-0.2106	83091	-0.1827	-0.2097	39665	-0.1863	-0.2082
10.	Vertical Propeller	Induction	59264	-0.1817	-0.2106	70299	-0.1826	-0.2125	34852	-01865	-0.212
11.	Bulb Propeller	Synchronous	64017	-0.185	-0.2031	91696	-0.1893	-0.2137	42641	-0.1929	-0.2048
12.	Bulb Propeller	Induction	64017	-0.185	-0.2031	78258	-0.1833	-0.2091	37513	-0.1831	-0.2119
13.	Tubular Kaplan	Synchronous	70170	-0.1853	-0.2053	81881	-0.1858	-0.2095	41982	-0.187	-0.2099
14.	Tubular Kaplan	Induction	70170	-0.1853	-0.2053	72121	-0.1868	-0.2082	37168	-0.184	-0.2156
15.	Vertical Kaplan	Synchronous	73624	-0.1872	-0.2105	85377	-0.1816	-0.2082	44729	-0.1924	-0.2166
16.	Vertical Kaplan	Induction	73624	-0.1872	-0.2105	77693	-0.184	-0.2096	39199	-0.1805	-0.2072
17.	Bulb Kaplan	Synchronous	75048	-0.1873	-0.2086	99401	-0.1886	-0.209	45326	-0.1912	-0.2072
18.	Bulb Kaplan	Induction	75048	-0.1873	-0.2086	85417	-0.188	-0.2096	40096	-0.1847	-0.2156

Table 5.46: Coefficients in cost correlation for electro-mechanical equipment having one generating unit

S. No.	Type of turbine	Type of generator	Coefficient for cost of electro-mechanical								
			Turbine			Generator			Auxiliary		
			a_{12}	x_{12}	y_{12}	a_{13}	x_{13}	y_{13}	a_{14}	x_{14}	y_{14}
1.	Tubular semi Kaplan	Synchronous	39845	-0.1902	-0.2167	48568	-0.1867	-0.2090	31712	-0.1900	-0.2122
2.	Tubular semi Kaplan	Induction	39485	-0.1902	-0.2167	41374	-0.1905	-0.2084	28196	-0.1850	-0.2109
3.	Vertical Semi Kaplan	Synchronous	39170	-0.1835	-0.2084	51612	-0.1845	-0.2107	33101	-0.1874	-0.2096
4.	Vertical Semi Kaplan	Induction	39170	-0.1835	-0.2084	43544	-0.1841	-0.2136	28850	-0.1856	-0.2098
5.	Bulb Semi Kaplan	Synchronous	41572	-0.1839	-0.2102	56729	-0.1907	-0.2147	34222	-0.1867	-0.2146
6.	Bulb Semi Kaplan	Induction	41572	-0.1839	-0.2102	48433	-0.1847	-0.2102	30832	-0.1820	-0.2002
7.	Tubular Propeller	Synchronous	38971	-0.1972	-0.2119	48568	-0.1867	-0.2090	30034	-0.1919	-0.2148
8.	Tubular Propeller	Induction	38971	-0.1972	-0.2119	41374	-0.1905	-0.2084	26644	-0.1912	-0.2207
9.	Vertical Propeller	Synchronous	38329	-0.1843	-0.2121	51612	-0.1845	-0.2107	31108	-0.1881	-0.2095
10.	Vertical Propeller	Induction	38329	-0.1843	-0.2121	43544	-0.1841	-0.2136	27383	-0.1885	-0.2133
11.	Bulb Propeller	Synchronous	40964	-0.1865	-0.2042	56729	-0.1907	-0.2147	33352	-0.1944	-0.2059
12.	Bulb Propeller	Induction	40964	-0.1865	-0.2042	48433	-0.1847	-0.2102	29158	-0.1840	-0.2126
13.	Tubular Kaplan	Synchronous	43967	-0.1867	-0.2064	50623	-0.1871	-0.2105	32591	-0.1878	-0.2104
14.	Tubular Kaplan	Induction	43967	-0.1867	-0.2064	44689	-0.1883	-0.2093	28563	-0.1838	-0.2155
15.	Vertical Kaplan	Synchronous	45725	-0.1888	-0.2117	52730	-0.1828-	0.2091	34900	-0.1937	-0.2176
16.	Vertical Kaplan	Induction	45725	-0.1888	-0.2117	48043	-0.1853	-0.2106	30564	-0.1817	-0.2081
17.	Bulb Kaplan	Synchronous	47565	-0.1889	-0.2098	62515	-0.1898	-0.2099	35341	-0.1924	-0.2081
18.	Bulb Kaplan	Induction	47565	-0.1889	-0.2098	53901	-0.1892	-0.2104	31201	-0.1857	-0.2164

Table 5.47 Coefficients in cost correlation for electro-mechanical equipment having three generating units

S. No.	Type of turbine	Type of generator	Coefficient for cost of electro-mechanical								
			Turbine			Generator			Auxiliary		
			a_{12}	x_{12}	y_{12}	a_{13}	x_{13}	y_{13}	a_{14}	x_{14}	y_{14}
1.	Tubular semi Kaplan	Synchronous	83464	-0.1922	-0.2178	105046	-0.1859	-0.2085	49338	-0.1898	-0.2122
2.	Tubular semi Kaplan	Induction	83464	-0.1922	-0.2178	88783	-0.1889	-0.2075	43566	-0.1841	-0.2105
3.	Vertical Semi Kaplan	Synchronous	83007	-0.1842	-0.2097	110869	-0.1830	-0.2100	50967	-0.1862	-0.2086
4.	Vertical Semi Kaplan	Induction	83007	-0.1842	-0.2097	93879	-0.1830	-0.2127	44839	-0.1853	-0.2097
5.	Bulb Semi Kaplan	Synchronous	88255	-0.1829	-0.2096	122454	-0.1897	-0.2139	53127	-0.1863	-0.2144
6.	Bulb Semi Kaplan	Induction	88255	-0.1829	-0.2096	104632	-0.1838	-0.2095	47321	-0.1805	-0.1990
7.	Tubular Propeller	Synchronous	80534	-0.1967	-0.2115	105046	-0.1859	-0.2085	46194	-0.1906	-0.2138
8.	Tubular Propeller	Induction	80534	-0.1967	-0.2115	88783	-0.1889	-0.2075	41203	-0.1903	-0.2200
9.	Vertical Propeller	Synchronous	78033	-0.1822	-0.2109	110869	-0.1830	-0.2100	47895	-0.1869	-0.2086
10.	Vertical Propeller	Induction	78033	-0.1822	-0.2109	93879	-0.1830	-0.2127	42038	-0.1870	-0.2123
11.	Bulb Propeller	Synchronous	84291	-0.1855	-0.2034	122454	-0.1897	-0.2139	51436	-0.1934	-0.2052
12.	Bulb Propeller	Induction	84291	-0.1855	-0.2034	104632	-0.1838	-0.2095	45203	-0.1835	-0.2122
13.	Tubular Kaplan	Synchronous	92315	-0.1857	-0.2056	109346	-0.1862	-0.2098	50641	-0.1875	-0.2102
14.	Tubular Kaplan	Induction	92315	-0.1857	-0.2056	96329	-0.1872	-0.2085	44880	-0.1846	-0.2161
15.	Vertical Kaplan	Synchronous	96760	-0.1875	-0.2108	113919	-0.1819	-0.2084	54010	-0.1930	-0.2171
16.	Vertical Kaplan	Induction	96760	-0.1875	-0.2108	103771	-0.1844	-0.2099	47284	-0.1810	-0.2075
17.	Bulb Kaplan	Synchronous	99681	-0.1876	-0.2089	135174	-0.1890	-0.2093	54627	-0.1916	-0.2076
18.	Bulb Kaplan	Induction	99681	-0.1876	-0.2089	115426	-0.1885	-0.2099	48324	-0.1851	-0.2160

Table 5.48: Coefficients in cost correlation for E electro-mechanical equipment having four generating units

S. No.	Type of turbine	Type of generator	Coefficient for cost of electro-mechanical								
			Turbine			Generator			Auxiliary		
			a_{12}	x_{12}	y_{12}	a_{13}	x_{13}	y_{13}	a_{14}	x_{14}	y_{14}
1.	Tubular semi Kaplan	Synchronous	101464	-0.1920	-0.2177	127038	-0.1858	-0.2085	56625	-0.1896	-0.2121
2.	Tubular semi Kaplan	Induction	101464	-0.1920	-0.2177	107360	-0.1888	-0.2074	49633	-0.1832	-0.2098
3.	Vertical Semi Kaplan	Synchronous	100639	-0.1841	-0.2096	134207	-0.1829	-0.2099	58665	-0.1863	-0.2087
4.	Vertical Semi Kaplan	Induction	100639	-0.1841	-0.2096	114096	-0.1834	-0.2130	51453	-0.1851	-0.2096
5.	Bulb Semi Kaplan	Synchronous	107542	-0.1833	-0.2098	148404	-0.1898	-0.2141	61232	-0.1865	-0.2146
6.	Bulb Semi Kaplan	Induction	107542	-0.1833	-0.2098	127040	-0.1841	-0.2098	54191	-0.1801	-0.1987
7.	Tubular Propeller	Synchronous	97830	-0.1967	-0.2115	127038	-0.1858	-0.2085	53171	-0.1907	-0.2138
8.	Tubular Propeller	Induction	97830	-0.1967	-0.2115	107360	-0.1888	-0.2074	47289	-0.1901	-0.2199
9.	Vertical Propeller	Synchronous	94524	-0.1820	-0.2108	134207	-0.1829	-0.2099	54913	-0.1866	-0.2084
10.	Vertical Propeller	Induction	94524	-0.1820	-0.2108	114096	-0.1834	-0.2130	48396	-0.1871	-0.2124
11.	Bulb Propeller	Synchronous	102626	-0.1858	-0.2037	148404	-0.1898	-0.2141	59395	-0.1938	-0.2054
12.	Bulb Propeller	Induction	102626	-0.1858	-0.2037	127040	-0.1841	-0.2098	52100	-0.1837	-0.2124
13.	Tubular Kaplan	Synchronous	112150	-0.1858	-0.2056	132762	-0.1865	-0.2101	58358	-0.1877	-0.2104
14.	Tubular Kaplan	Induction	112150	-0.1858	-0.2056	116839	-0.1874	-0.2086	51773	-0.1849	-0.2164
15.	Vertical Kaplan	Synchronous	117794	-0.1878	-0.2109	138178	-0.1821	-0.2085	62239	-0.1932	-0.2172
16.	Vertical Kaplan	Induction	117794	-0.1878	-0.2109	125741	-0.1845	-0.2100	54489	-0.1812	-0.2077
17.	Bulb Kaplan	Synchronous	120851	-0.1875	-0.2088	164272	-0.1894	-0.2096	62887	-0.1917	-0.2076
18.	Bulb Kaplan	Induction	120851	-0.1875	-0.2088	140014	-0.1887	-0.2100	55688	-0.1853	-0.2161

Table 5.49 Values of coefficients in cost correlation for transformer and switchyard

S. No.	Alternatives	Coefficients in cost correlation		
		a_{15}	x_{15}	y_{15}
1.	Layout with one generating unit	14062	-0.1817	-0.2082
2.	Layout wth two generating units	18739	-0.1803	-0.2075
3.	Layout with three generating units	23051	-0.1811	-0.2080
4.	Layout with four generating units	26398	-0.1809	-0.2079

5.3 TOTAL INSTALLATION COST

Based on the correlations developed for the cost of different components under different type of SHP schemes, installation cost has been worked for various layouts having different soil conditions, type of turbines and generators and number of generating units.

The total project cost includes cost of civil works, cost of electro- mechanical equipment, cost of other miscellaneous items and other indirect costs. Eestablishment related cost including designs, audit & account, indirect charges, tools and plants, communication expenses, preliminary expenses on report preparation, survey and investigations and cost of land were considered under miscellaneous and indirect costs. 13% of the cost of civil works and electro- mechanical equipment has been taken on account of these costs [16]. Percentage cost for miscellaneous items considered are given in Table 5.50:

Table 5.50 Percentage cost of miscellaneous items

S. No.	Items	Rate
1.	Establishment including designs	@ 8%
2.	Audit & Account etc. indirect charges	@ 1%
3.	Maintenance of works	@ 1%
4.	T&P	@ 1%
5.	Losses on stock	@ 0.25%
6.	Preliminary expenses, Land, Communication and Miscellaneous	@ 1.75%
	Total	**@ 13.00%**

Correlations for various components under different schemes for different alternatives have been developed and presented in the previous part of the chapter. The total installation cost is computed by taking the sum of the developed correlations of respective schemes alongwith the miscellaneous cost. Total installation cost for different schemes are represented as follows.

5.3.1 Canal based scheme

Under civil works the cost of diversion channel, spillway and power house have been correlated as function of capacity and head. Electro-mechanical equipment consisting of turbine, generator, auxilliaries and transformer have been considered and the cost of these correlated. Various costs are represented as follows,

(i) Cost of civil works (Rs. per kW), $C_c = C_1 + C_2 + C_3$ (5.18)

(ii) Cost of electro-mechanical equipment (Rs. per kw),

$$C_{e\&m} = C_{12} + C_{13} + C_{14} + C_{15} \quad (5.19)$$

(iii) Miscellaneous cost (Rs. per kW), $C_{mc} = 0.13\ (C_{c} + C_{e\&m})$ (5.20)

(iv) Total cost (Rs. per kW), $C_{tc} = C_c + C_{e\&m} + C_{mc}$ (5.21)

Based on Eq. 5.21 total installation cost of canal based scheme for different alternatives has been computed. Fig. 5.31 shows that the cost per kW decreases with increase in the capacity in all the cases. The effect of different alternatives on installation are discussed as follows.

5.3.1.1 Effect of Layout

In order to discuss the effect of layout on installation cost, three layouts i.e (i) power house building in diversion channel and spillway in main channel, (ii) powerhouse building and spillway combined in main canal and bye pass channel, (iii) powerhouse building and spillway combined in main canal and no bye pass channel have been considered. The installation costs for these layouts has been determined having two numbers tubular semi Kaplan turbines and synchronous generators for different capacities at three different heads i.e. 2 m, 10m and 20 m.

For a typical case the installation costs per kW corresponding to layout considered of power house building in diversion channel and spillway in main canal comes out to be maximum for all values of capacity and head. It comes out to be as Rs 70,229 for 2000 kW capacity and Rs. 50,460 for 10000 kW capacity at a head of 3 m. While it is minimum for the layout of powerhouse building and spillway combined in main canal without bye pass channel. It come out to be as Rs. 67, 142/kW and Rs. 48,291/kW for 2000 kW and 10000 kW installed capacity respectively. This is due to elimination of diversion channel and cost of civil works get reduced substantially as power house and spillway structure are combined.together.

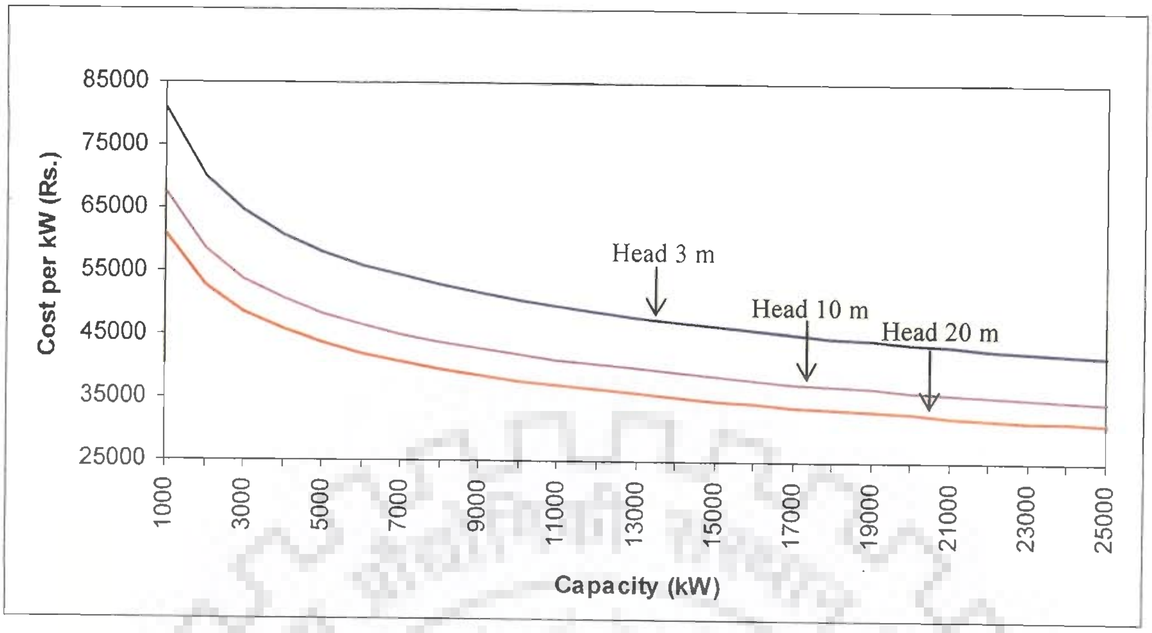


Fig. 5.31 Canal based SHP scheme with two units

5.3.1.2 Effect of soil condition

Three different types of soil conditions have been considered to discuss the effect of soil condition on the installation cost of a canal based scheme. The installation cost of a canal based scheme having a layout of power house building in diversion channel and spillway in main canal of plant capacity of 2000 kW at 3 m head for different soil conditions i.e. (i) ordinary soil, (ii) soft rock and (iii) hard rock has been determined. It is found that the layout for ordinary soil conditions has minimum installation cost. The installation cost of 2000 kW plant capacity at 3 m head has been found as Rs. 70,229 per kW, Rs. 71,084 per kW and Rs. 71,805 per kW for ordinary soil, soft rock and hard rock conditions respectively. The maximum difference in cost with these soil conditions has been observed as 2.2%. However, in case of soft rock and hard rocks, the excavation costs are higher but there is saving on account of less dewatering, thus the difference in cost is not substantial.

5.3.1.3 Effect of head

Based on the correlations developed for components of canal based SHP schemes, installation cost has been worked out for layouts at different heads. The layouts have been considered with powerhouse building in diversion channel and spillway in main canal having soil condition as ordinary soil. The installation costs are worked out considering all the layouts based on different heads with two numbers tubular semi Kaplan turbines and synchronous generators at different capacities and shown in Fig. 5.31. The cost break up of various components considered at heads of 3 m and 20 m having the same plant capacity of 2000 kW with two units have been worked out and shown in Fig. 5.32.

Fig. 5.31 shows that the cost of such schemes decreases with increase in head. It is observed from Fig. 5.32 that electro-mechanical equipment constitutes the major part of the overall cost for a low head scheme. Cost of electro-mechanical equipment is found to be 54.5% for a plant of 3 m head and 50.3% for 20 m head. This can be explained on the fact that at low head, the speed of turbine is low and decreases with the decrease in head. The generators driven by these turbines will be of low speed. Low speed generators are bigger in size as the number of poles is more in low speed generators. Therefore the cost of generators for low head schemes is more. Further, the size of the turbines are bigger for low head SHP sites in order to accommodate large quantity of water for the required power, therefore the low head turbines are costlier.

5.3.1.4 Effect of number of generating units

Fig. 5.33 shows the cost per kW of a scheme having installed capacity of 2000 kW at 3m head. The type of layouts as powerhouse building in diversion channel and spillway in main channel having soil condition as ordinary soil was considered. The type of turbine was considered as tubular semi Kaplan coupled with synchronous generators having number of generating units as one, two, three and four. Total installation cost for layouts having one, two, three and four generating units comes out to be as Rs. 49,510, 70,229, 88,178 and 104,006 respectively. Fig. 5.33 shows that the cost of such schemes increases with number of units.

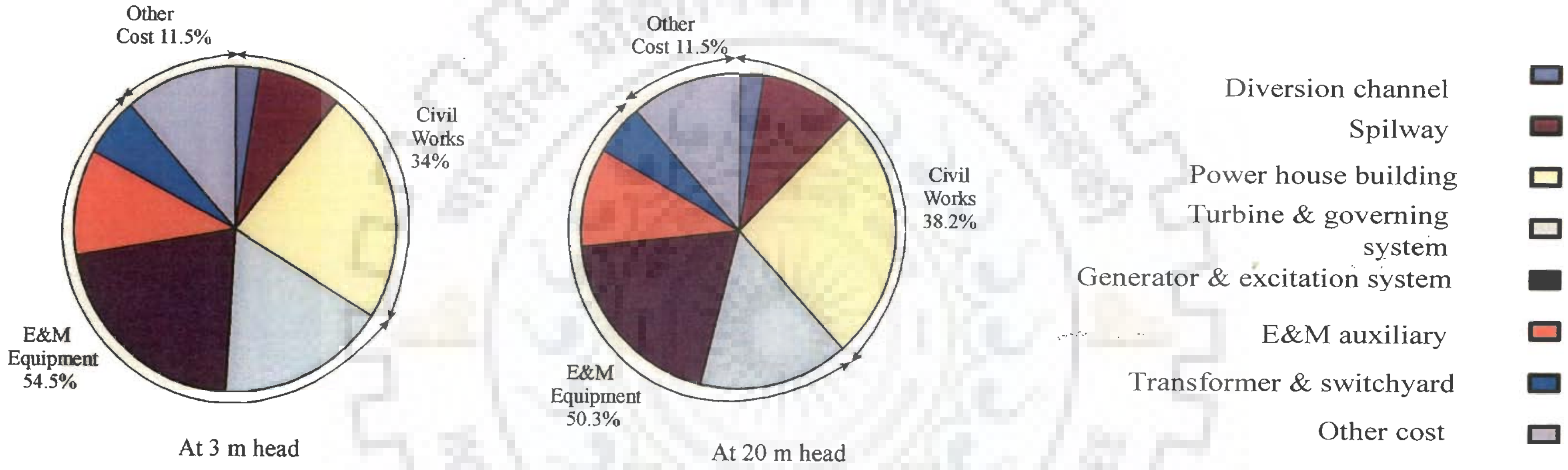
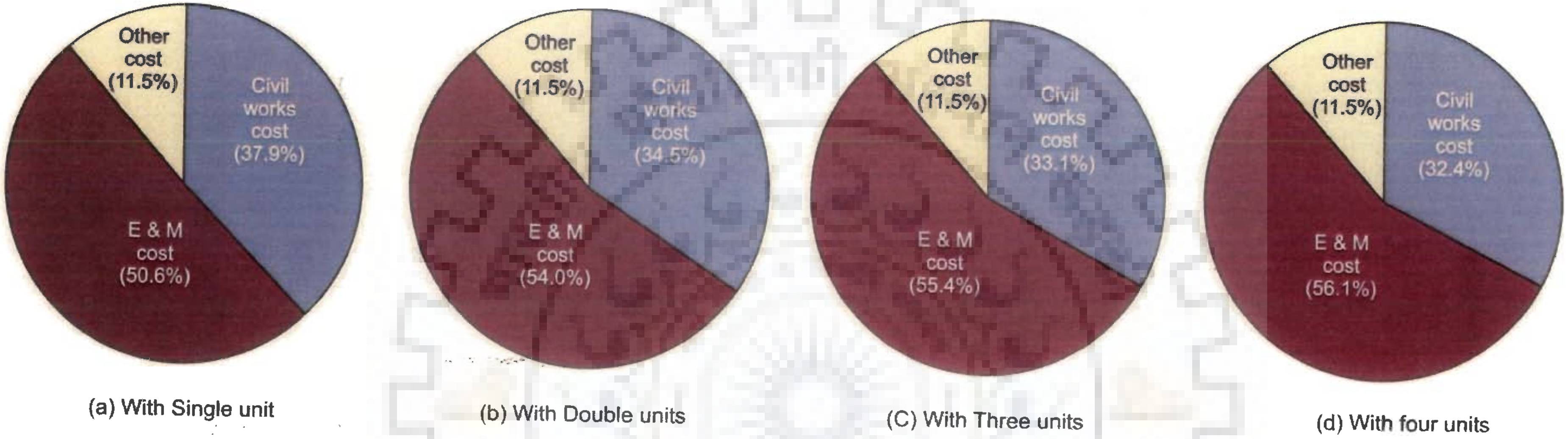


Fig. 5.32 Break up of costs at different heads for a given capacity of canal based scheme



(a) With Single unit

(b) With Double units

(C) With Three units

(d) With four units

Fig. 5.33 Cost break up of canal based SHP Scheme

5.3.1.5 Effect of type of turbines and generators

In order to observe the effect of type of turbine and generator on total installation cost of canal based SHP schemes having soil condition as ordinary soil Types of turbines are considered Tubular, vertical and bulb turbines with propeller, semi Kaplan and Kaplan runners as discussed in chapter 3. Two types of generators i.e. synchronous and induction are considered. The installation costs are computed considering layouts with two generating units at different head and capacities.. It is seen that the scheme having tubular-propeller turbine and induction generator has minimum installation cost which comes out be as Rs. 64508/- per kW. While layout of bulb turbine having Kaplan runner with synchronous generator has maximum cost which comes out to be as Rs 75622 /- per kW. A maximum difference of 17.2% in the cost has been observed for a layout having 2 generating units. It is also seen that the cost of layout having synchronous generator comes out to be more than induction generator instllations.

5.3.2 Run of River SHP Schemes

For a run of river scheme, cost of diversion weir, power channel, desilting tank, forebay, penstock, power house and tail race channel have been considered. Correlations for different costs of the above components as function of capacity and head have been developed and presented earlier in this chapter. Various costs for run of river schemes are represented as follows,

(i) Cost of civil works (Rs. per kW), C_{cr}

$$= C_4 + C_5 + C_6 + C_7 + C_8 + C_9 + C_{10} \qquad (5.22)$$

(ii) Cost of electro-mechanical equipment(Rs. per kW), $C_{e\&m}$

$$= C_{12} + C_{13} + C_{14} + C_{15} \qquad (5.23)$$

(iii) Miscellaneous cost (Rs. per kW), $C_{mr} = 0.13\ (C_{cr} + C_{e\&m})$ (5.24)

(iv) Total installation cost (Rs. per kW), $C_{tr} = C_c + C_{e\&m} + C_{mc}$ (5.25)

Based on the correlations developed for components of run of river SHP schemes, installation cost of different layouts has determined for different soil conditions, type of turbines & generators and number of generating units on the similar lines as worked out for canal based schemes. For a typical layout having two numbers tubular semi Kaplan turbines and synchronous generators at different heads and capacities the installation costs are worked out and are shown in Fig. 5.34. The cost break up of various components considered at heads of 3 m and 20 m having the same plant capacity of 2000 kW with two units have also been determined and shown in Fig. 5.35.

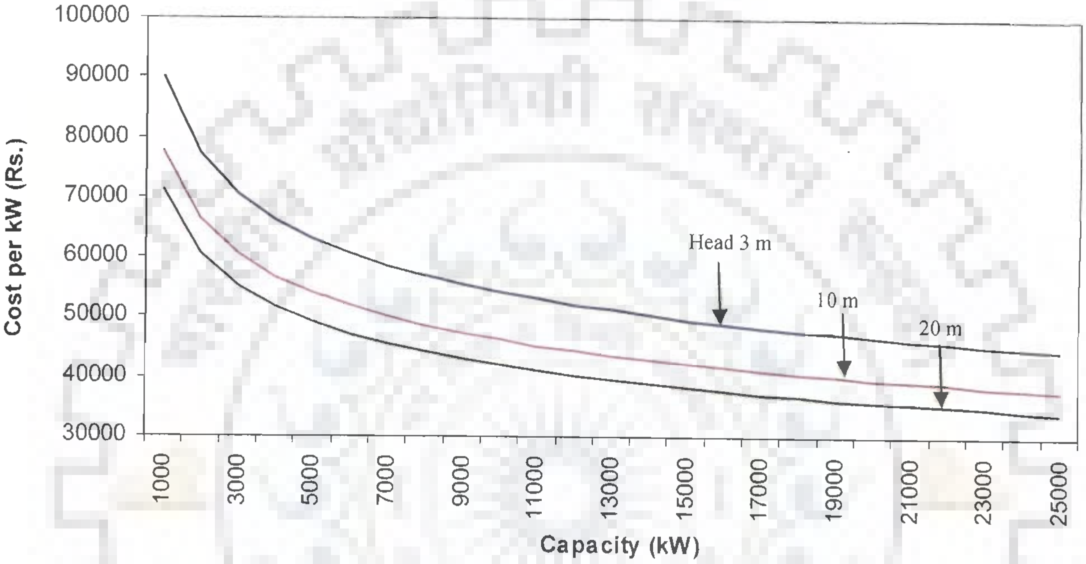


Fig. 5.34 Cost of run-of-river SHP scheme with two units

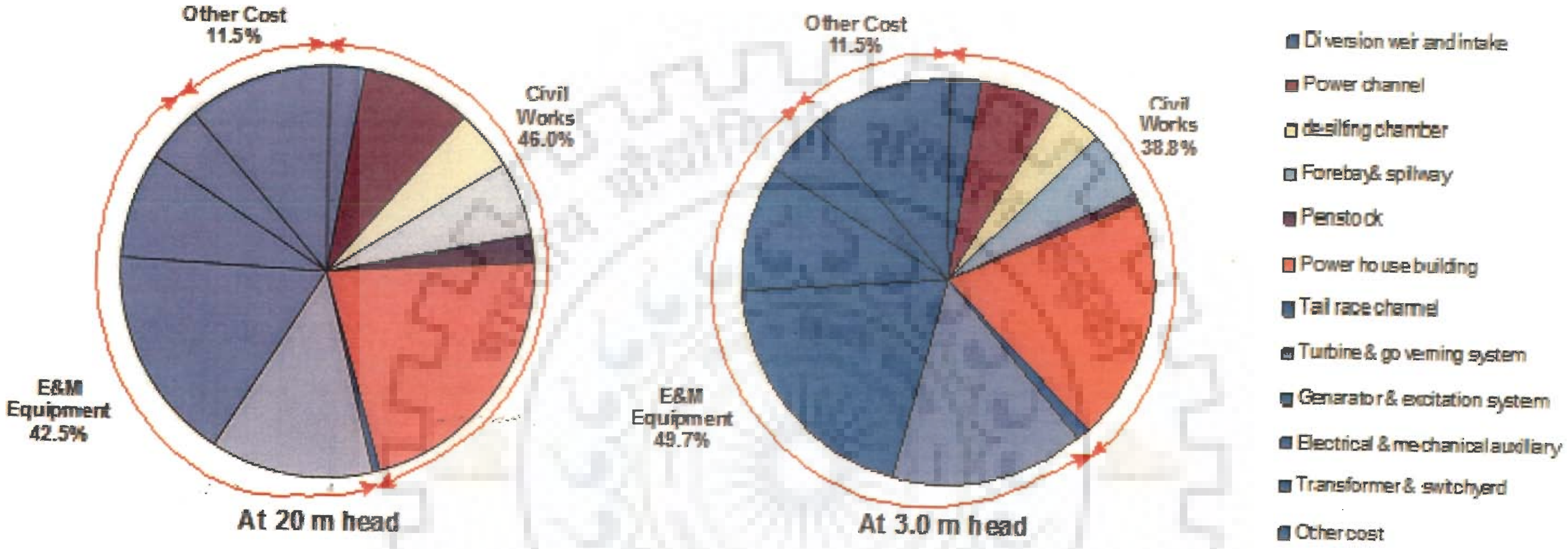


Fig. 5.35 Break up of costs at different heads for a given capacity

Fig. 5.34 shows that the cost of such schemes decreases with increase in head and capacity. The installation cost per kW of a typical run of river scheme of 2000 kW plant capacity is found as Rs. 77,247, 66421 and 60557 at heads 3 m, 10 m and 20 m respectively. Fig. 5.34 shows that the major part of the cost at lower head (=3 m) is of electro-mechanical equipment i.e. 49.7 %, while at higher head (=20 m) cost contribution as 46% of civil works is found to be more than electro-mechanical equipment.

5.3.3 Dam Toe Schemes

As discussed earlier, the main components of a dam toe scheme are; intake, penstock, power house and tailrace channel. Correlations for cost of different components under this type scheme are developed on similar lines as in the case of canal based scheme and run of river scheme as presented in the earlier part of this chapter. The correlations developed are reproduced as follows;

(i) Cost of civil works (Rs. per kW), C_{cd}

$$= C_8 + C_9 + C_{10} + C_{11} \qquad (5.26)$$

(ii) Cost of electro-mechanical equipment (Rs. per kW), $C_{e\&m}$

$$= C_{12} + C_{13} + C_{14} + C_{15} \qquad (5.27)$$

(iii) Miscellaneous cost (Rs. per kW), C_{md}

$$= 0.13 (C_{cd} + C_{e\&m}) \qquad (5.28)$$

(iv) Total cost (Rs. per kW), C_d

$$= C_{td} + C_{e\&m} + C_{md} \qquad (5.29)$$

Based on the correlations developed for components of dam toe SHP schemes, installation cost has been worked out for different types of layouts for different soil conditions, type of turbines and generators and number of generating units on the similar lines as worked out for canal based schemes. The installation costs are worked out considering a typical layout with civil works as discussed in chapter 3, having two numbers tubular semi Kaplan turbines and synchronous generators at different heads and capacities. Soil condition is considered as ordinary soil. The installation costs as determined are shown in Fig. 5.36. The cost break up of various components considered at heads of 3 m and 20 m having the same plant capacity of 2000 kW with two units have also been computed and shown in Fig. 5.37.

Fig. 5.36 shows that the cost of such schemes also decreases with increase in head and capacity. The installation cost per kW for a typical layout of 2000 kW capacity is found is found to be Rs. 64,652, 53,505 and 48,394 at heads 3 m, 10 m and 20 m respectively. Fig. 5.37 shows that the major part of the cost is of electro-mechanical equipment which decreases with increase in head. By increasing head the length of penstock increases and size of electro-mechanical equipment reduces, thus with increase in head cost contribution of civil works increases and electro-mechanical equipment decreases.

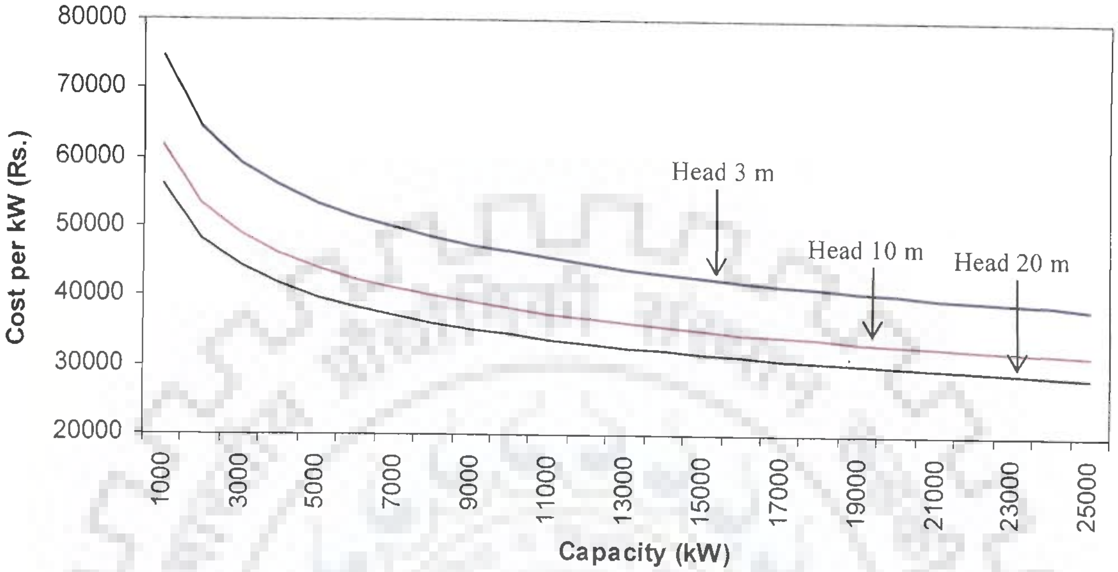
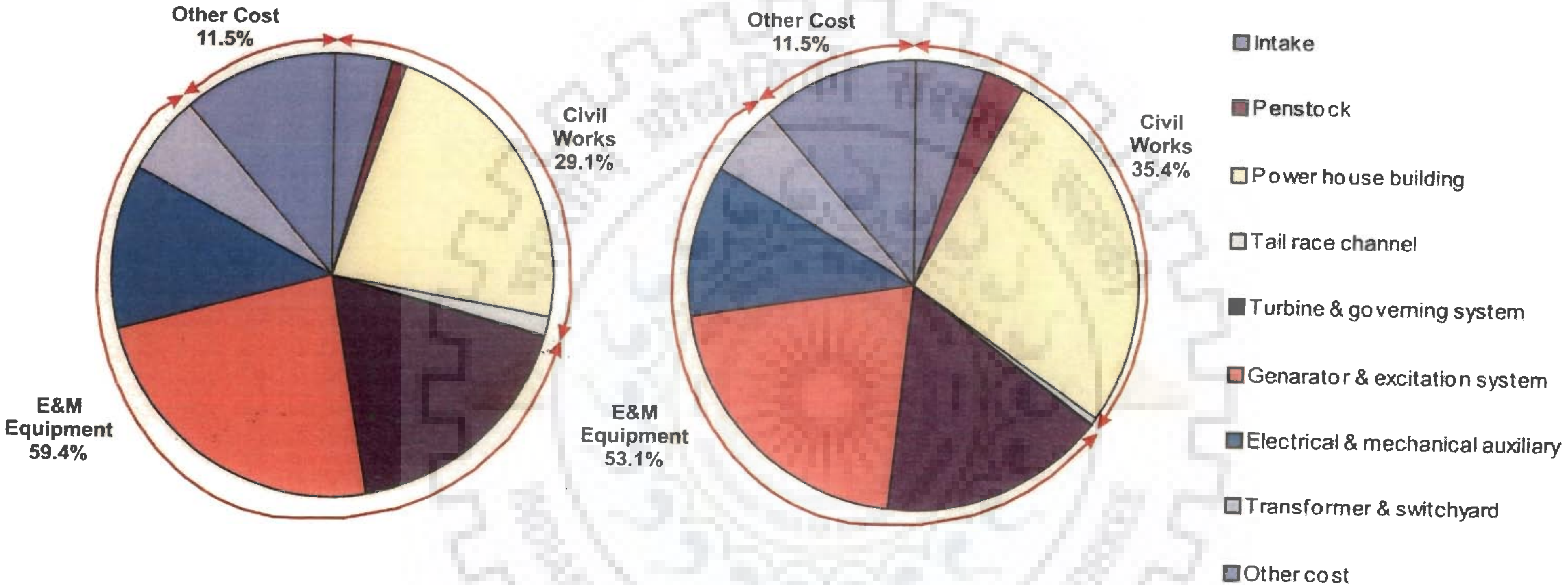


Fig. 5.36 Dam toe SHP scheme with two units



At 3.0 m head At 20 m head

Fig. 5.37 Break up of costs at different heads for a given capacity

5.4 VALIDATION OF CORRELATIONS WITH ACTUAL COST DATA

In order to verify the developed correlations for cost, comparison was made with the actual cost of such plants installed recently. For this, data for installation costs were collected from 107 small hydro power plants. These plants were installed/planned during last 12 years (1995 onwards) under different schemes such as canal based, run of river and dam toe. The cost data of these plants were pertaining to different periods. Thus, the collected cost data were escalated to bring all the costs at the level of year 2007. The inflation based on consumer price index for the years 1995 to 2007 varied from 3.3% to 8% in India. The average inflation during this period comes out to be around 5%. Thus the cost of these projects was increased by 5% per annum from the year of commissioning or year of cost estimation, to bring them at the level of 2007. The cost data as modified for base year 2007 and project details are given in Tables 5.51- 5.53 for canal based, run of river and dam toe schemes respectively.

The cost data of SHP schemes as determined from developed co-relations based on actual quantities of various items and prevailing rates were compared with the cost data of existing/planned SHP plants. The comparison of cost per kW based on developed correlations and cost data of existing power stations are shown in Figs. 5.38 to 5.40 for canal based, run of river and dam toe schemes. It is found that the variation in cost is ±12% in canal based schemes, ± 12.5 % in case of run of river schemes and ± 11 % for dam toe schemes. The deviation in the costs is found to be within reasonable limits. This shows the accuracy of the developed correlations. The factors responsible for this variation of cost may be due to geological/soil conditions, type of turbine, type of generator, location of site etc.

Table 5.51 Cost data of existing canal based SHP plants

S. No.	Name of project	State	Capacity (kW)	Head (m)	Cost per kW (Rs.)
1.	Addanki 18-0-550	Andhra Pradesh	2000	6.37	63520
2.	Addanki 18-4-440	Andhra Pradesh	2000	6.71	61770
3.	Guntoor	Andhra Pradesh	4300	8.85	54530
4.	Guntoor 0-0-550	Andhra Pradesh	3750	7.00	55370
5.	Lock-in-Sula	Andhra Pradesh	4000	12.00	52220
6.	Ongole 2-3-150	Andhra Pradesh	1500	7.50	65430
7.	Pothireddipadu	Andhra Pradesh	7500	7.00	50610
8.	TB Dam Canal	Andhra Pradesh	8250	10.00	50485
9.	Agnoor	Bihar	1000	3.00	103480
10.	Agnoor	Bihar	1000	3.37	75680
11.	Triveni	Bihar	3000	4.94	53375
12.	Dhelebagh	Bihar	1500	3.20	68750
13.	Nasariganj	Bihar	1000	4.50	67160
14.	Jainagara	Bihar	1000	4.45	61065
15.	Tejpura	Bihar	1500	4.25	65260
16.	Dhaba	Bihar	2000	3.42	65940
17.	Kattanya	Bihar	2000	3.33	69090
18.	Mathauli	Bihar	1000	3.93	75460
19.	Belsar	Bihar	1000	3.25	71250
20.	Paharma	Bihar	1000	4.70	66630
21.	sebari	Bihar	1000	4.50	68180
22.	Sipaha	Bihar	1000	3.20	70590
23.	Saurashtra	Gujarat	16000	11.00	44850
24.	Dhupdal	Karnatka	2800	4.80	66050
25.	Kilara	Karnatka	2000	10.00	62180
26.	Malprabha	Karnatka	2400	9.00	52770
27.	Rajankolur	Karnatka	2000	19.00	57000
28.	Shahpur_III	Karnatka	1300	6.20	67290
29.	Shahpur-I	Karnatka	1300	6.20	66510

S. No.	Name of project	State	Capacity (kW)	Head (m)	Cost per kW (Rs.)
30.	Shahpur-II	Karnatka	1300	6.20	64720
31.	Shahpur-IV	Karnatka	1300	6.20	68670
32.	Shahpur-V	Karnatka	1400	9.80	59470
33.	Shiva	Karnatka	3000	8.10	61100
34.	Chambal	Madhya Pradesh	1800	4.45	71930
35.	Chargaon	Madhya Pradesh	1000	12.00	66060
36.	Korba	Madhya Pradesh	1850	6.35	55020
37.	Morand	Madhya Pradesh	1005	3.65	80120
38.	Kanhar	Maharashtra	4000	20.00	39000
39.	Potteru	Orissa	6000	11.58	50210
40.	Jagera	Punjab	1000	3.00	98540
41.	Kanganwal	Punjab	1300	3.00	83650
42.	Narangal	Punjab	1500	3.00	80080
43.	Tugal	Punjab	1500	3.00	75000
44.	Chupki	Punjab	1500	3.00	74910
45.	Dalla	Punjab	1000	3.00	97500
46.	Bowani	Punjab	1000	3.00	99190
47.	Killa	Punjab	1750	4.45	79180
48.	Sahoke	Punjab	1000	5.17	73650
49.	Mukerian	Punjab	18000	8.23	45660
50.	Anoopgarh-I	Rajasthan	4500	8.24	54080
51.	Anoopgarh-II	Rajasthan	4500	8.24	54250
52.	Charanwala	Rajasthan	1200	5.28	72875
53.	Pugal-I	Rajasthan	1500	9.73	64000
54.	Suratgarh	Rajasthan	4000	8.48	58500
55.	Birupa	Tamil Nadu	2250	4.50	59020
56.	Sarkari	Uttar Pradesh	1500	4.10	60590
57.	Nirgazni	Uttar Pradesh	6500	4.30	65120
58.	Mohammadpur	Uttarakhand	10500	5.18	48870

Table 5.52 Cost data of existing run of river SHP plants

S. No.	Name of project	State	Capacity (kW)	Head (m)	Cost per kW (Rs.)
1.	Dhansiri -1	Assam	4000	9	65310
2.	Dhansiri -2	Assam	4000	9	61400
3.	Dhansiri -3	Assam	4000	9	68620
4.	Dhansiri -4	Assam	4000	9	60200
5.	Dhansiri -5	Assam	4000	9	69500
6.	Matehill	Jammu & Kashmir	1000	11	88320
7.	Ganglas	Jammu & Kashmir	1000	18	53000
8.	Stakna	Jammu & Kashmir	4000	20	56460
9.	Tilaiya	Jharkhand	4000	20	38200
10.	Tennu Bokaro	Jharkhand	1000	15	91980
11.	Bhadra	Karnataka	6000	16	53000
12.	Bhadra R.B.	Karnataka	7200	18	51600
13.	Shomeswara	Karnataka	24750	17.5	44000
14.	Maniyar SHP	Kerala	12000	16	45300
15.	Ullunkal	Kerala	6000	10	56300
16.	Vajra	Maharashtra	1500	10	77000
17.	Majalgaon	Maharashtra	1500	6	82440
18.	Tuichang -V	Mizoram	6000	20	51400
19.	Dikhu	Nagaland	1000	20	77625
20.	Bansadhara	Orissa	1000	13	81730
21.	Baura	Orissa	3000	20	60200
22.	Chiplima	Orissa	4800	3	70430
23.	Gohire	Orissa	1500	6	82440
24.	Lower Indravati	Orissa	3000	16	61900
25.	Lower Nagavalli	Orissa	3000	19	378640

Table 5.53 Cost data of existing dam toe SHP plants

S. No.	Name of project	State	Installed capacity (kW)	Head (m)	Cost per kW (Rs.)
1.	Mid Pennar MHS	Andhra Pradesh	2000	12.50	56250
2.	Singoor	Andhra pradesh	15000	20.00	34670
3.	Mid Pennar	Andhra pradesh	2000	11.00	48330
4.	TB Dam SHP	Karnataka	8000	10.00	34690
5.	Madhanmantri SHP	Karnataka	3000	4.70	67600
6.	Malaprabha SHP	Karnataka	2400	10.00	40625
7.	Deverebelekara	Karnataka	2000	10.90	40500
8.	Harangi	Karnatka	9000	20.00	44500
9.	Hemawathi	Karnatka	16000	16.00	41290
10.	Karikkayam St. 1&2	Kerala	15000	10.00	28325
11.	Ullunkal	Kerala	7000	10.00	31200
12.	Maniyar SHP	Kerala	12000	16.00	23750
13.	Bhimgarh SHP	Madhya Pradesh	2400	10.00	52700
14.	Bhincrarh	Madhya Pradesh	2400	10.00	38160
15.	Majalgaon	Maharashtra	2250	5.25	63270
16.	Harbhangi SHP	Orissa	2000	12.00	51500
17.	Mukurthy	Tamil Nadu	1000	20.00	47830
18.	Perunchani	Tamil Nadu	1300	15.00	59900

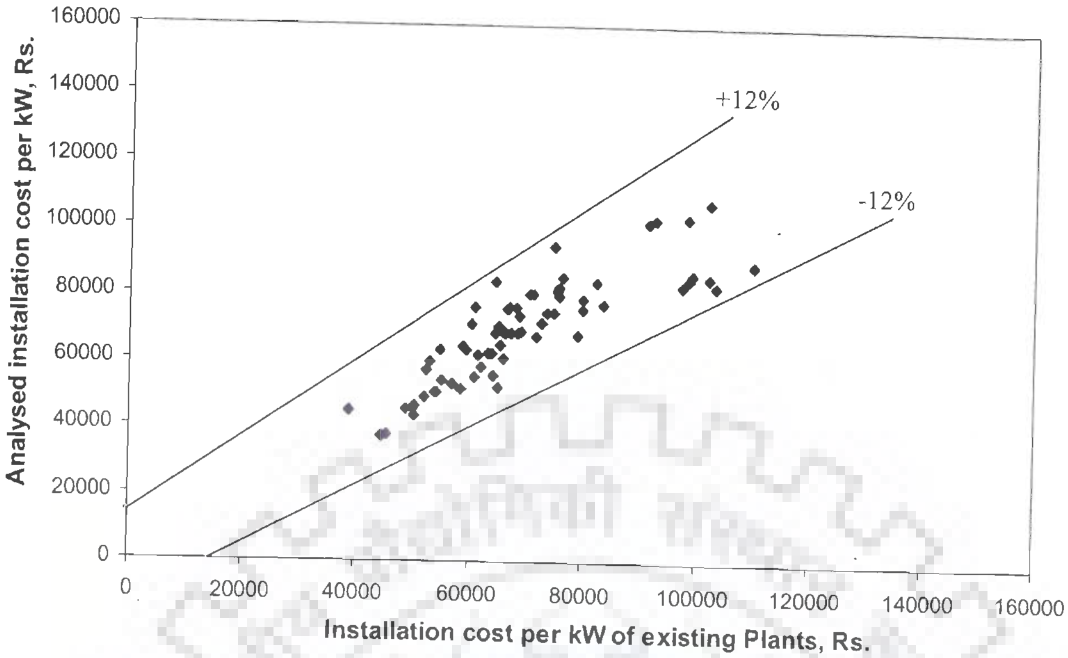


Fig. 5.38 Comparison of total cost per kW as analysed with the cost data collected for the existing for canal based schemes

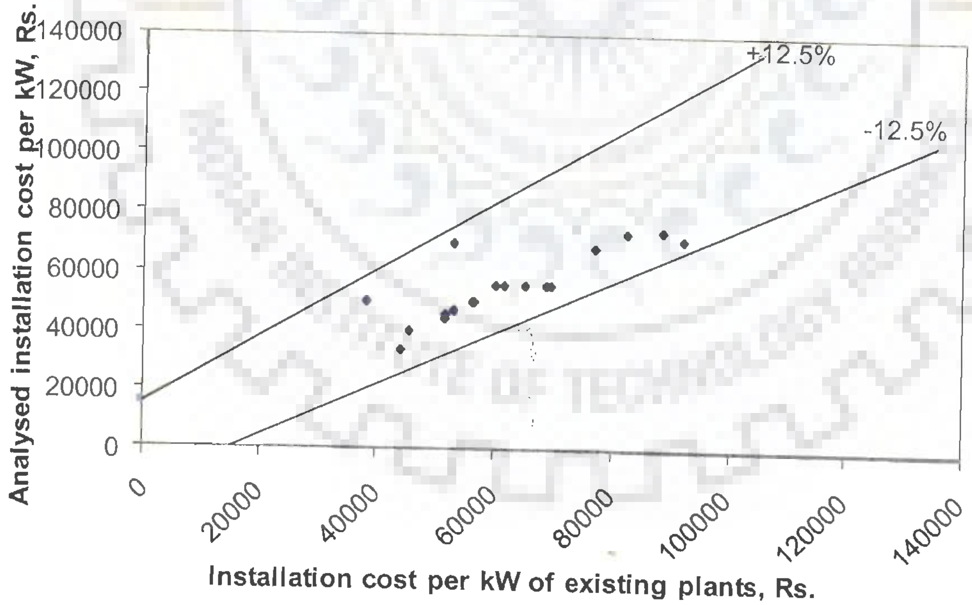


Fig. 5.39 Comparison of total cost per kW as analysed with the cost data collected for the existing run of river schemes

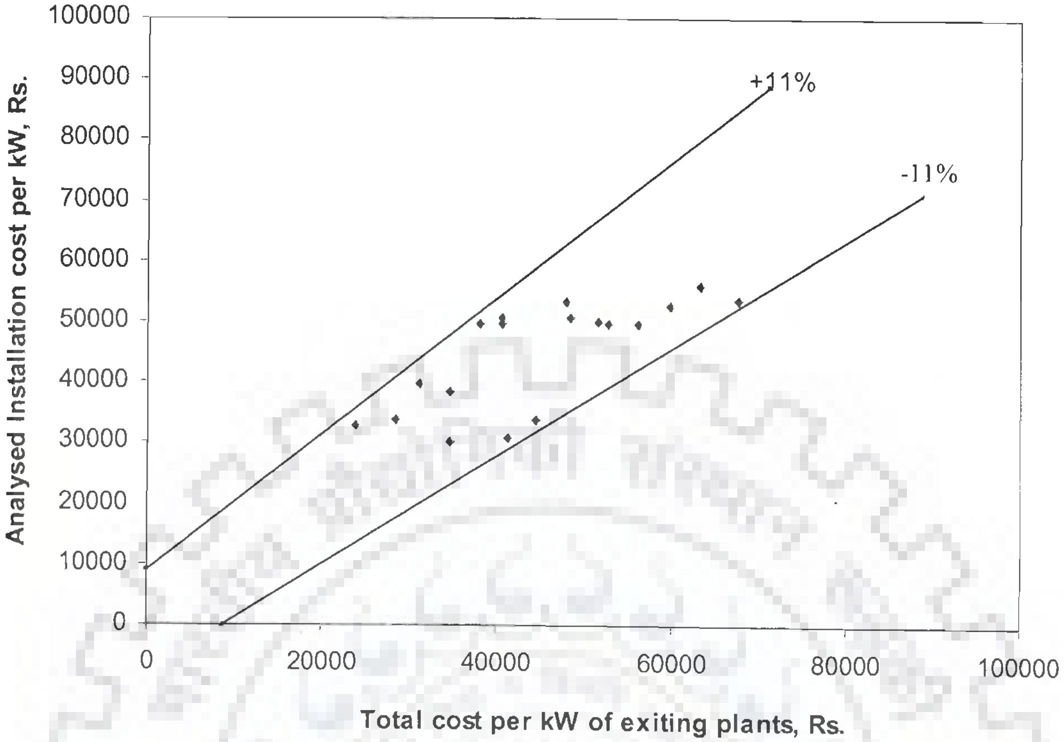


Fig. 5.40 Comparison of total cost per kW as analysed with the cost data collected for the existing dam toe schemes

CHAPTER – 6

ANALYSIS FOR COST OPTIMISATION

6.1 GENERAL

For implementation of SHP projects, alternative solutions are available to meet the same objective. It is therefore, technical as well as financial viability are required to finalize the project layout. Before establishing technical feasibility of a project, financial analysis is carried out to have the best suited techno-economic solution. Study of alternative options is required to be carried out in terms of installation cost (investment), recurring expenditure and the benefits from the SHP scheme. Hence the cost optimization requires review of technical features of the scheme so that resources are used efficiently. The detailed analysis of cost of different type of schemes has been carried out and correlations for cost of various components of different layouts under various SHP schemes have been developed and presented in Chapter-5. Using developed correlations, installation cost of SHP schemes have also been determined and discussed. Based on installation cost, generation cost for various layouts of different SHP schemes are determined and discussed under this Chapter.

In order to determine the optimum cost for layout under different schemes, financial analysis has been carried out. As discussed in earlier Chapters, the costs of the schemes depend significantly with the cost of electromechanical equipment. Further the energy generation cost is found to be affected with the plant load factor. The part load efficiency of the generating unit will depend upon the plant load factor and the values of part load efficiency of different turbines are different. Keeping this in view, type of generating machines i.e. turbines and generators and plant load factors are considered for analysis of cost optimisation. Type of turbines, generators and values of plant load factors considered for different schemes are given in Table-6.1.

Table 6.1 Types of turbines generators and values of plant load factors considered for optimisation

S. No.	Items	Details
1.	Turbine	Tubular propeller
		Vertical propeller
		Bulb propeller
		Tubular semi Kaplan
		Vertical semi Kaplan
		Bulb semi Kaplan
		Tubular Kaplan
		Vertical Kaplan
		Bulb Kaplan
2.	Generator	Synchronous
		Induction
3.	Plant load factor	90%
		80%
		70%
		60%
		50%

6.2 METHODOLOGY

SHP project utilizes funds for its execution and repayments are made as per agreed terms with the lending institutions. Financial feasibility quantifies a project's ability to obtain funds for implementation and repayment of funds on a selfliquidating basis. The methodology adopted to determine the optimum cost of different layouts under different schemes has been evolved and presented as below.

- **Determination of installation cost:** The total cost of schemes under different conditions has been computed and presented in Chapter-5.

- **Determination of generation cost based on annual cost and annual energy :** Considering prevailing annual interest rate, depreciation and operation and maintenance cost, annual cost has been computed for all the cases. Annual energy has been determined based on capacity, plant load factor and part load efficiency of the equipment.

- **Consideration of financial parameters:** The values of financial parameters considered for analysis are given in Table 6.2.

- **Identification of technical parameters for financial analysis for optimisation:** The parameters considered in the study are; types of turbines, types of generators and plant load factor.

- **Selection of financial parameters for analysis:** Financial analysis has been carried out to evaluate various layouts based on installation cost, generation cost, benefit cost (B-C) ratio, net present value (NPV) and financial internal rate of return (FIRR) based on market prices. These financial terms and parameters are discussed in subsequent part of this Chapter.

Table 6.2 Values of parameters considered for financial analysis [156, 157, 158]

S. No.	Parameters	Value
1.	Annual interest rate	11%
2.	Annual depreciation	3.4%
3.	Annual operation and maintenance cost	1.5%
4.	Selling price of electricity	Rs. 2.50 per kWh
6.	Annual escalation on operation and maintenance expenses and electricity prices	4%
6.	Life of plant considered for analysis	25 years
7.	Construction period	2 years
8.	Investment in first year	77%
9.	Investment in second year	23%
10.	Debt equity ratio	70:30

- Financial internal rate of return (FIRR) has been considered as objective function for optimisation and the optimum layout is considered based on maximum FIRR.

6.3 Generation Cost, C_g

Generation cost has been computed for different layouts at different load factors having different type of turbines and generators. It is determined based on annual energy generation and annual cost apportioned fixed cost.

6.3.1 Annual cost, C_a

Annual cost for generation of electrical energy has been determined considering operation and maintenance (O&M) including insurance cost, depreciation of works & equipment and interest on the capital borrowed.

6.3.1.1 Operation and maintenance cost, $C_{o\&m}$

Operation and maintenance (O&M) cost has been considered based on cost of salary/wages of the personnel, labour, insurance, spares and consumables to keep the power plant in operating condition. These costs are taken 1.5% of the project cost and annual escalation has been considered 4% [157, 158].

6.3.1.2 Depreciation, C_d

The civil works and equipment get depreciated over the life of the project. An annual rate of depreciation has been taken based on life of the project. The life of hydro power plant is considered 35 years, accordingly annual depreciation rate is taken as 3.4% [158].

6.3.1.3 Interest, C_i

The prevailing annual interest rate has been considered based on prevailing interest charged by the leading financial institutions for such projects. The rate of interest has been taken 11% for the analysis.

6.3.2 Energy Generation, E

Annual energy has been computed for various cases having different head and capacity based on type of electro-mechanical equipment such as turbine and generator. The annual energy generation is determined by using following expression [20].

$$E = P \times 8760 \times \eta_T \times \eta_g \times P_L \quad (6.1)$$

Where,

E is the energy in kWh

P is the installed capacity in kW

η_T is the efficiency of turbine

η_g is the efficiency of generator

P_L is the plant load factor

Following the methodology discussed above and considering the values of different parameters the generation cost for different schemes are determined and discussed as;

6.3.3 Generation Cost of Canal Based Schemes

Using correlations developed for installation cost and considering annual costs of canal based scheme for different turbines and generators at different plant load factors, generation cost has been determined. Following expressions are used for computing the generation cost;

$$\text{Annual cost, } C_a = C_{o\&m} + C_d + C_i \tag{6.2}$$

$$\text{Generation cost, } C_g = C_a / E \tag{6.3}$$

Where,

$C_{o\&m}$ is operation and maintenance cost

C_d is depreciation cost

C_i is annual interest

E is annual energy

It has been observed that generation cost decreases as the plant capacity increases. It also decreases as the value of head increases. This can be explained by considering a typical layout of the canal based SHP scheme of different capacities having two numbers tubular-semi Kaplan turbines and synchronous generators at different heads of 3 m, 10 m and 20 m. A fixed value of plant load factor as 90 % has been considered as this value of plant load factor is normally considered for a canal based scheme. Fig. 6.1 shows the variation in generation cost with respect to the capacity for different values of head. For this typical layout the maximum value of generation cost as Rs. 1.90 is found for plant capacity of 1000 kW at 3 m head. While the minimum value of generation cost as Rs. 0.82 has been obtained for a plant capacity of about 15000 kW at a head of 20 m. Different values of installation cost, annual energy, annual cost and generation cost for this typical example considered are given in Table 6.3. These values of cost for other cases can also be determined on similar lines.

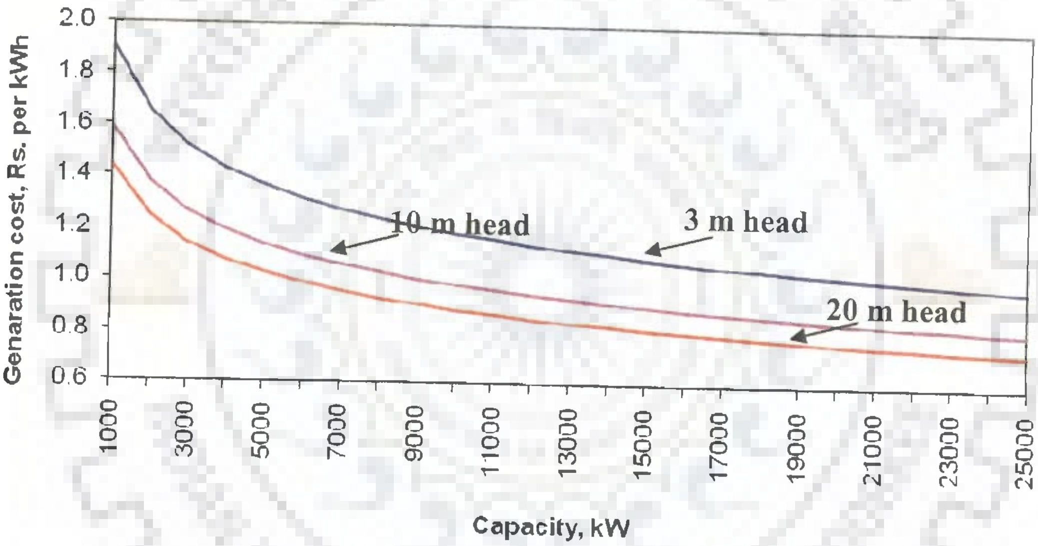


Fig. 6.1 Variation in generation cost with plant capacity for a canal based schemes having two generating units at 90% load factor

Table 6.3 Generation cost of canal based schemes having two generating units at 90% load factor for different capacity and head combinations.

Capacity (kW)	Installation cost per kW (Rs.)			Annual energy (MkWh)	Annual cost (Million Rs.)			Generation cost (Rs. per kWh)		
	3 m head	10 m head	20 m head		3 m head	10 m head	20 m head	3 m head	10 m head	20 m head
1000	81011	67645	61197	6.81	12.96	10.82	9.79	1.90	1.59	1.44
2000	70229	58557	52930	13.62	22.47	18.74	16.94	1.65	1.38	1.24
3000	64609	53825	48629	20.44	31.01	25.84	23.34	1.52	1.26	1.14
4000	60899	50704	45793	27.25	38.98	32.45	29.31	1.43	1.19	1.08
5000	58171	48410	43709	34.06	46.54	38.73	34.97	1.37	1.14	1.03
6000	56033	46614	42078	40.87	53.79	44.75	40.40	1.32	1.09	0.99
7000	54289	45149	40748	47.68	60.80	50.57	45.64	1.28	1.06	0.96
8000	52822	43917	39629	54.49	67.61	56.21	50.73	1.24	1.03	0.93
9000	51561	42858	38669	61.31	74.25	61.72	55.68	1.21	1.01	0.91
10000	50460	41933	37829	68.12	80.74	67.09	60.53	1.19	0.98	0.89
11000	49484	41114	37086	74.93	87.09	72.36	65.27	1.16	0.97	0.87
12000	48609	40381	36421	81.74	93.33	77.53	69.93	1.14	0.95	0.86
13000	47819	39717	35819	88.55	99.46	82.61	74.50	1.12	0.93	0.84
14000	47099	39113	35271	95.36	105.50	87.61	79.01	1.11	0.92	0.83
15000	46438	38559	34768	102.18	111.45	92.54	83.44	1.09	0.91	0.82
16000	45828	38048	34305	108.99	117.32	97.40	87.82	1.08	0.89	0.81
17000	45263	37574	33875	115.80	123.12	102.20	92.14	1.06	0.88	0.80
18000	44737	37133	33475	122.61	128.84	106.94	96.41	1.05	0.87	0.79
19000	44245	36720	33101	129.42	134.50	111.63	100.63	1.04	0.86	0.78
20000	43783	36333	32750	136.24	140.10	116.27	104.80	1.03	0.85	0.77
21000	43348	35969	32419	143.05	145.65	120.85	108.93	1.02	0.84	0.76
22000	42937	35625	32107	149.86	151.14	125.40	113.02	1.01	0.84	0.75
23000	42549	35299	31812	156.67	156.58	129.90	117.07	1.00	0.83	0.75
24000	42180	34990	31532	163.48	161.97	134.36	121.08	0.99	0.82	0.74
25000	41829	34696	31266	170.29	167.32	138.79	125.06	0.98	0.81	0.73

6.3.3.1 Effect of load factor, type of turbine and generator on generation cost

In order to discuss the effect of load factor and type of turbine and generator on generation cost, a typical layout of canal based SHP scheme has been considered and generation cost is determined on similar lines as discussed above. Fig. 6.2 shows the generation cost for different type of turbines, generators at different plant load factors. It is seen from the figure that for 2000 kW plant capacity at 3 m head the generation costs comes out to be as Rs.3.26, Rs.2.62, Rs.2.17, Rs.1.86 and Rs.1.65, at load factor of 50%, 60%, 70%, 80% and 90% respectively for tubular semi Kaplan turbine with synchronous generator. However, for this case the values of these cost come out to be as Rs.3.11, Rs.2.56, Rs.2.17, Rs.1.88 and Rs.1.67 corresponding to the load factors of 50%, 60%, 70%, 80% and 90% respectively for bulb-Kaplan with induction generator. Further it is also seen that at higher load factor i.e. 90 %, layout having tubular turbine with propeller runner coupled with induction generator has minimum generation cost of Rs.1.58. While at load factors of 60%, 70% and 80%, tubular turbine having semi Kaplan runner coupled with induction generator correspond the minimum generation cost of Rs.2.54, 2.10 and 1.80 per kWh respectively. At low load factor i.e. 50%, it is seen that, bulb turbine with Kaplan runner coupled with induction generator gives minimum generation cost of Rs.3.11 per kWh. These values of cost are relative and it is obvious that generation cost is found to be higher at low load factors due to less amount of energy available.

On similar lines the generation cost has been shown for different cases for different load factors in Figs. 6.3 - 6.5. Similar trends in generation cost with respect to different load factors and type of turbines and generators are observed for all the cases.

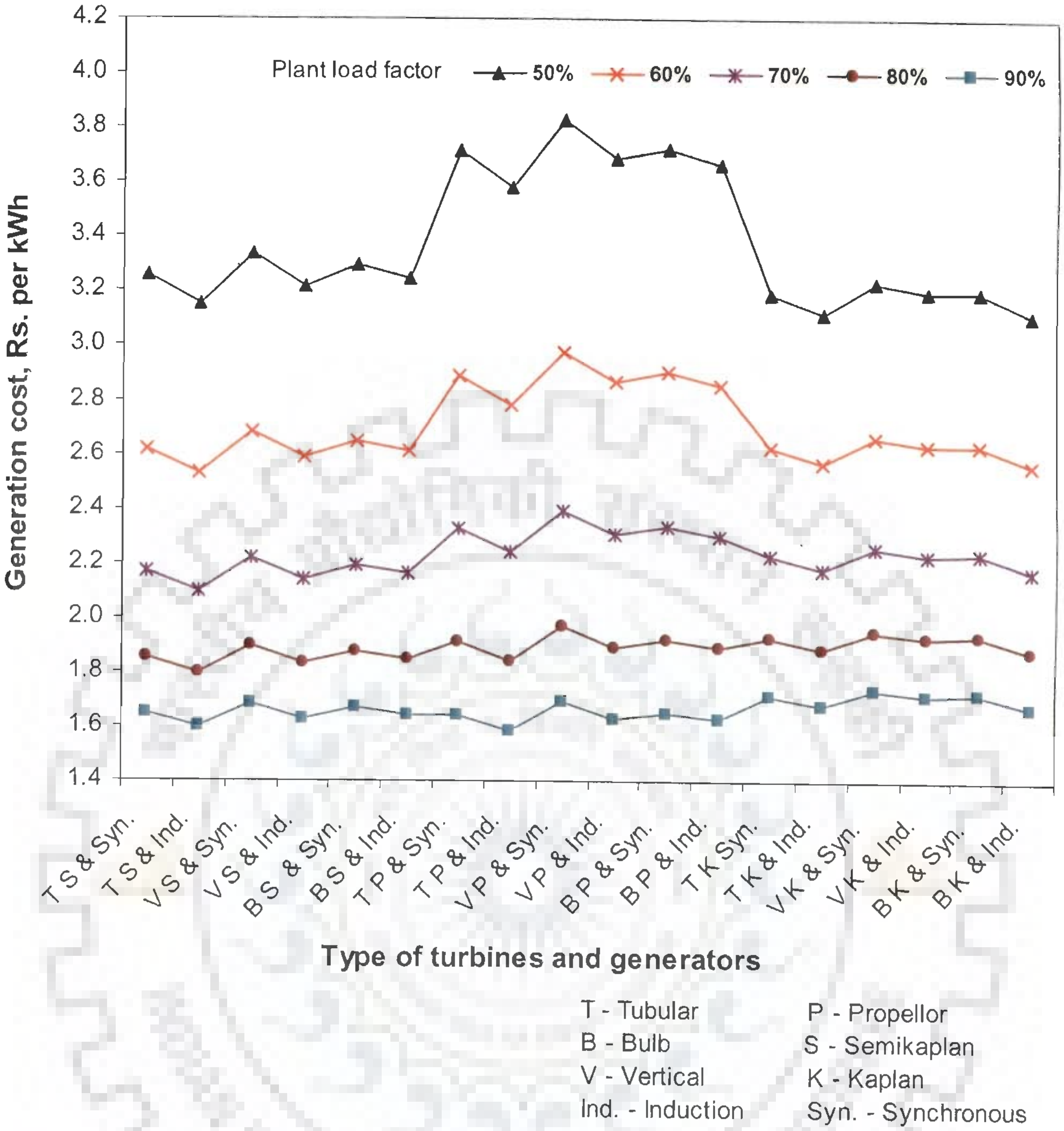


Fig. 6.2 Generation cost for canal based scheme of 2000 kW capacity at 3 m head having different turbines and generators at different load factors

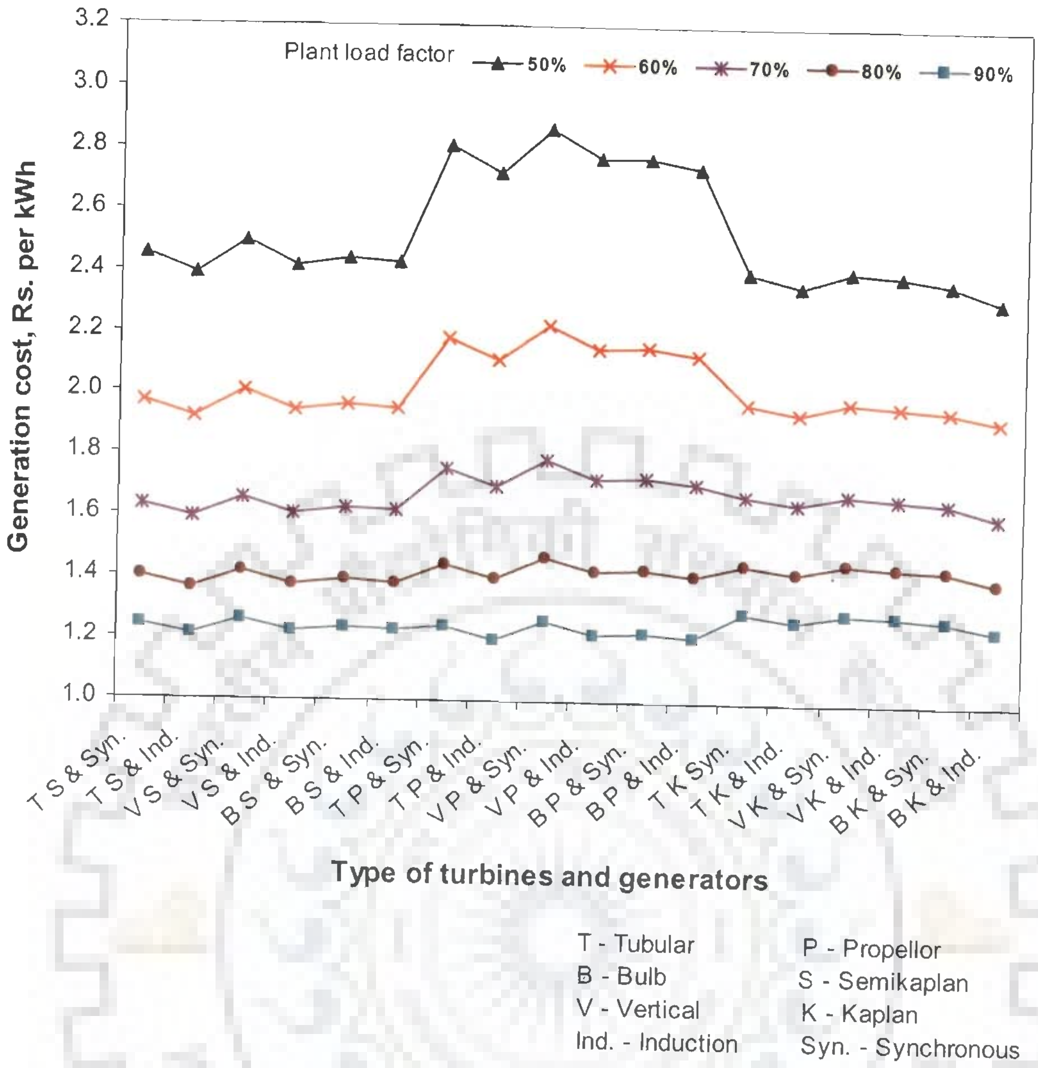


Fig. 6.3 Generation cost for canal based scheme of 2000 kW capacity at 20 m head having different turbines and generators at different load factors

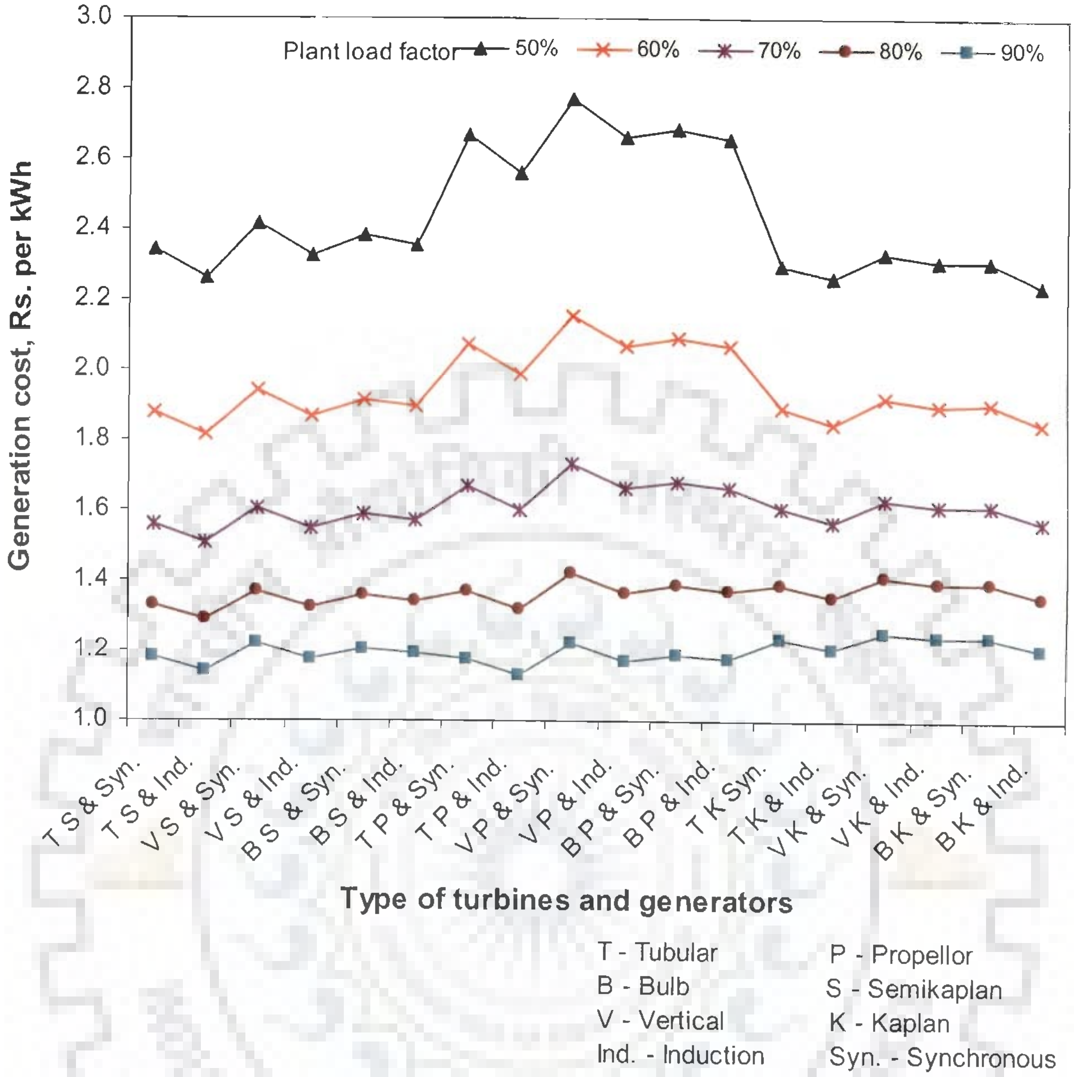


Fig. 6.4 Generation cost for canal based scheme of 10000 kW capacity at 3 m head having different turbines and generators at different load factors

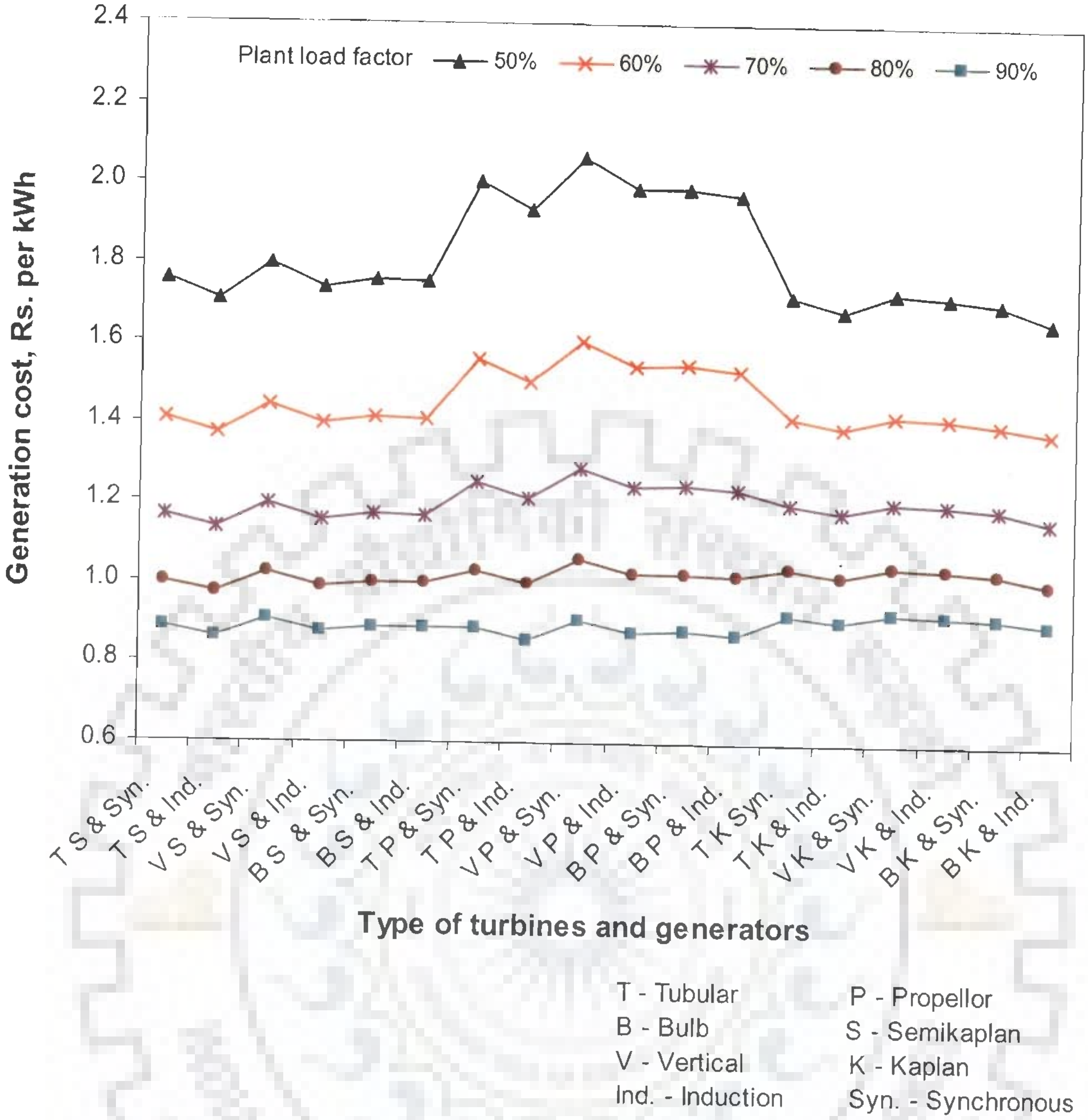


Fig. 6.5 Generation cost for canal based scheme of 10000 kW capacity at 20 m head having different turbines and generators at different load factors

6.3.4 Generation Cost of Run of River Schemes

Based on the methodology discussed above, generation cost has been computed for run of river SHP schemes. For a typical case of run of river scheme having two numbers of tubular-semi Kaplan turbines and synchronous generators for different plant capacity at different heads of 3 m, 10 m, and 20 m, the generation cost is determined at a plant load factor of 90%. Fig. 6.6 shows that the generation cost decreases with increase in head and capacity of the SHP scheme. Similar trend have been observed for run of river scheme also. The values of generation cost vary from Rs. 0.99 per kWh at 20 m head for 10000 kW plant capacity to Rs.1.81 per kWh at 3 m head for 2000 kW capacity. Table 6.4 gives the different values of installation cost, annual energy, annual cost and generation cost for this typical example of run of river scheme. These values of cost for other cases can also be determined on the similar lines as discussed above.

6.3.4.1 Effect of load factor, type of turbine and generator on generation cost

Generation cost has also been determined for run of river SHP scheme layouts having two generating units for different turbines, generators and plant load factors on similar lines. Figs. 6.7-6.10 show the generation cost for plant capacity of 2000 kW and 10000 kW, at different head of 3 m and 20 m head. Fig. 6.7 shows the generation cost for a plant capacity of 2000 kW at 3 m head. It is seen that at higher load factors i.e. 90 %, layout having tubular turbine with propeller runner coupled with induction generator has minimum generation cost of Rs.1.76 per kWh.

At load factors 60%, 70% and 80%, tubular turbine having semi Kaplan runner coupled with induction generator has been found to have the minimum generation cost i.e. Rs.2.80, 2.32 and 1.99 per kWh respectively. At low load factor i.e. 50%, it is found that, bulb turbine with Kaplan runner coupled with induction generator gives minimum generation cost as Rs.3.42 per kWh from Fig. 6.8, 6.9 and

6.10, it is seen that the trend of generation cost is similar for all heads and capacities considered.

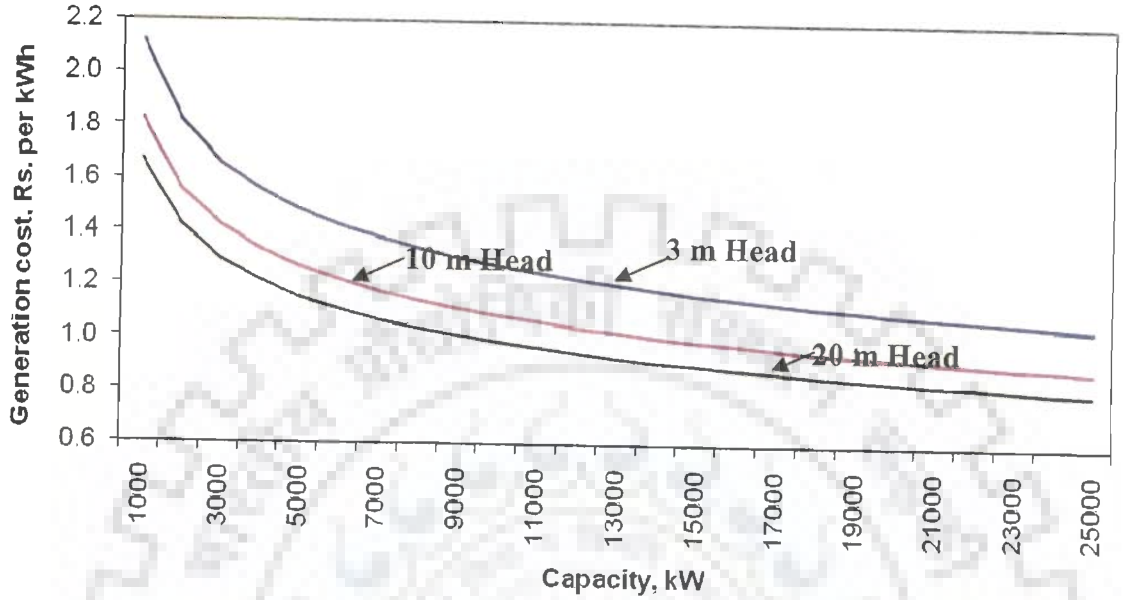
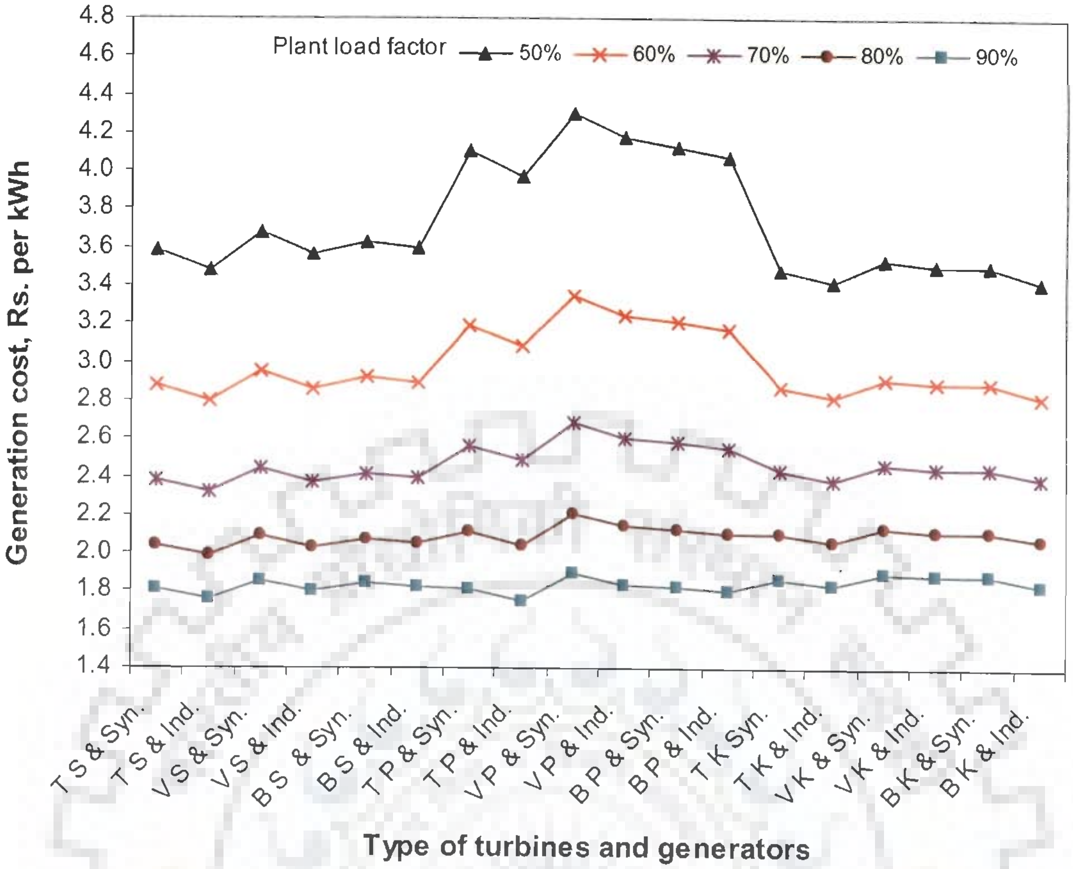


Fig. 6.6 Variation in generation cost with plant capacity for run of river schemes having two generating units at 90% load factor



T - Tubular
B - Bulb
V - Vertical
Ind. - Induction

P - Propellor
S - Semikaplan
K - Kaplan
Syn. - Synchronous

Fig. 6.7 Generation cost for run of river scheme 2000 kW capacity at 3 m head having different turbines and generators at different load factors

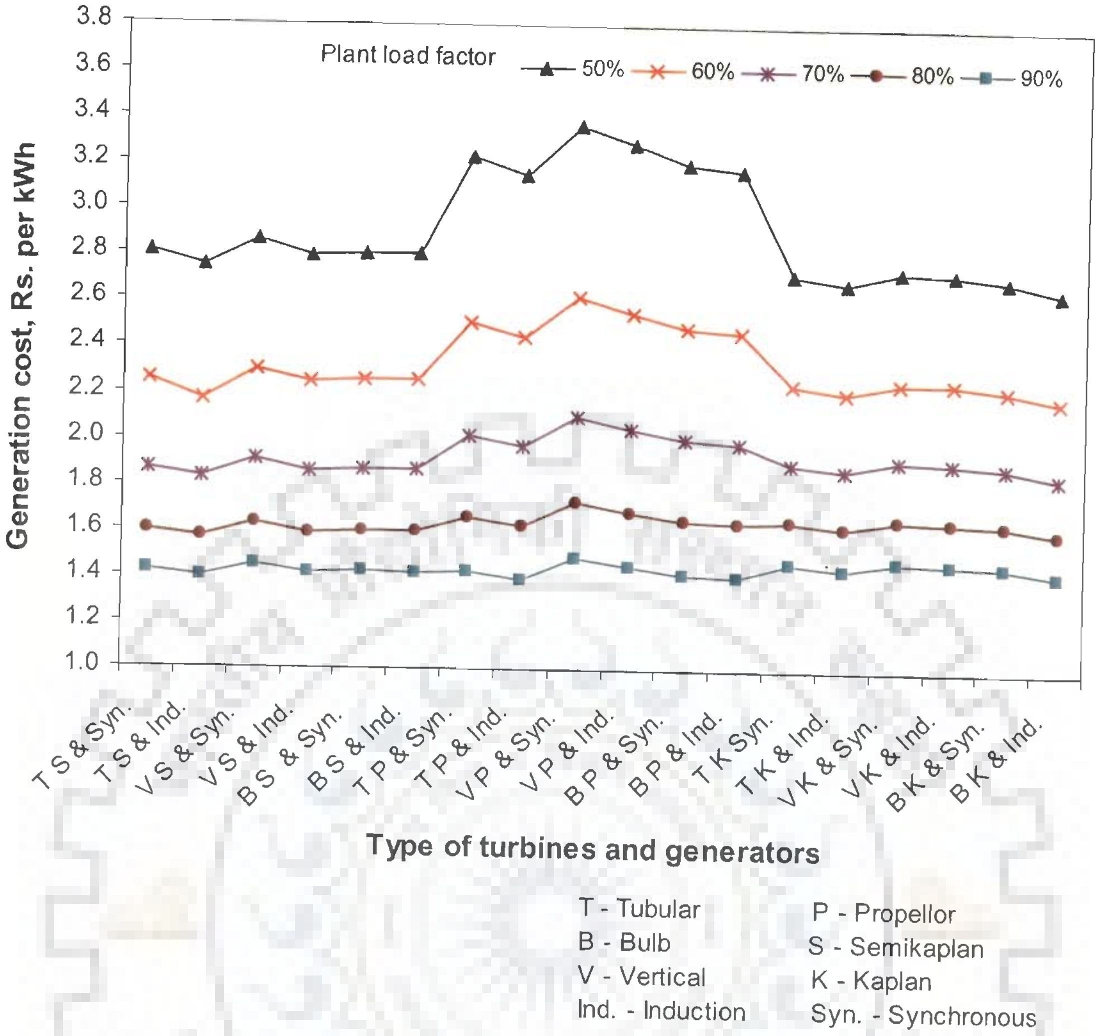


Fig. 6.8 Generation cost for run or river scheme 2000 kW capacity at 20 m head having different turbines and generators at different load factors

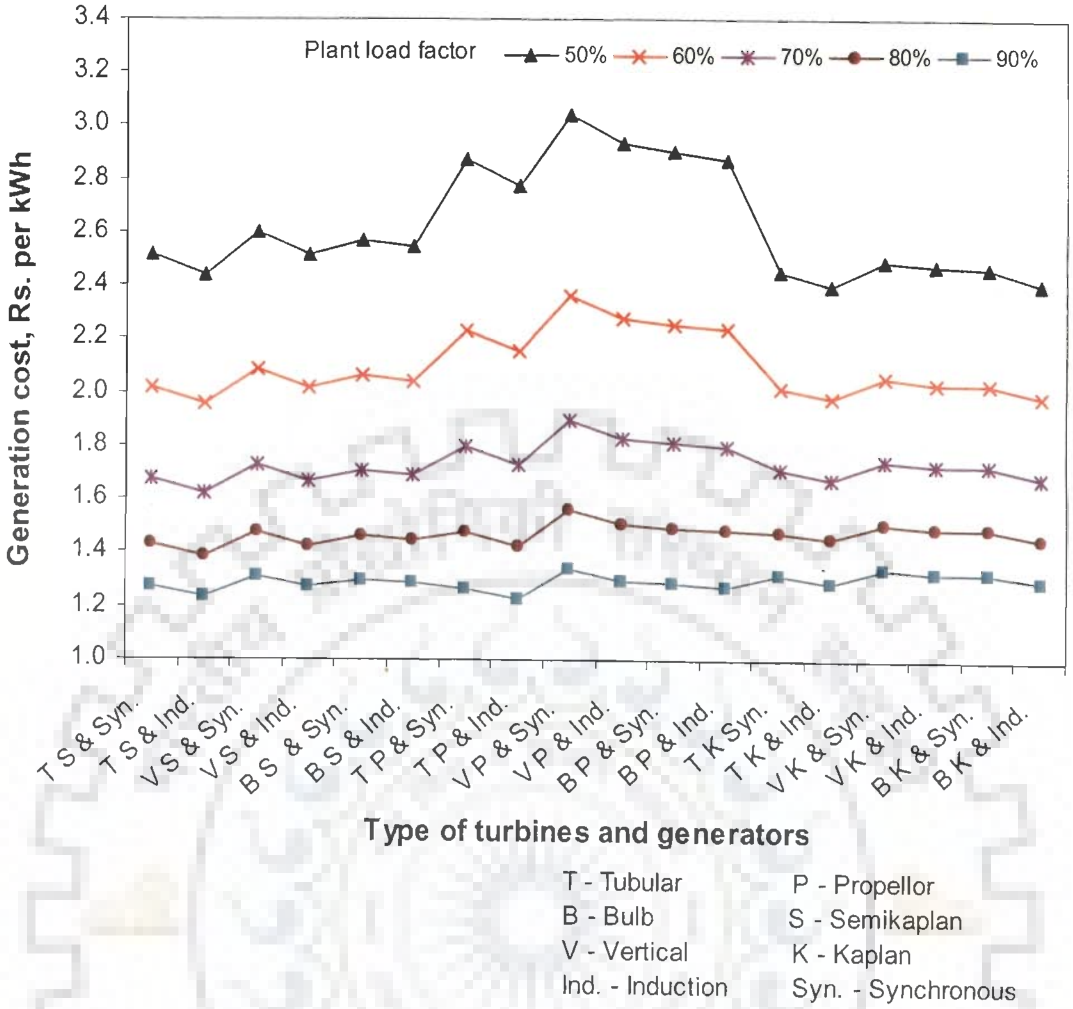


Fig. 6.9 Generation cost for run or river scheme 10000 kW capacity at 3 m head having different turbines and generators at different load factors

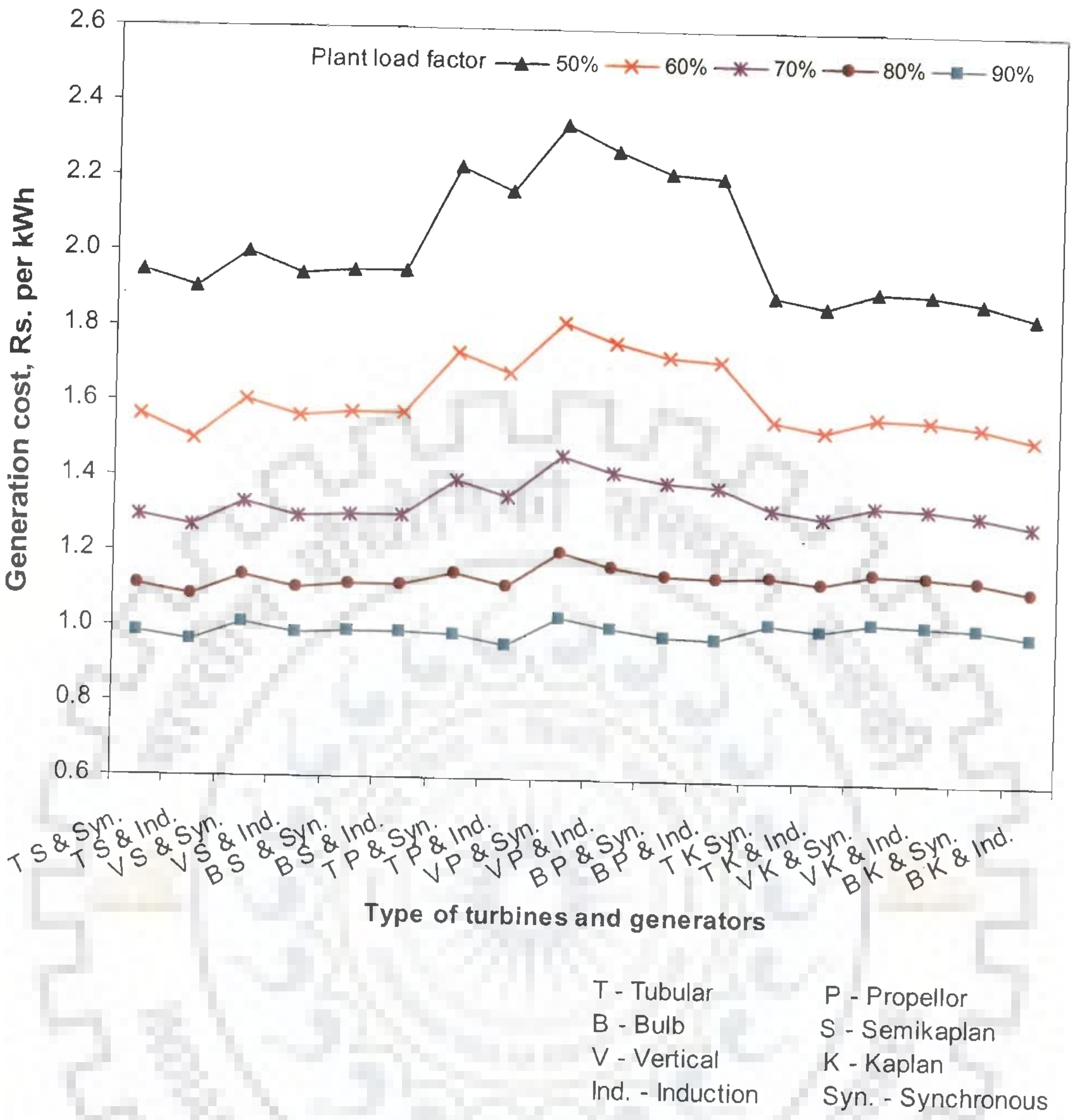


Fig. 6.10 Generation cost for run of river scheme 10000 kW capacity at 20 m head having different turbines and generators at different load factors

Table 6.4 Generation cost of run of river SHP schemes having two generating units at 90% load factor for different capacity and head combinations.

Capacity (kW)	Installation cost per kW (Rs.)			Annual energy (MkWh)	Annual cost (Million Rs.)			Generation cost (Rs. per kWh)		
	3 m head	10 m head	20 m head		3 m head	10 m head	20 m head	3 m head	10 m head	20 m head
1000	90171	77823	71137	6.81	14.43	12.45	11.38	2.12	1.83	1.67
2000	77248	66422	60558	13.62	24.72	21.25	19.38	1.81	1.56	1.42
3000	70613	60590	55161	20.44	33.89	29.08	26.48	1.66	1.42	1.30
4000	66274	56785	51645	27.25	42.42	36.34	33.05	1.56	1.33	1.21
5000	63103	54008	49083	34.06	50.48	43.21	39.27	1.48	1.27	1.15
6000	60631	51847	47090	40.87	58.21	49.77	45.21	1.42	1.22	1.11
7000	58621	50091	45472	47.68	65.66	56.10	50.93	1.38	1.18	1.07
8000	56937	48620	44119	54.49	72.88	62.23	56.47	1.34	1.14	1.04
9000	55494	47362	42960	61.31	79.91	68.20	61.86	1.30	1.11	1.01
10000	54236	46265	41951	68.12	86.78	74.02	67.12	1.27	1.09	0.99
11000	53123	45296	41061	74.93	93.50	79.72	72.27	1.25	1.06	0.96
12000	52129	44430	40265	81.74	100.09	85.31	77.31	1.22	1.04	0.95
13000	51231	43649	39547	88.55	106.56	90.79	82.26	1.20	1.03	0.93
14000	50414	42938	38895	95.36	112.93	96.18	87.12	1.18	1.01	0.91
15000	49666	42288	38298	102.18	119.20	101.49	91.91	1.17	0.99	0.90
16000	48977	41689	37748	108.99	125.38	106.72	96.63	1.15	0.98	0.89
17000	48339	41135	37239	115.80	131.48	111.89	101.29	1.14	0.97	0.87
18000	47746	40619	36766	122.61	137.51	116.98	105.89	1.12	0.95	0.86
19000	47191	40138	36325	129.42	143.46	122.02	110.43	1.11	0.94	0.85
20000	46671	39687	35911	136.24	149.35	127.00	114.91	1.10	0.93	0.84
21000	46183	39262	35522	143.05	155.17	131.92	119.35	1.08	0.92	0.83
22000	45722	38862	35155	149.86	160.94	136.80	123.75	1.07	0.91	0.83
23000	45285	38484	34809	156.67	166.65	141.62	128.10	1.06	0.90	0.82
24000	44872	38126	34480	163.48	172.31	146.40	132.40	1.05	0.90	0.81
25000	44479	37785	34168	170.29	177.92	151.14	136.67	1.04	0.89	0.80

6.3.5 Generation Cost of Dam Toe Schemes

Following the same procedure as discussed for other schemes, generation cost has also been determined for a typical layout of dam toe SHP scheme having two numbers tubular semi Kaplan turbine and synchronous generator for different capacities at 3 m, 10 m and 20 m heads. Plant load has been considered as 90 %. The determined values of generation costs are given in Table 6.5.

Fig. 6.11 shows that the generation cost decreases with the increase in head and capacity of the scheme. The minimum value of generation cost comes out to be as Rs. 0.81 per kWh for a capacity of 10000 kW at 20 m head, while it comes as maximum of Rs.1.52 per kWh for 2000 kW capacity at 3 m head.

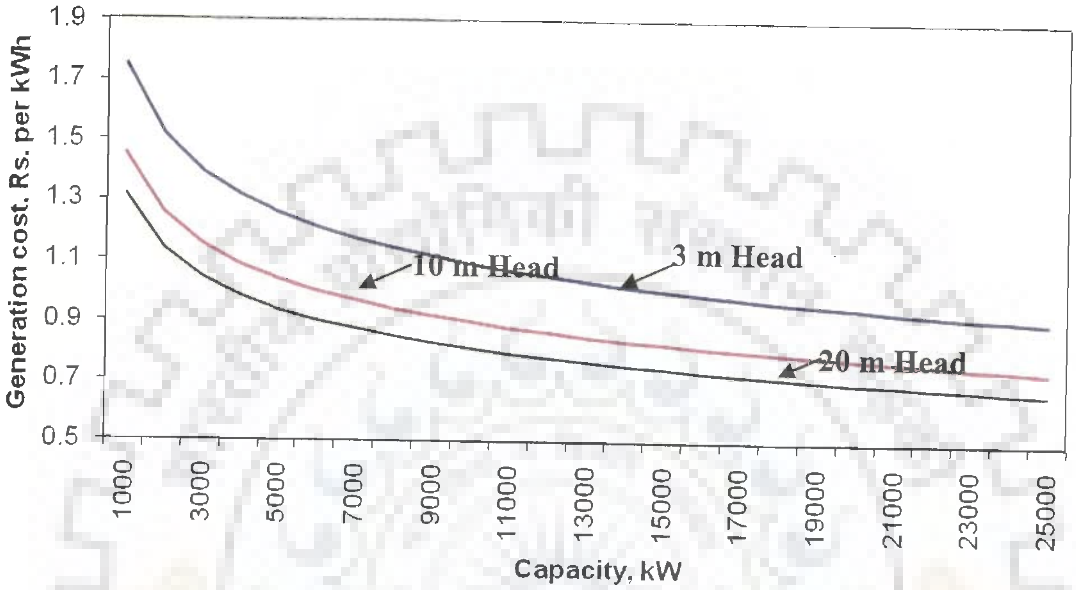


Fig. 6.11 Variation in generation cost with plant capacity for dam toe schemes having two generating units at 90% load factor.

6.3.5.1 Effect of load factor, type of turbine and generator on generation cost for dam toe scheme

Figs.6.12 - 6.15 show the generation cost for plant capacity of 2000 kW and 10000 kW, at different head of 3 m and 20 m head. Fig. 6.12 shows the generation cost for a plant capacity of 2000 kW at 3 m head. It is seen that at higher load factors i.e. 90 %, layout having tubular turbine with propeller runner coupled with induction generator has minimum generation cost of Rs.1.45 per kWh.

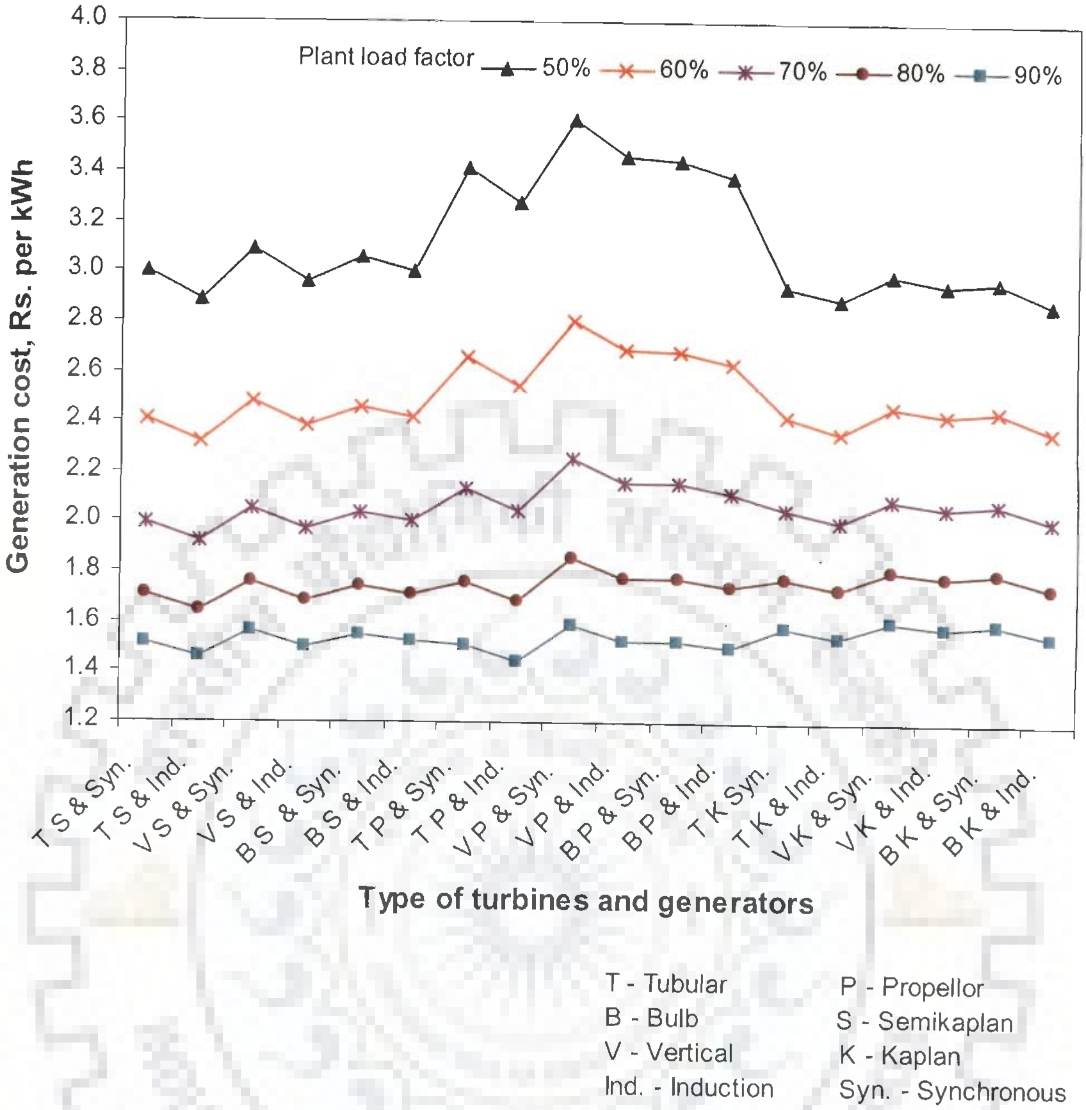


Fig. 6.12 Generation cost for dam toe scheme of 2000 kW capacity at 3 m head having different turbines and generators at different load factors

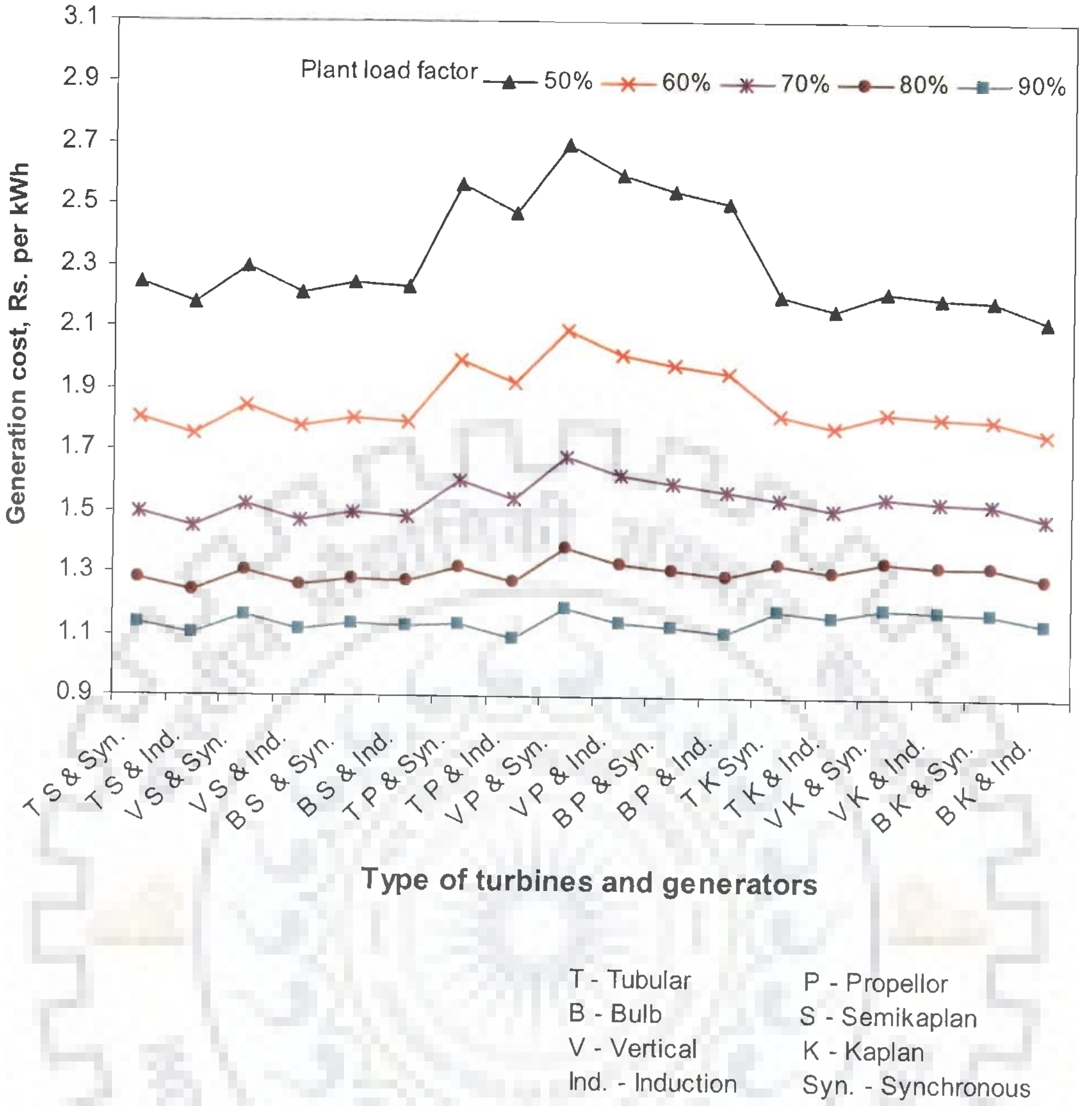


Fig. 6 .13 Generation cost for dam toe scheme of 2000 kW capacity at 20 m head having different turbines and generators at different load factors

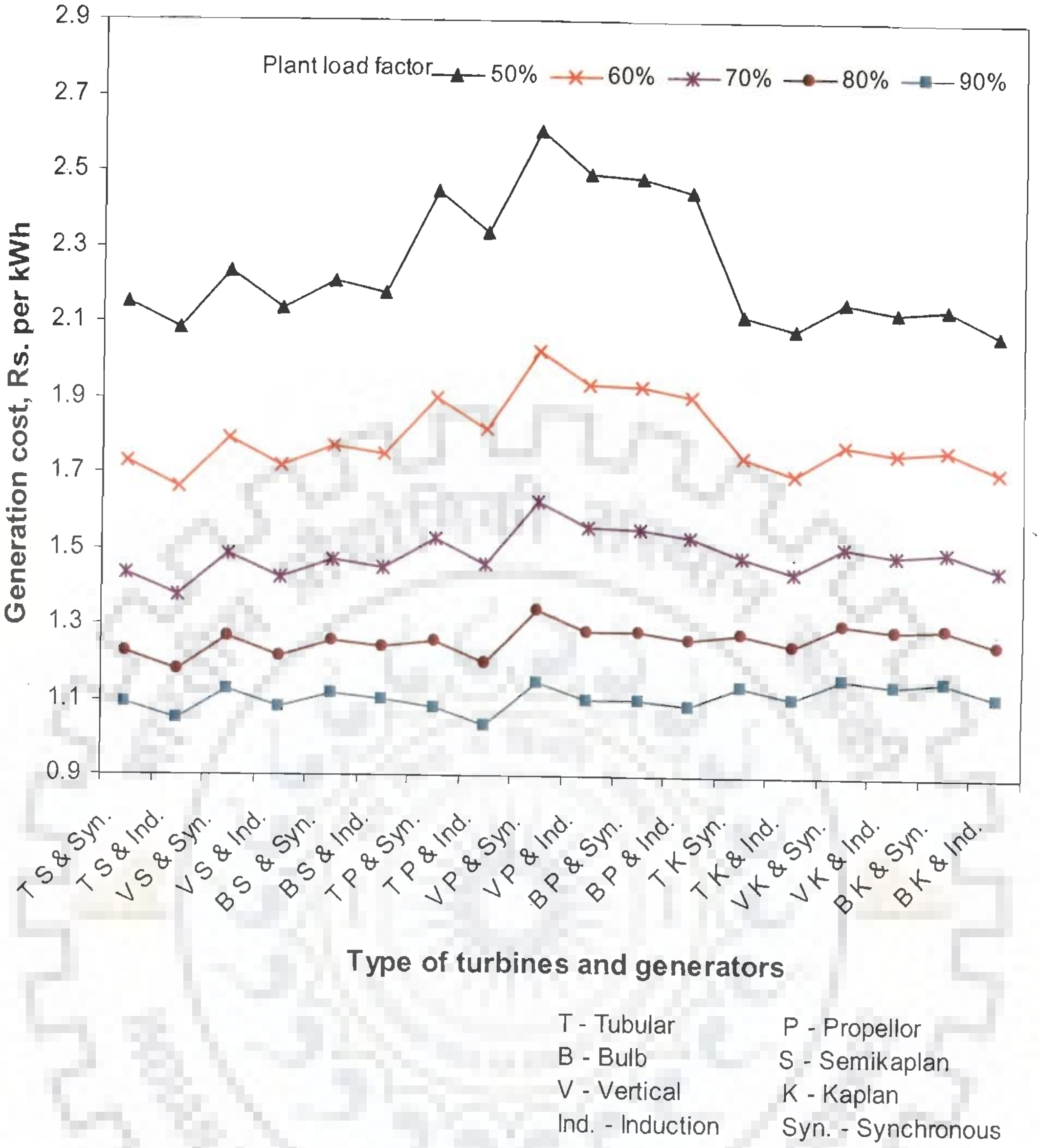
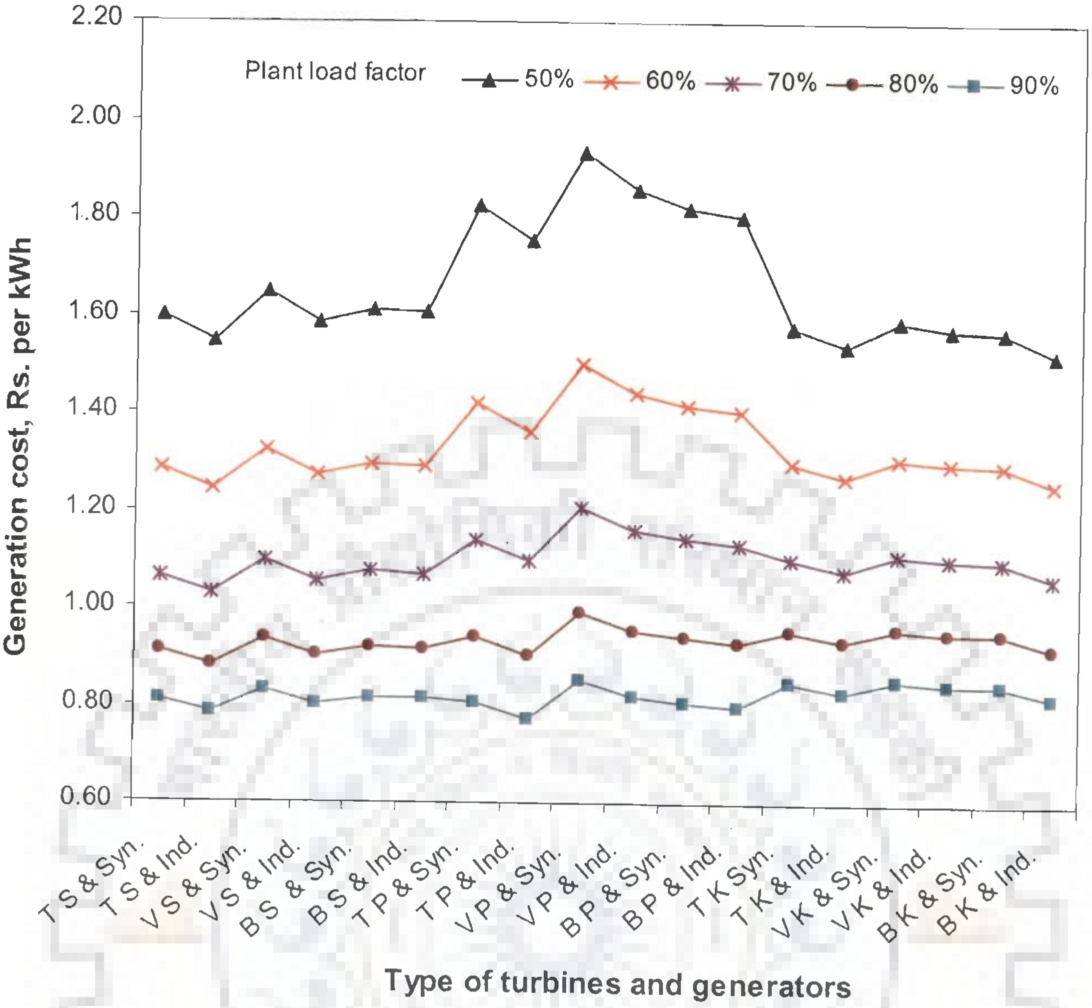


Fig. 6.14 Generation cost for dam toe scheme of 10000 kW capacity at 3 m head having different turbines and generators at different load factors



T - Tubular
B - Bulb
V - Vertical
Ind. - Induction

P - Propellor
S - Semikaplan
K - Kaplan
Syn. - Synchronous

Fig. 6.15 Generation cost for dam toe scheme of 10000 kW at 20 m head having different turbines and generators at different load factors

At load factors 60 %, 70 % and 80%, tubular turbine having semi Kaplan runner coupled with induction generator has been found to have the minimum generation cost i.e. Rs. 2.32 and 1.92 and 1.65 per kWh respectively. At low load factor i.e. 50%, it is found that, bulb turbine with Kaplan runner coupled with induction generator gives minimum generation cost of Rs.2.88 per kWh. It is seen from Figs. 6.13-6.15, it is seen that the trend of generation cost is similar for all heads and capacities considered.

Table 6.5 Generation cost of dam toe SHP schemes having two generating units at 90% load factor for different capacity and head combinations

Capacity (kW)	Installation cost per kW (Rs.)			Annual energy (MkWh)	Annual cost (Million Rs.)			Generation cost (Rs. per kWh)		
	3 m head	10 m head	20 m head		3 m head	10 m head	20 m head	3 m head	10 m head	20 m head
1000	74645	61893	56078	6.81	11.94	9.90	8.97	1.75	1.45	1.32
2000	64652	53505	48394	13.62	20.69	17.12	15.49	1.52	1.26	1.14
3000	59456	49151	44413	20.44	28.54	23.59	21.32	1.40	1.15	1.04
4000	56031	46285	41795	27.25	35.86	29.62	26.75	1.32	1.09	0.98
5000	53515	44181	39874	34.06	42.81	35.34	31.90	1.26	1.04	0.94
6000	51545	42535	38373	40.87	49.48	40.83	36.84	1.21	1.00	0.90
7000	49938	41193	37150	47.68	56.93	46.14	41.61	1.17	0.97	0.87
8000	48587	40065	36122	54.49	62.19	51.28	46.24	1.14	0.94	0.85
9000	47427	39097	35240	61.31	68.29	56.30	50.75	1.11	0.92	0.83
10000	46413	38251	34470	68.12	74.26	61.20	55.15	1.09	0.90	0.81
11000	45515	37502	33788	74.93	80.11	66.00	59.47	1.07	0.88	0.79
12000	44711	36832	33178	81.74	85.84	70.72	63.70	1.05	0.87	0.78
13000	43984	36226	32627	88.55	91.49	75.35	67.86	1.03	0.85	0.77
14000	43322	35674	32125	95.36	97.04	79.91	71.96	1.02	0.84	0.75
15000	42714	35168	31665	102.18	102.51	84.40	76.00	1.00	0.83	0.74
16000	42154	34701	31240	108.99	107.91	88.84	79.98	0.99	0.82	0.73
17000	41635	34269	30847	115.80	113.25	93.21	83.90	0.98	0.80	0.72
18000	41151	33866	30481	122.61	118.51	97.53	87.79	0.97	0.80	0.72
19000	40699	33489	30139	129.42	123.72	101.81	91.62	0.96	0.79	0.71
20000	40274	33136	29818	136.24	128.88	106.04	96.42	0.95	0.78	0.70
21000	39875	32804	29516	143.05	133.98	110.22	99.17	0.94	0.77	0.69
22000	39498	32490	29231	149.86	139.03	114.36	102.89	0.93	0.76	0.69
23000	39141	32193	28961	156.67	144.04	118.47	106.58	0.92	0.76	0.68
24000	38802	31911	28705	163.48	149.00	122.54	110.23	0.91	0.75	0.67
25000	38481	31643	28462	170.29	153.92	126.57	113.85	0.90	0.74	0.67

6.4 ECONOMIC AND FINANCIAL ANALYSIS

Prior to the year 1991, small hydro power projects in India were developed in government sector only as government departments were the licencee to generate, transmit and distribute electrical energy. Besides, in case of government owned projects all the investments to establish the project were made available/ invested by the government as grant in aid and no repayment of capital was required. The concern was to evaluate economic viability of the project. From the year 1991 onwards, power generation was opened to private sector as well and government departments were streamlined as companies. Since it has become commercial sector and repayment of investments is of prime concern, therefore financial analysis has been attempted to evaluate the scheme for evolving optimum solution. In this context, financial analysis has been carried out in this Chapter to evaluate various layouts.

An important part of establishing financial feasibility is the anticipated borrowing cost. The cost of capital is the return expected by potential investors and other market and economic costs. The costs are the sum of the real interest rate that compensates the lender for surrendering the use of funds, the purchasing power, risk premium that compensates for expected inflation, the business and financial risk and the marketability risk associated with low-liquidity of long-term debt. A financially feasible SHP project, where necessary funds are available to pay for it through sale of electricity generated does not mean that the project is best of all the available alternatives or that the proposed execution is appropriate. Besides, a economically feasible project cannot be financed. Also, the debt limit of an agency or organisation's jurisdiction can prohibit borrowing of additional funds to finance a project.

Financial analysis includes cost on operation and maintenance, administration and replacement. The amounts of these are estimated at the time of making an economic assessment of the project. Dependent upon the owner's practices, other items included, such as insurance, taxes etc. Any of the foregoing cost can be assumed in the analysis to be constant or escalated to include effects of inflation.

Each cost included in the annual cost analysis is regarded to be either a constant value for the life of the project or treated as an equivalent uniform annual cost by using of uniform series of annual payments reflecting the life of the project and the cost of money. If the owner finances the project from internal funds, then the annual cost is based on a required rate of return rather than the interest rate of borrowed money.

The extent to which developer must bear the burden of project repayment affects the beneficiaries benefits and costs. If the beneficiaries are required to repay a very little of the project costs, they have an incentive and may like the project, even if the project may not pass the test of economic feasibility. Thus, financial incentives put hindrance in planning from the overall view point when those benefitting are required to pay so little of the costs.

Funds for financing the initial construction of public sector (government) projects are appropriated from the general budget which ultimately come from tax revenues or borrowing. This ends up with the increase in the national debt. Government cost sharing practice divides the burden of this cost between the beneficiaries. However, the part of the funds required to be repaid by the beneficiaries depends on the agency constructing the project and the type of the benefits received. But the repayment needs allocation of the total project cost among different project purposes and setting specific charges from allocated costs. An investor-owned project is financed partly by own equity and partly by the borrowed money which is related to the financial strength of the firm.

In both economic and financial analysis, recurring annual costs and revenues are of primary concern. However, some other costs and benefits like recreational benefits available to the population because of the impoundment which may not yield revenue to the project are considered in the economic analysis but not in the financial analysis. Financial analysis is different than economic analysis in many ways. In financial analysis net returns are considered to the equity capital while in case of economic analysis, net return are to the society. In financial analysis prices are considered as market or administered prices and subsidies are considered as source of revenue. In economic analysis, prices are considered as shadow prices and subsidies are considered as society benefits. In financial analysis loans are considered as increased capital resources and interest or repayments are considered as financial cost. In economic analysis loan and interest or repayment are considered as transfer payment. Discount rate on future receipt/ expenditure is considered in both the cases for evaluation of the project [27, 159].

6.5 PARAMETERS/CONDITIONS CONSIDERED FOR COST OPTIMISATION

The layouts of SHP schemes have been evaluated for cost optimization, considering type of turbines, type of generators and plant load factor. The selection criteria and type of turbines and generators considered under low head range has been discussed in Chapter-4. The efficiency of different turbines and generators are different as discussed in Chapter-3, which affect the energy generation. At part load the values of efficiency of different turbines are different thereby affecting the energy generation.

6.6 FINANCIAL ANALYSIS FOR OPTIMISATION

Financial analysis has been carried out to evaluate various layouts based on installation cost, generation cost; benefits cost (B-C) ratio, net present value (NPV) and internal financial rate of return (FIRR). The project is evaluated for optimisation by adopting the following criteria:

(i) Installation cost is minimum

(ii) Generation cost is minimum

(iii) B-C ratio is maximum

(iv) NPV is maximum

(v) FIRR is maximum (with an insight in to opportunity cost)

6.6.1 Installation Cost

Based on the correlations developed for cost of components under different type of SHP schemes, the installation cost has been determined as detailed in Chapter-5.

6.6.2 Generation Cost

Keeping in view the installation cost, annual cost and annual energy of different SHP schemes under different conditions the generation cost has been determined and presented under the present Chapter.

6.6.3 Benefit-Cost Ratio

The benefit-cost (B-C) ratio has been determined as the ratio of the present value of future cash flows (benefits) to the present value of the original and subsequent costs based on installation cost, annual cost, annual energy, and selling price of the electricity. This ratio has been computed as follows [27] :

$$\text{Benefit-cost ratio (B-C ratio)} = \frac{\text{Present value of benefits}}{\text{Present value of expenditure}} \tag{6.4}$$

6.6.3.1 Discount rate

Discount rate signifies the time value of money and is the cost of the capital investment. Discount rate is also the opportunity cost of the capital. The source of capital is the equity and the loan. The equity and debt (loan) ratio has been considered as 30:70 based on the guidelines for financing by leading financial institutions. In the public sector investments, the discount rate is the cost of borrowing in the bond market or from other financing institutions. The Government fixes the discount rates either by law or by notifications for the projects being funded by them. For investments by private sector, the usual practice of fixing discount rates is based on weighted average cost of capital. In the present exercise the discount rate has been taken 11% as prevailing.

6.6.3.2 Selling price of electricity

Project with B-C ratio of less than one is considered as economically infeasible. There are two types of benefits from small hydro power projects. (i) Tangible benefits (ii) Intangible benefits. The tangible benefit is the sale of electrical energy generated. In India different states have different rates i.e. tariff for electricity varying from Rs. 1.75 to Rs. 3.00 per kWh. However, an average value of Rs. 2.50 per kWh which is also prevailing rate in many states is considered for the analysis and annual escalation has been adopted at 4%. The intangible benefits are the positive environmental effects, recreation opportunities due to development in water bodies, social upliftment due to development activities and infrastructure development. The intangible benefits are qualitative in nature and hence not quantified in the analysis and considered beyond the scope of the present study.

6.6.3.3 Present value of benefits

For arriving at consistent values for both benefits and costs so that they can be compared, the present value criterion is adopted. The present value has been determined at the time of first expenditure of the future stream of benefits based on a fixed value of discount rate considered as 11% in the present study.

The present value (PV) of a project has been computed by adopting the formula given below [27]:

$$\mathrm{PV} = \sum_{i=1}^{n}\left[\frac{CF_i}{(1+d)^i}\right]+\left[\frac{S_n}{(1+d)^n}\right] \tag{6.5}$$

Where,

PV	is present value
CF_i	is Cash flow in year i starting with initial investment
S_n	is Salvage value
d	is discount rate
n	is number of years of the schemes / projects

The life of small hydro power plant is generally 35 years, while it has been considered that after 25 years major replacement of equipment and renovation of works due to wear is required which has more annual cost in that particular year due to this and energy will not be available during renovation period of the unit and associated works. Thus present value of benefits has been determined for 25 years after the plant puts in to operation.

6.6.3.4 Present value of expenditure

The construction / implementation period is considered 2 years as it has been found that such plants were installed even in less than 2 years in the recent past, however exceptions are there. The installation cost has been divided as 77% in I year and 23% in II year [156]. Present value of expenditure has been determined by apportioning installation cost in 2 years and considering annual cost in subsequent 25 years after plant starts generating electricity in the similar manner as present value of benefits is determined.

6.6.4 Net Present Value (NPV)

Net present value (NPV) has been calculated as the difference of present value of benefits and present value of expenditure. NPV has been computed for various layouts under different types of schemes considered for analysis.

6.6.5 Financial Internal Rate of Return

For a project to be feasible, the anticipated project receipts must exceed the project disbursements, funds must be available, and the project must be able to service the debt. An important part of establishing financial feasibility is the anticipated borrowing cost. The cost of capital is the return expected by potential investors and other market and economic costs. In view of these facts, the financial feasibility with emphasis on internal financial rate of return has been attempted.

Financial Internal rate of return (FIRR) is the discount rate at which present value of benefits becomes equal to the present value of expenditure. FIRR has been determined for 25 years after the plant puts in to operation. If the financial internal rate of return determined is less than the interest rate (or in other words, cost of funding) for the project, the project is not considered financially feasible.

6.6.6 Optimisation Analysis

Optimisation is the process of obtaining best result under given circumstances. The ultimate goal is to minimize the investment/efforts to maximize the desired benefit. Optimization is also defined as the process of finding the conditions that give maximum or minimum valve of variable responsible for decision. The optimisation problem is defined as follows;

Objective function;

$$Z = f(z_1, z_2, z_3, z_4, z_5, z_6) \qquad (6.6)$$

Subject to;

$$A \leq z_1 \leq B$$

$$C \leq z_2 \leq D$$

$$z_1, z_2, z_3, z_4, z_5, z_6 \geq 0$$

Where,

z_1 is efficiency of turbine (Values of A and B are 0.69 and 0.93 respectively)

z_2 is efficiency of generator(Values of C and D are 0.94 and 0.96 respectively)

z_3 is annual energy

z_4 is annual cost

z_5 is installation cost

z_6 is selling price of electricity (Rs.2.50 per kWh)

The above stated problem for single load factor, head and capacity of a given scheme has been optimized for maximum value of objective function considering different type of turbines and generators. Objective function Z i.e. FIRR, has been determined by an iterative technique using Microsoft Excel software.

Financial analysis has been carried out to determine the optimum layout under different type of schemes based on type of turbines, type of generators and plant load factor. Different layouts were evaluated for cost optimisation based on installation cost, generation cost, benefits cost (B-C) ratio, net present value (NPV) and financial internal rate of return (FIRR).

6.6.7 Optimum Layouts for Canal Based SHP Schemes

In view of the methodology discussed above, financial analysis has been carried out for the canal based SHP schemes for layouts under ordinary soil condition where power house is in the diversion channel and spillway in the main canal, having two numbers different type of turbines and generators at different load factors. In the financial analysis, determined values of the B-C ratio, NPV and financial parameter FIRR for the layouts considered for plant capacity of 2000 kW at 3 m head and at 90% load factor are given in Table 6.6. The values of B-C ratio, NPV and financial parameter FIRR have also been determined on the similar lines at other load factors. Figs. 6.16-6.18 show the values of these parameters at different load factors.

It is seen from the figures that in case of canal based layout of plant capacity of 2000 kW at 3 m head, where power house is in the diversion channel and spillway in the main channel, tubular turbine with propeller runner coupled with induction generator is found to be optimum layout as it has minimum installation cost i.e. Rs. 64,510 per kW as well as generation cost of Rs.1.58 per kWh, maximum B-C ratio (1.32), maximum NPV (74.38 Million Rs.) and maximum FIRR (16.56%) at 90% load factor.

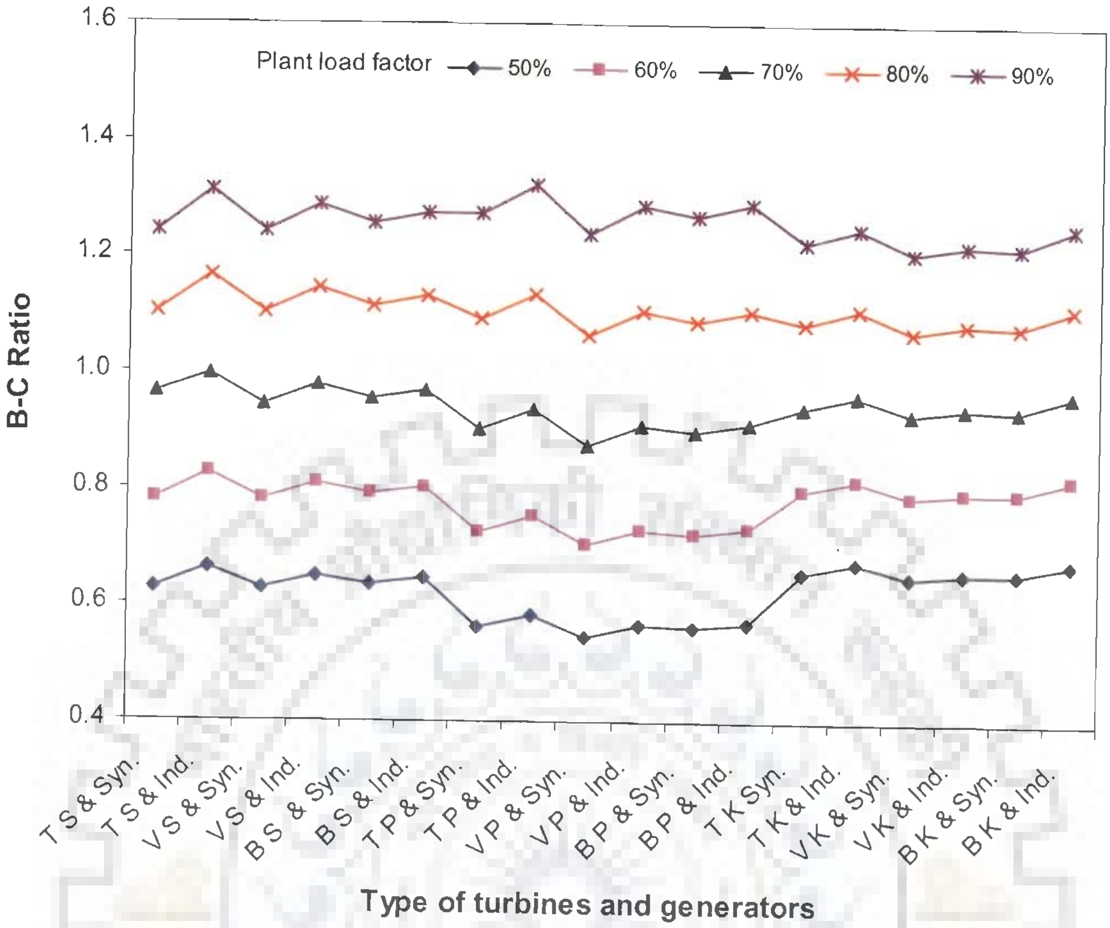
It is also found that these financial parameters follow the same trend for the optimum layout i.e. minimum installation cost, minimum generation cost, maximum B-C ratio, maximum NPV and maximum FIRR values. Further, international financial institutions (World Bank, Asian development bank) evaluate development projects based on FIRR. Thus FIRR has been considered as financial parameter to determine the optimum layout.

Fig. 6.18 shows that at load factor 50%, bulb turbine with Kaplan runner coupled with induction generator is the optimum layout as it has maximum FIRR (3.8%). At load factors of 60%, 70% and 80%, tubular turbine having semi Kaplan runner coupled with induction generator give the maximum FIRR values as 7.5%, 11% and 14% respectively and considered as optimum. Canal based SHP scheme having tubular turbine with propeller runner coupled with induction generator is found to be optimum at higher load factor i.e. 90% as this layout has maximum FIRR value of 16.6%.

Table 6.6 Financial parameters determined for canal based SHP schemes having 2000 kW capacity at 3 m head and 90% load factor.

Type of turbine	Type of generator	Installation cost (Rs.)	Generation cost (Rs per kWh)	B-C ratio	NPV (million Rs.)	FIRR (%)
Tubular SemiKaplan	Synchronous	70229	1.65	1.24	60.94	15.26
Tubular SemiKaplan	Induction	66567	1.60	1.31	73.97	16.37
Vertical Semikaplan	Synchronous	71071	1.69	1.24	61.03	15.22
Vertical Semikaplan	Induction	67102	1.63	1.29	68.61	15.97
Bulb Semikaplan	Synchronous	71853	1.67	1.26	65.30	15.45
Bulb Semikaplan	Induction	69355	1.65	1.27	67.50	15.75
Tubular Propellor	Synchronous	68410	1.64	1.28	66.97	15.77
Tubular Propellor	Induction	64510	1.58	1.32	74.38	16.56
Vertical Propellor	Synchronous	69497	1.69	1.24	59.58	15.21
Vertical Propellor	Induction	65504	1.63	1.29	67.39	16.00
Bulb Propellor	Synchronous	69499	1.65	1.27	66.62	15.68
Bulb Propellor	Induction	66984	1.62	1.29	69.03	16.01
Tubular Kaplan	Synchronous	74515	1.71	1.22	59.36	14.93
Tubular Kaplan	Induction	71375	1.67	1.25	63.77	15.38
Vertical Kaplan	Synchronous	74660	1.73	1.21	55.32	14.67
Vertical Kaplan	Induction	72295	1.72	1.22	57.04	14.90
Bulb Kaplan	Synchronous	75622	1.72	1.22	58.94	14.85
Bulb Kaplan	Induction	71944	1.67	1.25	65.20	15.44

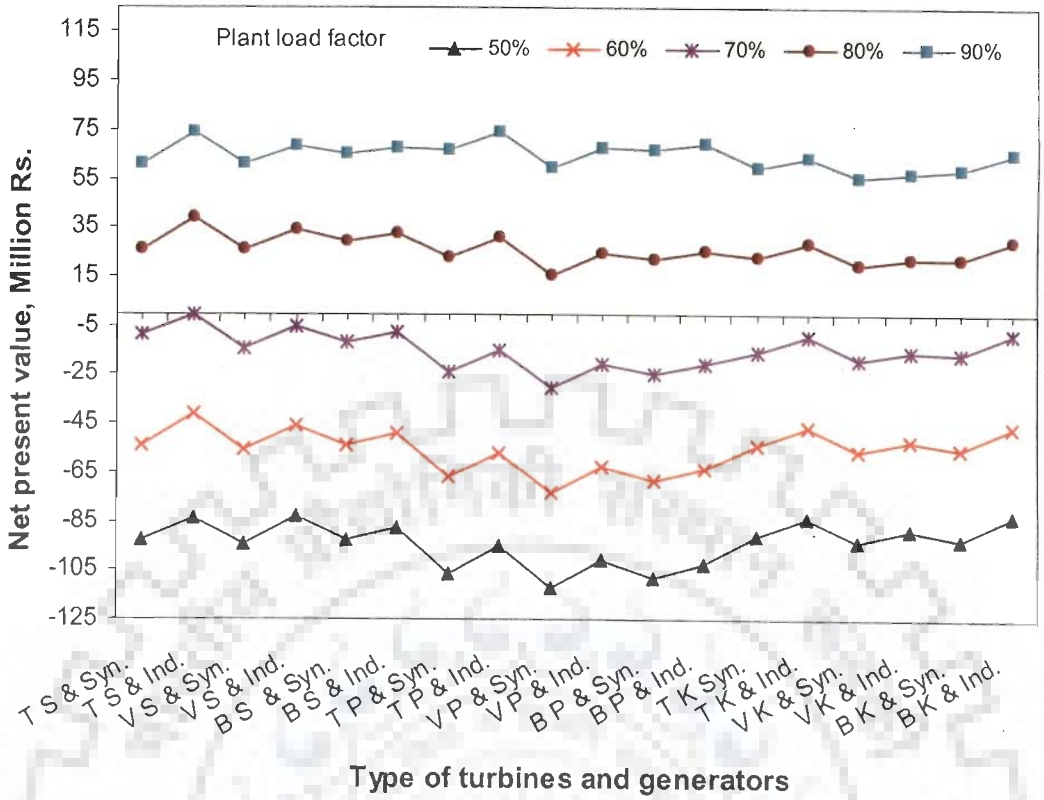
Values of FIRR have also been determined for layouts considered at different combinations of head and capacity i.e. 3 m head and 10000 kW, 20 m head and 2000 kW and 20 m head and 10000 kW.



T - Tubular
B - Bulb
V - Vertical
Ind. - Induction

P - Propellor
S - Semikaplan
K - Kaplan
Syn. - Synchronous

Fig. 6.16 Benefit cost ratio for canal based scheme of 2000 kW capacity at 3 m head having different turbines and generators at different load factors



T - Tubular
B - Bulb
V - Vertical
Ind. - Induction

P - Propellor
S - Semikaplan
K - Kaplan
Syn. - Synchronous

Fig. 6.17 Net present value for canal based scheme of 2000 kW capacity at 3 m head having different turbines and generators at different load factors

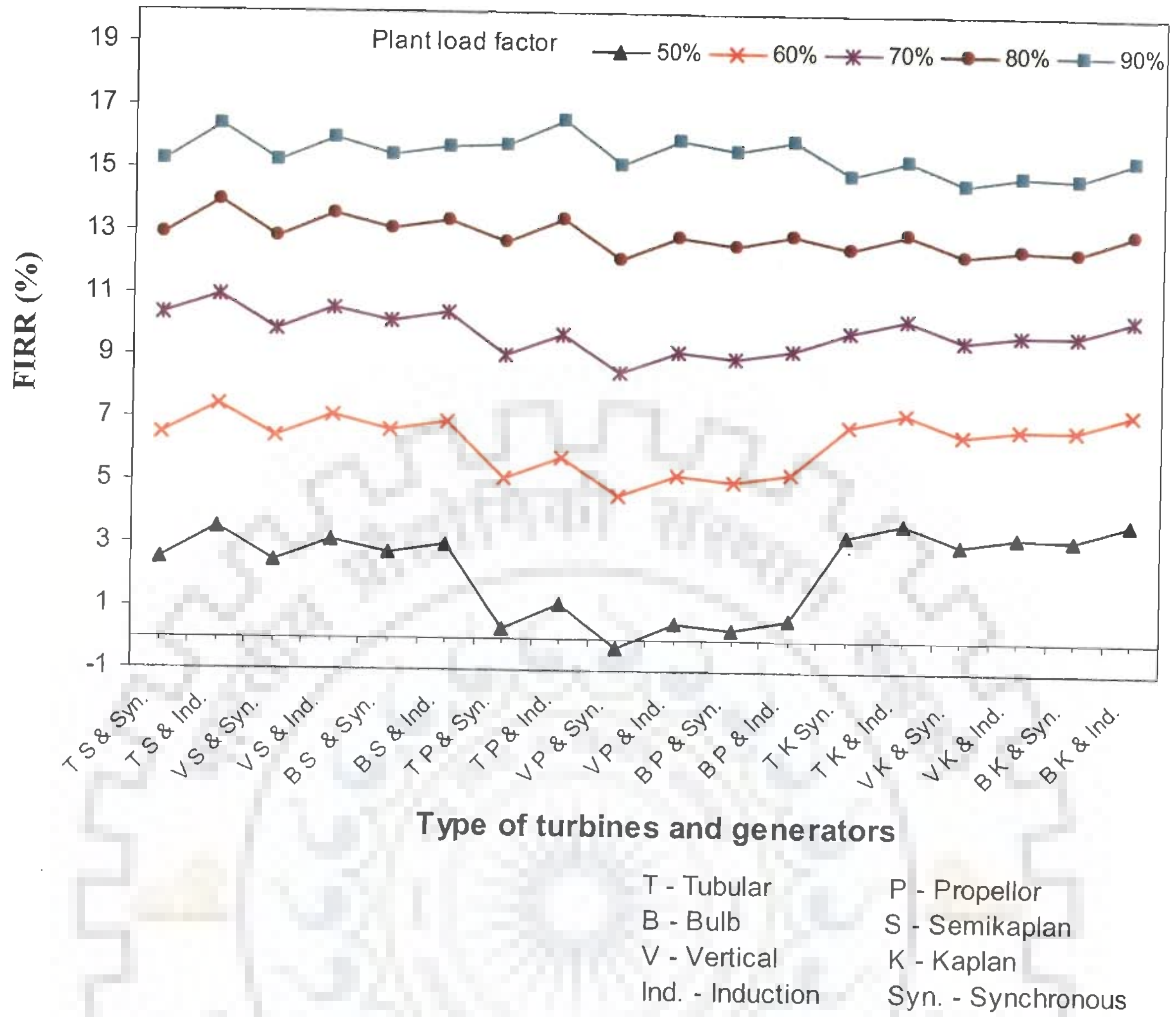
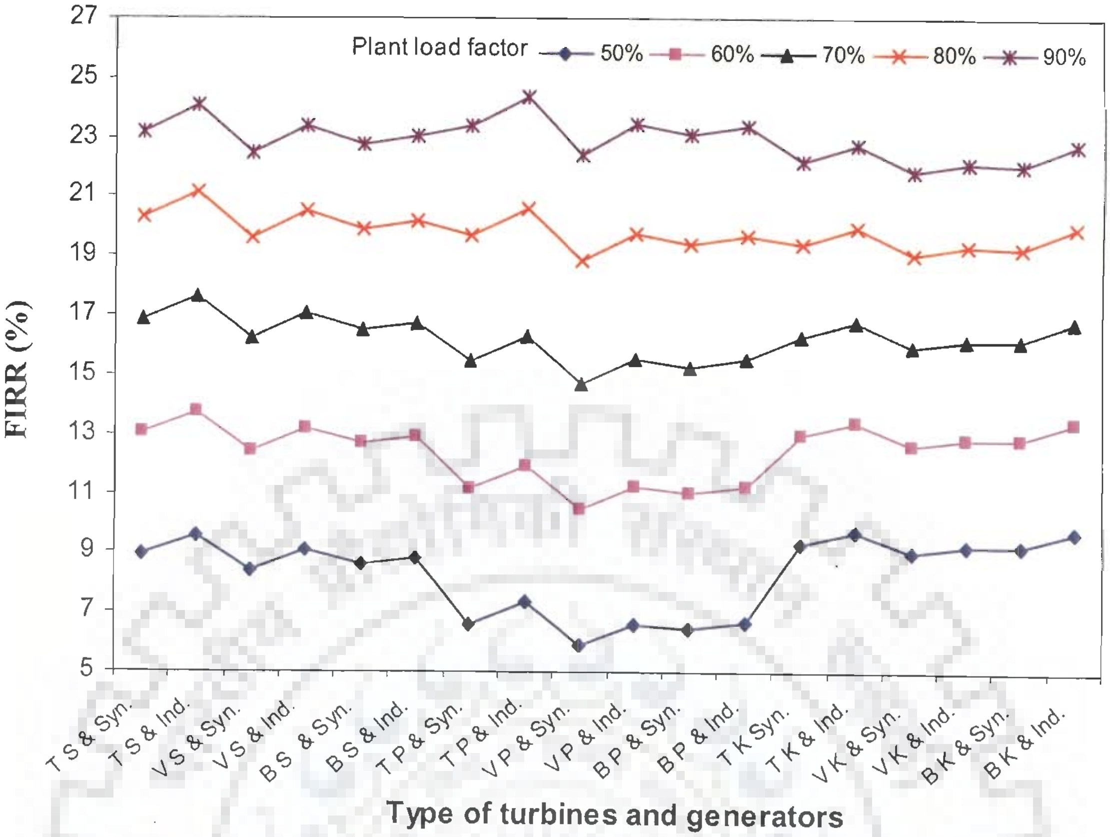


Fig. 6.18 FIRR for canal based scheme of 2000 kW capacity at 3 m head having different turbines and generators at different load factors

Figs. 6.19-6.21 show that at 50% load factor, bulb turbine with Kaplan runner is the optimum layout having maximum FIRR for all the combination considered. At 60%, 70% and 80 % load factors, tubular turbine having semi Kaplan runner is the optimum layout with maximum FIRR values. While, at 90% load factor, tubular turbine with propeller runner is found to be the optimum layout.



T - Tubular	P - Propellor
B - Bulb	S - Semikaplan
V - Vertical	K - Kaplan
Ind. - Induction	Syn. - Synchronous

Fig. 6.19 FIRR for canal based scheme of 10000 kW capacity at 3 m head having different turbines and generators at different load factors

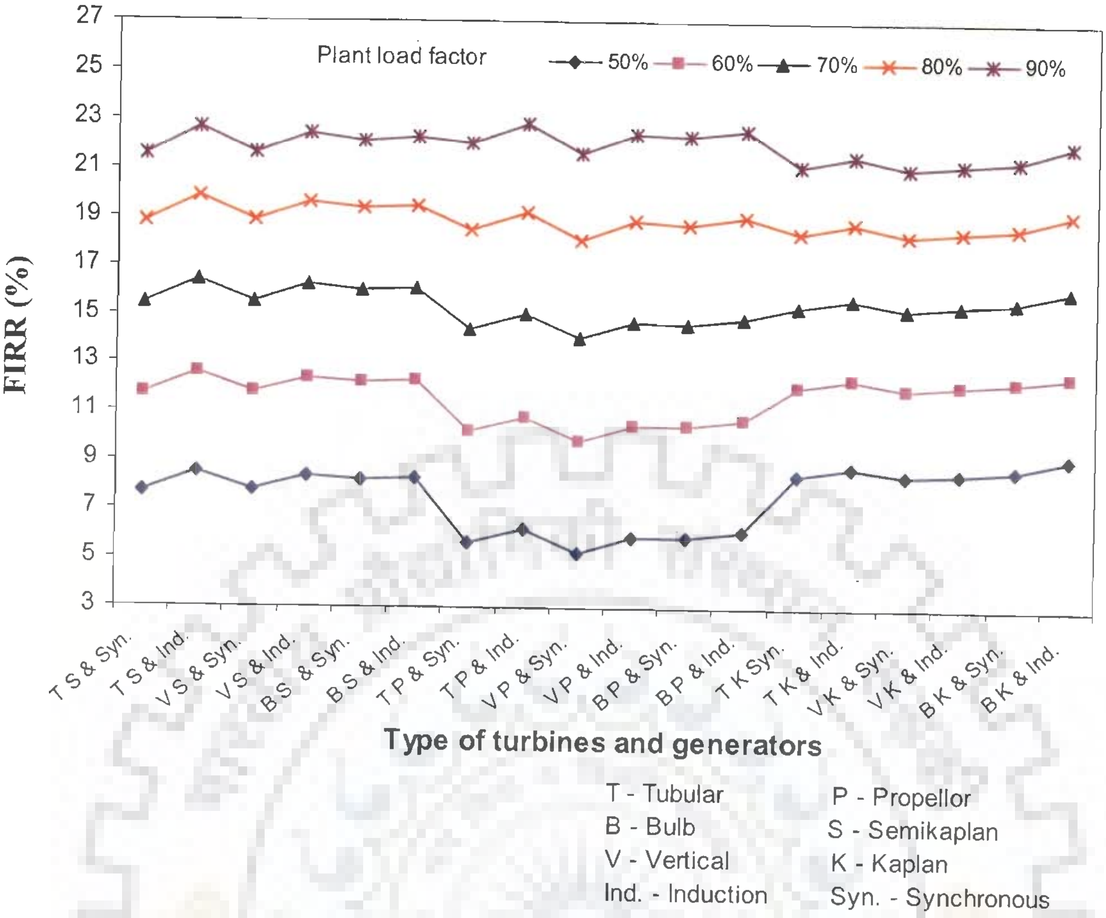


Fig. 6.20 FIRR for canal based scheme of 2000 kW capacity at 20 m head having different turbines and generators at different load factors

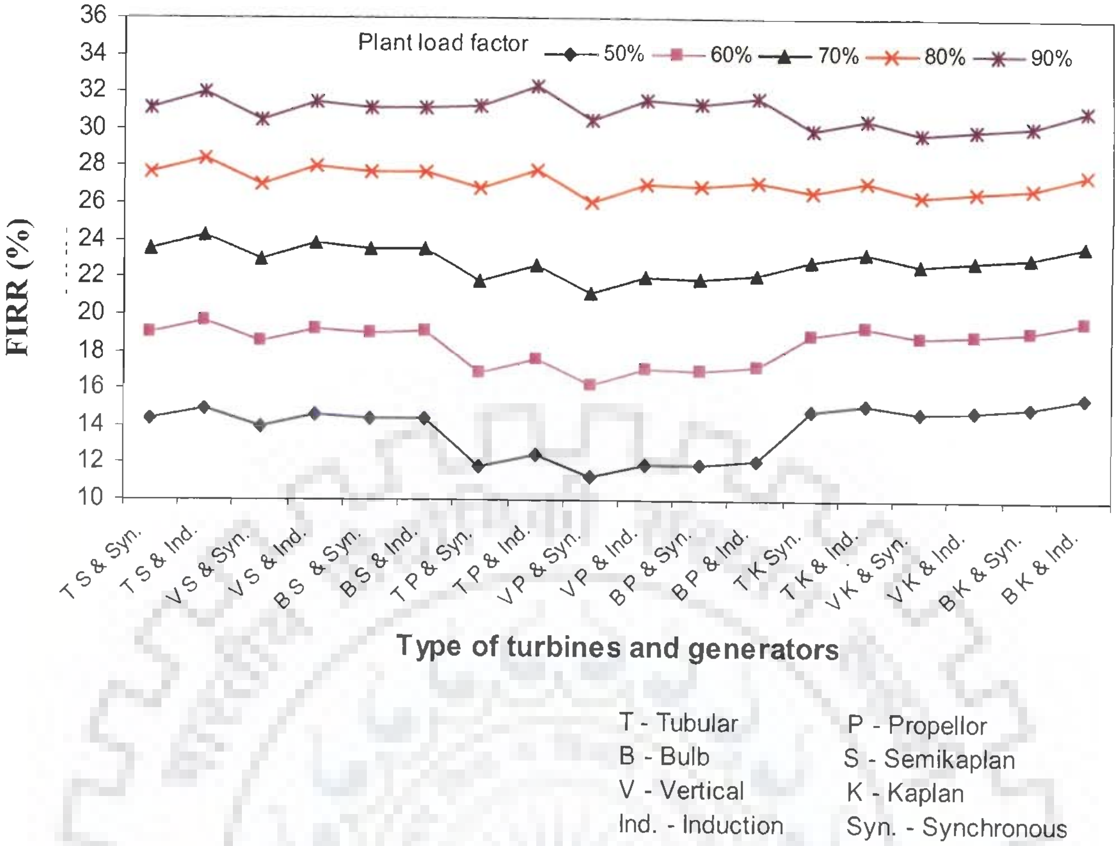


Fig. 6.21 FIRR for canal based scheme of 10000 kW capacity at 20 m head having different turbines and generators at different load factors

6.6.8 Optimum Layouts for Run of River SHP Schemes

Financial analysis has also been carried out for run of river SHP schemes for layouts under ordinary soil condition, having two numbers different type of turbines and generators at different load factors on the similar lines as carried out for canal based SHP schemes. Determined values of FIRR for the layouts of 2000 kW and 10000 kW plant capacity at 3 m and 20 m head combination are shown in Figs. 6.22-6.25. It is seen from the figures that at 50% load factor, bulb turbine with Kaplan runner is the optimum layout having maximum FIRR. At 60%, 70% and 80 % load factors, tubular turbine having semi Kaplan runner is the optimum layout with maximum FIRR values. At 90% load factor, tubular turbine with propeller runner is found to be the optimum layout with maximum FIRR values.

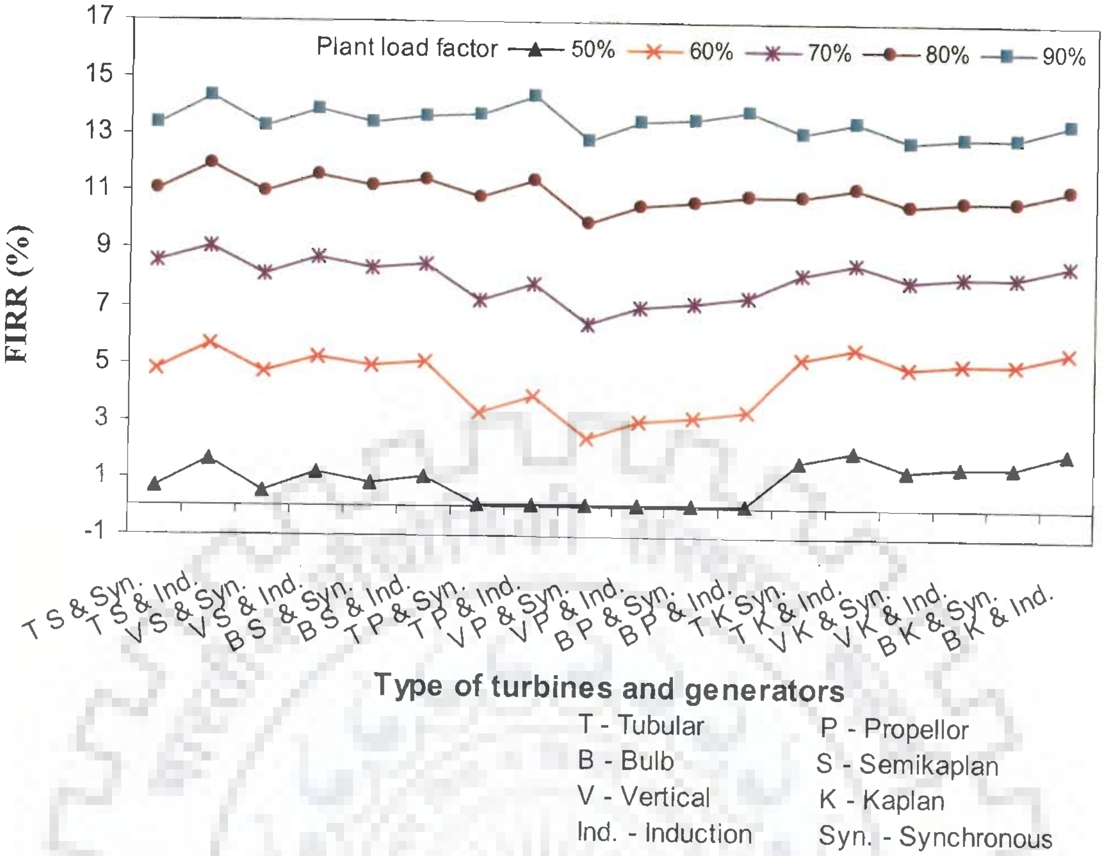


Fig. 6.22 FIRR for run of river scheme of 2000 kW capacity at 3 m head having different turbines and generators at different load factors

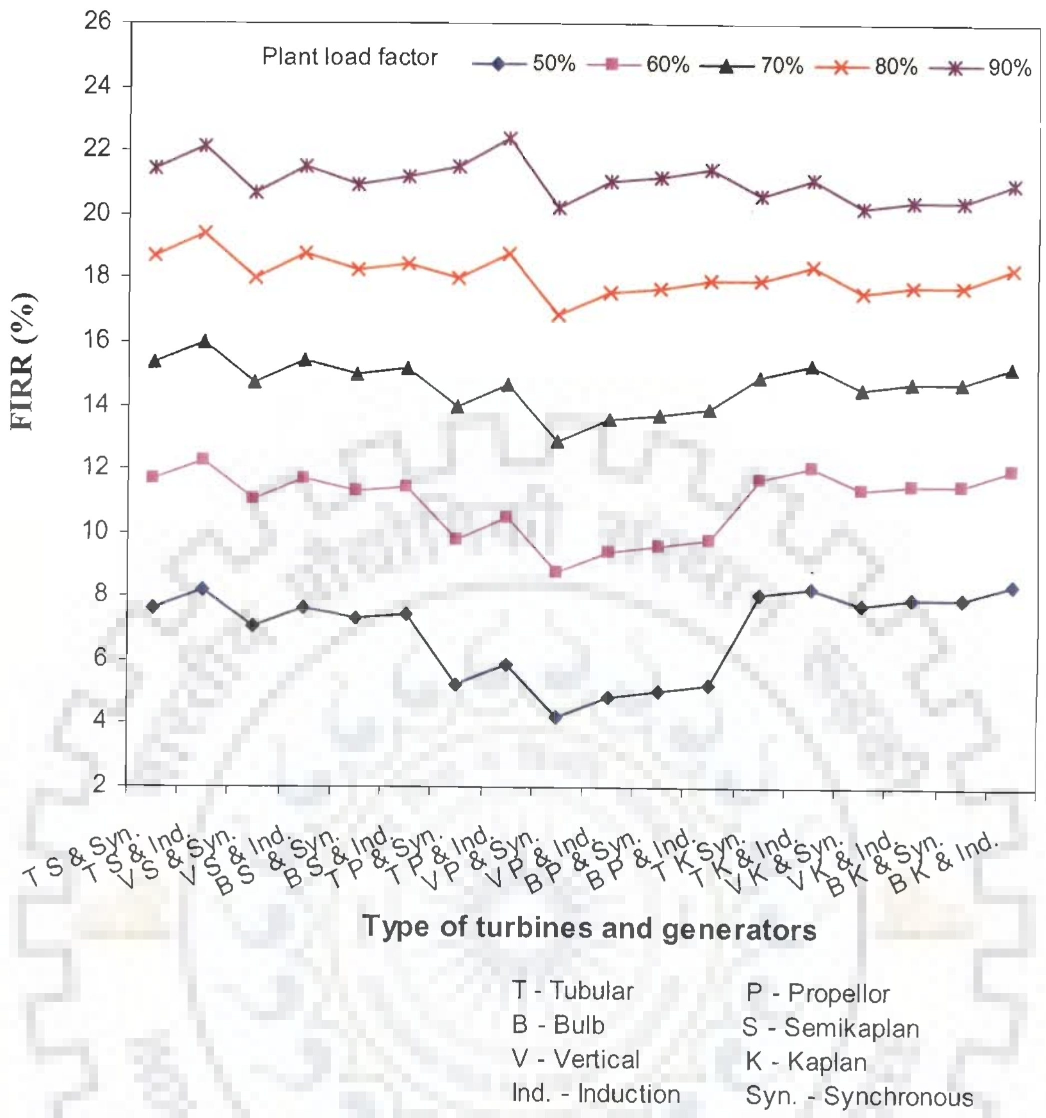


Fig. 6.23 FIRR for run of river scheme of 10000 kW capacity at 3 m head having different turbines and generators at different load factors

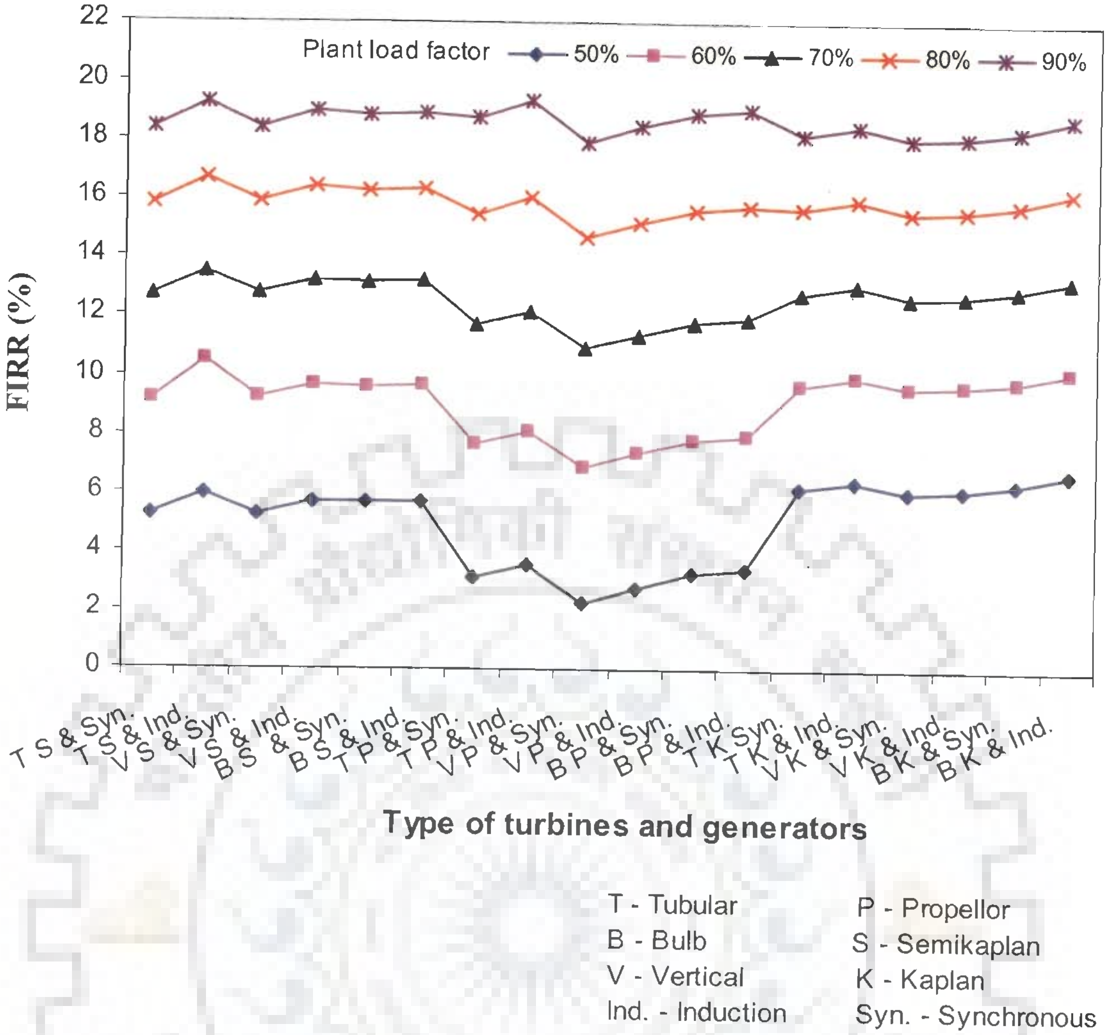


Fig. 6.24 FIRR for run of river scheme of 2000 kW capacity at 20 m head having different turbines and generators at different load factors

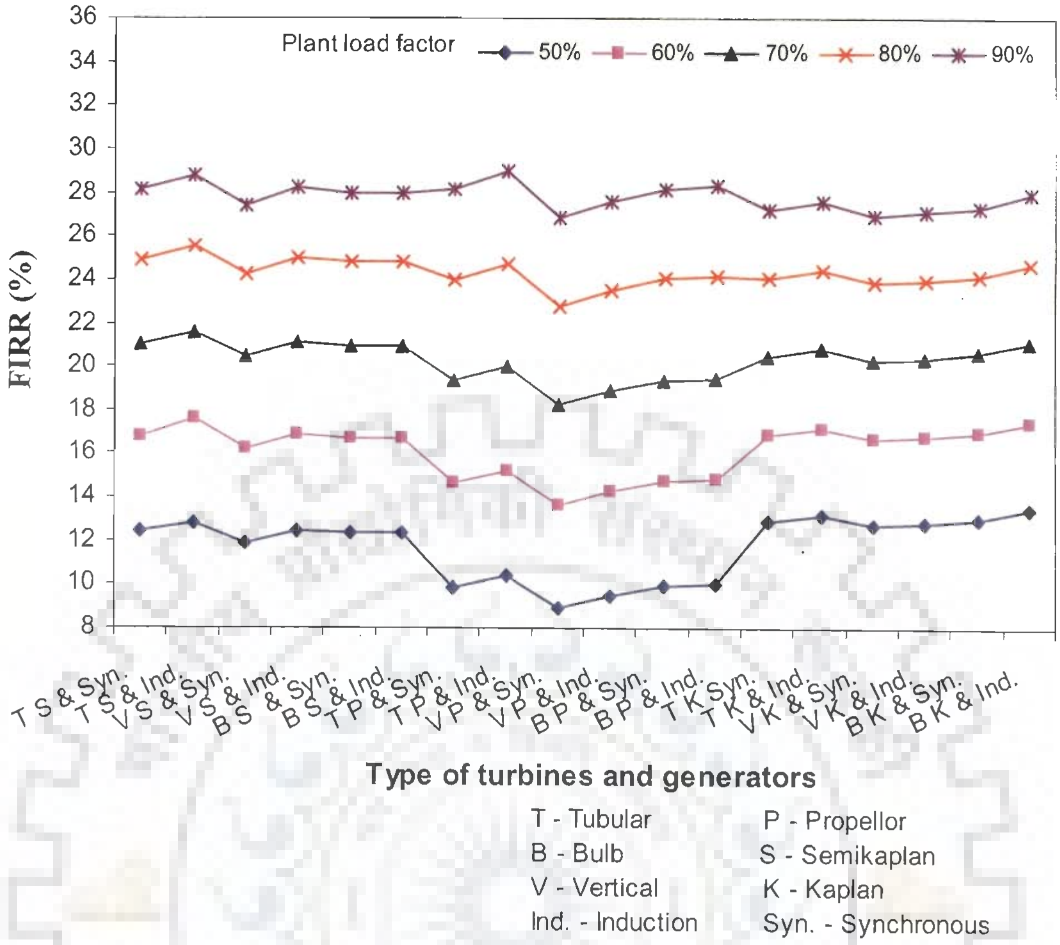


Fig. 6.25 **FIRR for run of river scheme of 10000 kW capacity at 20 m head having different turbines and generators at different load factors**

6.6.9 Optimum Layouts for Dam Toe SHP Schemes

Financial analysis has also been carried out for dam toe SHP schemes for layouts under similar soil conditions, number of units, type of turbines and generators at different load factors on the similar lines as carried out for canal based SHP schemes. FIRR values for different layouts of dam toe schemes having capacity of 2000 kW at 3 m, 1000 kW at 3 m, 2000 kW at 20 m and 10000 kW at 20 m were considered. It is seen from Figs. 6.26-6.29 that at 50% load factor, bulb turbine with Kaplan runner is the optimum layout having maximum FIRR. At 60%, 70% and 80 % load factors, tubular turbine having semi Kaplan runner is found to be the optimum layout with maximum FIRR values. At 90% load factor, tubular turbine with propeller runner is found as the optimum layout with maximum FIRR values.

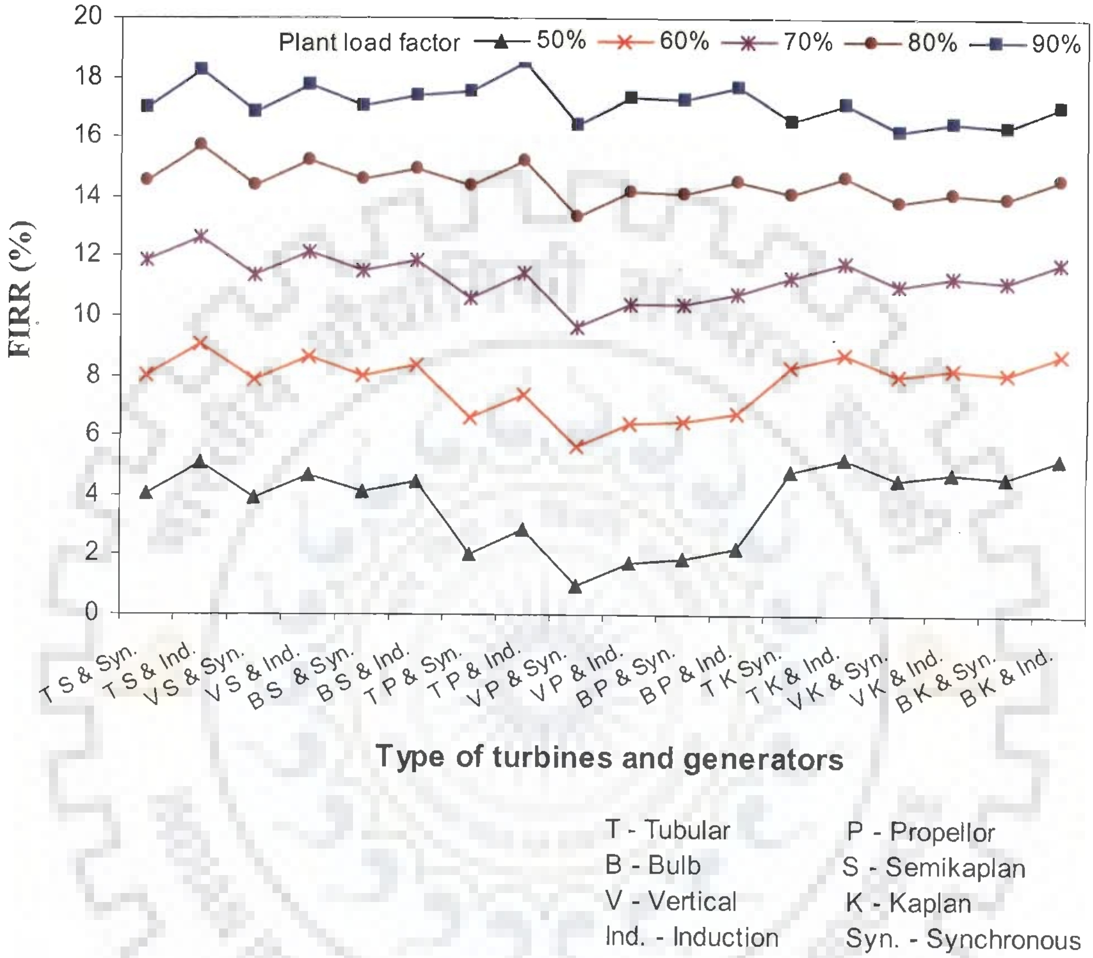


Fig. 6.26 FIRR for dam toe scheme of 2000 kW capacity at 3 m head having different turbines and generators at different load factors

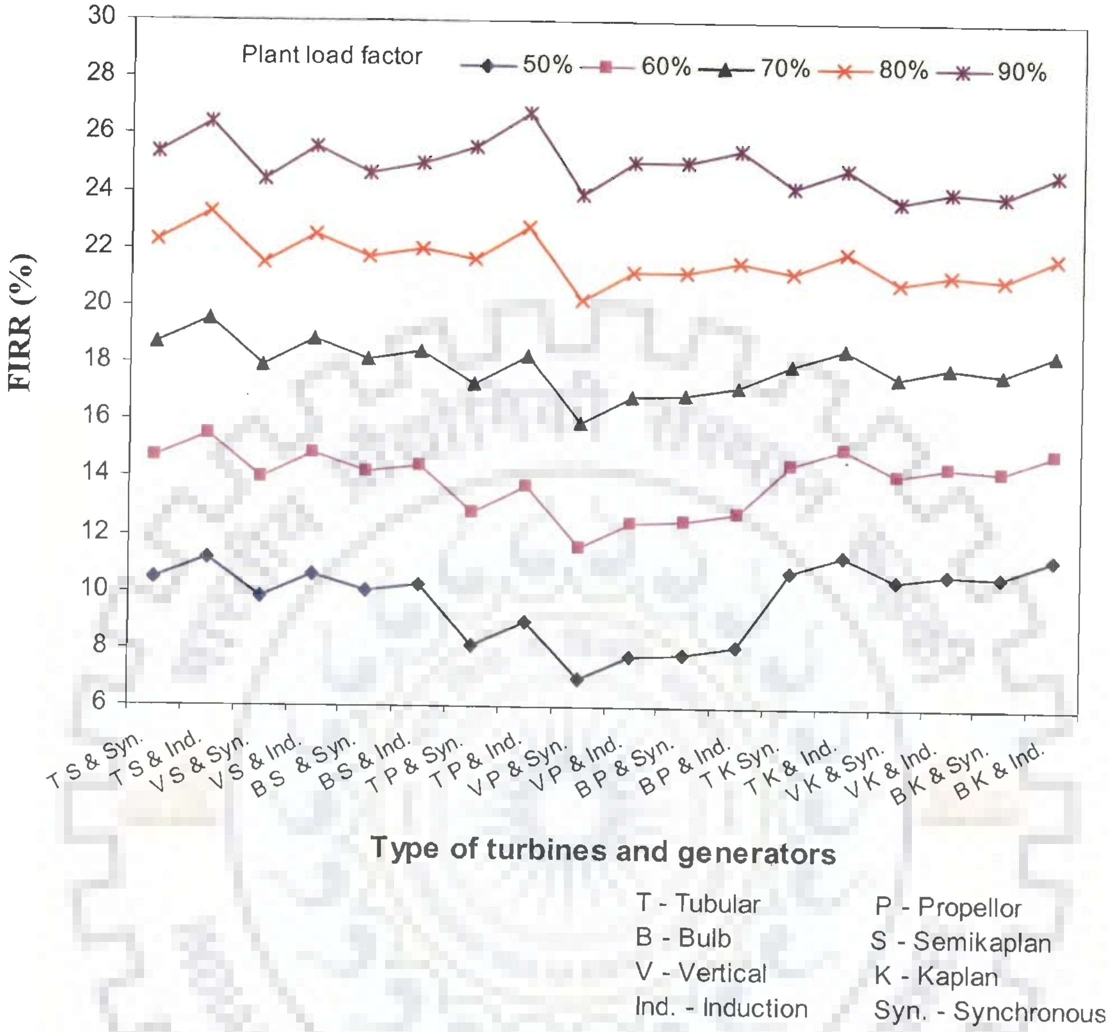


Fig. 6.27 FIRR for dam toe scheme of 10000 kW capacity at 3 m head having different turbines and generators at different load factors

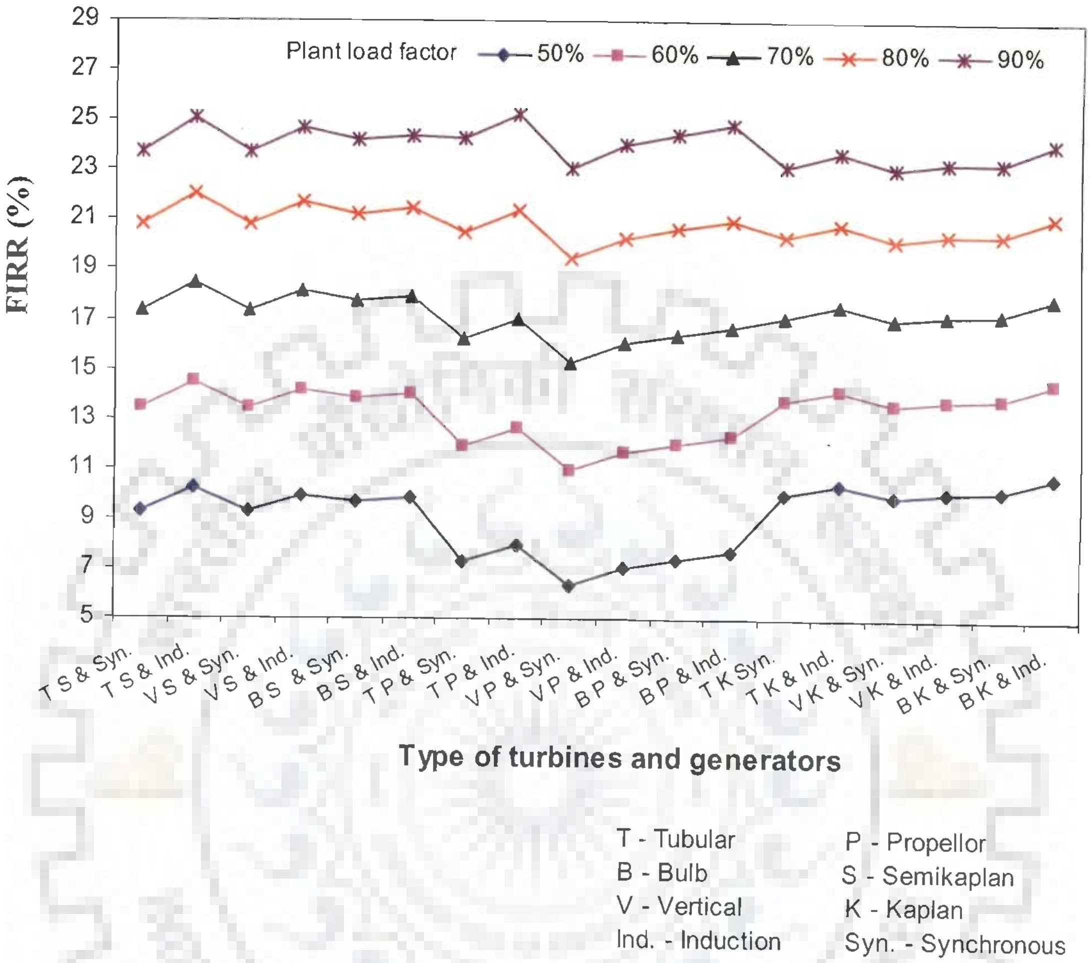
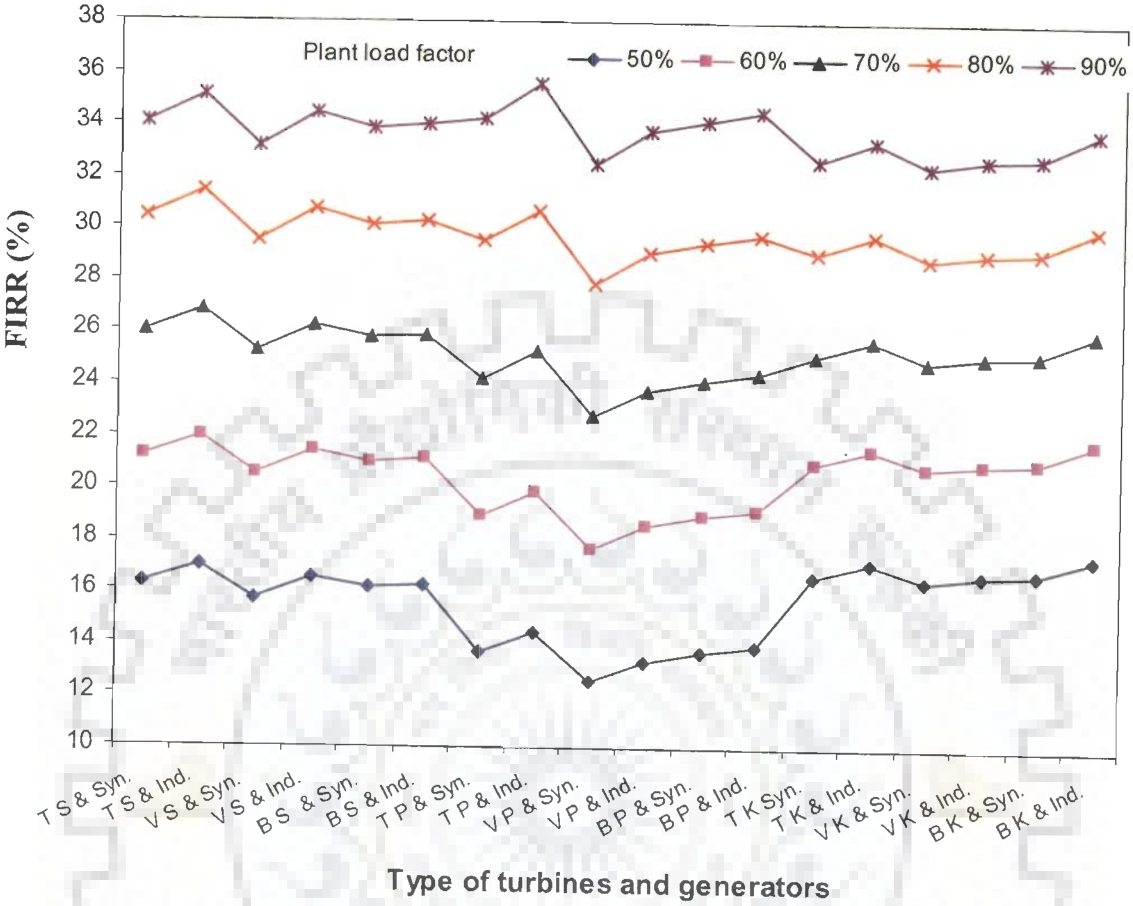


Fig. 6.28 FIRR for different turbines and generators at different load factors for dam toe scheme at 20 m head 2000 kW capacity



T - Tubular	P - Propellor
B - Bulb	S - Semikaplan
V - Vertical	K - Kaplan
Ind. - Induction	Syn. - Synchronous

Fig. 6.29 FIRR for dam toe scheme of 10000 kW capacity at 20 m head having different turbines and generators at different load factors

The financial analysis for some typical cases under different SHP schemes has been carried out as discussed above. In order to find out the optimum layouts under different conditions, FIRR is found to be the deciding parameter.

Further, to find out the FIRR values for other site conditions to determine the optimum layout, the following procedure is recommended.

i. Determine installation cost using correlations (Eq.5.21, Eq.5.25, Eq.5.29) developed in Chapet-5, for a particular type of scheme, for known values of head and installed capacity and soil condition and number of generating units.
ii. The installation cost based on developed correlations considering base year as 2007.For subsequent years, this cost is to be modified by considering inflation based consumer price index.
iii. Determine annual energy using Eq. 6.1 for different type of turbine and generator combinations at known plant load factor depending on water availability.
iv. Determine annual cost using Eq. 6.2, considering operation and maintenance (O&M) including insurance cost, depreciation and interest on the capital borrowed.
v. Determine FIRR values based on installation cost, annual cost, annual energy and selling price of electricity, by iterative technique.
vi. Determine optimum layout for maximum value of FIRR.

CHAPTER–7

CONCLUSIONS

World over small hydro power (SHP) schemes are defined based on the capacity by different countries. In India SHP schemes having plant installed capacity upto 25 MW are considered under small hydro power. Government of India through Ministry of New and Renewable Energy provides financial support for implementation of SHP projects.

In order to develop small hydro power (SHP) projects, assessment of cost is essential after establishing its technical feasibility as SHP projects are site specific. High and medium head SHP schemes, especially run of river schemes in high terrains are more site specific and installation cost is governed mainly by the cost of civil works. However, in low head schemes, especially canal based schemes, run of river schemes in low terrains and dam toe schemes, the cost is governed by the cost of civil works as well as electro-mechanical equipment. In such schemes the sizes of electro mechanical equipment are relatively bigger and hence the size of powerhouse. It therefore, there is a scope for cost optimisation for such schemes. Keeping this in view a study has been carried out for cost analysis of low head SHP schemes under different categories. The following conclusions have been drawn from the present study.

1. Under the present study all three types of low head SHP schemes i.e. canal based, run of river and dam toe have been considered for cost analysis. The main components of a SHP scheme are categorized in two parts i.e. (i) civil works and (ii) electro- mechanical equipment. Under civil works the components considered are; diversion weir & intake, channels (diversion,

power and tailrace), desilting tank, forebay, spillway, penstock and power house building. Out of these components under civil works specific components are considered based on type of scheme. The range of parameters and constraints considered under the present study are as given below;

S. No.	Range of parameters/ constraints	Value
1.	Head range	3-20 m
2.	Installed capacity	1000 - 25000 kW
3.	Unit size	1000 - 5000 kW
4.	Length of intake and head race channel, penstock, spillway channel and tail race channel in run of river schemes	Fixed based on head
5.	Length of penstock and tail race channel in dam toe schemes	Fixed based on head

2. For cost analysis the components under electro-mechanical equipment are considered similar for all the three types of SHP schemes. The items under electro-mechanical components are considered as; turbine with governing system, generator with excitation system, electrical and mechanical auxiliary, transformer and switchyard.

3. The sizing of civil works have been determined based on hydraulic design of the components. In order to determine the quantities of various items under civil works, layout drawings of various components are prepared for different schemes.

4. Type of schemes and alternative layouts considered for analysis are as given below;

S. No.	Alternatives	Details	Type of scheme
1.	Location of powerhouse	(i) Powerhouse in diversion channel and spillway in main canal	Canal based
		(ii) Powerhouse and spillway combined in main canal and diversion channel	
		(iii) Powerhouse and spillway combined in main canal and no diversion channel	
2.	Type of soil	(i) Ordinary soil, (ii) soft rock and (iii) hard rock	Canal based, run of river and dam toe
3.	Number of generating units	(i) One unit, (ii) two units, (iii) three units and (iv) four units	
4.	Type of turbine	(i) Tubular semi Kaplan, (ii) vertical semi Kaplan, (iii) bulb semi Kaplan, (iv) tubular propeller, (v) vertical propeller, (vi) bulb propeller (vii) tubular Kaplan (viii) vertical Kaplan and (ix) bulb Kaplan	
5.	Type of generator	(i) Synchronous and (ii) Induction	

5. Costs of various components have been determined for different cases based on actual quantities and prevailing market prices of different items. The cost of different electro-mechanical equipment has been collected from different manufacturers/suppliers through an extensive market survey.

6. Under civil works it has been found that power house building constitute major portion in the cost of civil works for low head SHP schemes. For a typical example of a canal based scheme of 2000 kW plant capacity at 10 m head, the cost of components such as diversion channel, spillway and power house building are found to be as Rs. 3.02 Millions, Rs. 10.98 Millions and Rs.30.09 Millions respectively. In this case, the power house was considered in the diversion channel and spillway in the main canal. Two numbers of semi Kaplan tubular turbines coupled with synchronous generators were considered for this layout.

7. In order to compare the civil components cost of a typical run of river scheme layout, same capacity and head has been considered. Cost of civil works for run of river scheme is found to be more than the civil cost of canal based schemes. For a typical run of river scheme of 2000 kW plant capacity at 10 m head, the cost of various components are found to be as Rs.3.57 Millions, Rs.10.24 Millions, Rs.5.85 Millions, Rs.7.40 Millions, Rs.2.10 Millions, Rs.27.11 Millions and Rs.0.77 Millions for diversion weir & intake, power channel, desilting tank, forebay, penstock, power house building and tail race channel respectively. In case of dam toe schemes, the cost of civil works components i.e. penstock, power house building and tail race channel are found to be same as of a run of river scheme under similar conditions. The cost of intake which is different in this scheme is found to be as Rs.5.17 Millions. However, number of civil components under dam toe schemes are less therefore cost of civil works of such scheme are found to be less in comparison of other schemes.

8. The cost of components under electro-mechanical equipment is similar in all three types of SHP schemes. For the typical layout considered, the cost of electro-mechanical components such as turbine with governing system,

generator with excitation system, electrical and mechanical auxiliary, transformer and switchyard are found to be as Rs.18.00 Millions, Rs.23.54 Millions, Rs.11.92 Millions and Rs.5.84 Millions respectively.

9. Based on the cost of different components under civil works and electro-mechanical equipment for different layouts and alternatives, correlations for cost has been developed using regression analysis approach in terms of head and capacity as these parameters are considered as cost sensitive parameters.

10. Total installation cost has been computed for different low head SHP schemes based on correlations developed for different components. Total installation cost includes civil works, electro mechanical and other indirect costs.

11. The validity of the developed correlations has been verified with the actual cost data collected from the developers. A maximum deviation in cost has been found to be as ±12% in canal based schemes, ±12.5% in case of run of river schemes and ±11% for dam toe schemes. The percentage deviation obtained in these costs has been found well within the limits.

12. For a typical canal based scheme of low head, cost of electro-mechanical equipment is found to be as 54.5% at 3m head and 50.3% for 20 m head. It is concluded that the cost of electro-mechanical equipment increases as the head of the scheme decreases for a given capacity. Further the major contribution in total installation cost is found to be of electro-mechanical component cost in low head SHP schemes.

13. Three types of soils i.e. ordinary soil, soft rock and hand rock are considered for civil works. It is found that the layout with ordinary soil condition has minimum installation cost and layout with hard rock has maximum installation

cost. A maximum difference of 2.2 % in cost with these soil conditions has been found.

14. The installation cost has been determined for three different types of layouts (i) Power house building in diversion channel and spillway in main canal, (ii) Power house building and spillway combined in main canal and bye pass channel and (iii) Power house building and spillway combined in main canal and no bye pass channel. It has been found that the layout of case (i) has the maximum cost while layout of case (iii) corresponds to the minimum cost. A difference in cost of 4.6% has been found. This shows that the cost is reduced by combining the spillway & power house structures and by eliminating the diversion channel.

15. Further, installation cost has been computed for different alternatives having different combination of turbines and generators. It has been found that the layout with tubular turbine having propeller runner and induction generator has minimum installation cost. However, layout of bulb turbine having Kaplan runner with synchronous generator has maximum cost. For a typical SHP scheme, a maximum difference in of the order of 17.2% in the installation cost has been found for different combinations of electro-mechanical equipment.

16. The effect of number of generating unit on installation cost has also been analysed. It is seen that electro-mechanical equipment contributes the major part in the total installation cost and it increases with the increase in number of units. For a typical layout of low head SHP scheme cost contribution of elector-mechanical equipment in total installation costs comes out to be about 50.6% and 56.1% correspond to 1 number and 4 numbers of generating units.

17. In order to determine the optimum layout, different layouts were evaluated for cost optimisation based on installation cost, generation cost, benefits cost (B-C) ratio, net present value (NPV) and financial internal rate of return (FIRR).

18. It has been found that for a typical canal based layout of 2000 kW capacity at 3 m head, tubular turbine with propeller runner coupled with induction generator is found to be the optimum layout at 90% load factor. This conclusion has been drawn based on the values of financial parameters. For this case, installation cost comes out to be minimum as Rs.0.65 Millions per kW, generation cost of Rs.1.58 per kWh with maximum values of B-C ratio as 1.32, NPV of Million Rs. 74.38 and FIRR as 16.56%.

19. It is found that the financial parameters follow the similar trend for optimum layout i.e. minimum installation cost, minimum generation cost, maximum B-C ratio, maximum NPV and maximum value of FIRR for the case considered. Further, financial institutions prefer FIRR for evaluation of such projects for financing. Therefore, FIRR has been considered as financial parameter for determining the optimum layouts.

20. For a load factor of 50%, bulb turbine with Kaplan runner coupled with induction generator is found to be optimum layout as it has maximum FIRR value of 3.8%, while, at 60%, 70% and 80% load factors, tubular turbine having semi Kaplan runner coupled with induction generator results in the maximum FIRR values of 7.5%, 11% and 14% respectively and is considered as optimum.

21. Layout having tubular turbine with propeller runner coupled with induction generator is found optimum at higher load factors beyond 90% as these layouts has been found to have a maximum FIRR value of 16.6%.

22. Further it has also been found that low head SHP schemes under canal based, run of river and dam toe follow the similar trend of FIRR values.

Summarizing, it can be stated that correlations for cost of installation of low head SHP schemes have been generated based on quantities of different items of civil works and type of electro-mechanical equipment. Methodology for determination of optimum installation based on financial parameters has been employed to compare different alternatives, which can be used by developers to plan their investments in low head SHP schemes. The financers may also use these cost correlations for appraisal of such schemes for financing.

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