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 in every sector such as trade and commerce, industrial, agriculture, transportation and domestic sectors. The total electricity generating capacity of India stands at 205.34 GW with 66.4% contribution from thermal, 19.1% from hydro, 2.3% from nuclear and remaining 12.1% from renewable energy sources such as wind, solar, small hydro, biomass and others. The all India average energy shortage is about 6%, whereas peaking shortage is 9%.

Increasing fossil fuel based energy generation significantly contribute to environmental related problems both locally and globally. Power sector is facing problem of increasing electricity demand as well as regulation on greenhouse gas emissions. It is crucial to exploit sustainable energy generation sources with high efficiency and low cost. Hydro power stations have inherent ability for instantaneous starting, stopping and load variations which help in improving the reliability of power system. Thus hydro power stations are the best choice for meeting the peak demand. However, economic and environmental factors restrict the exploitation of hydro power through conventional large reservoir based projects. Due to these constraints, renewable energy resources such as solar, wind, biomass, small hydro, which the country has in abundance, can be considered to meet the growing energy demand in environmentally benign manner. Among all the renewable energy sources, small hydropower (SHP) is considered as one of the most promising sources. SHP schemes can encourage the development of small industries across a wide range of new technologies. Multiple purpose projects for drinking water and irrigation systems can take the advantage to install small hydro schemes. World vide, small hydropower is defined by the installed capacity and in different countries the range of small hydropower is different. In India, hydropower projects upto 25 MW are defined as SHP projects. The potential under small hydropower range in the country has been estimated as 15,384 MW, out of which only 3252 MW has been tapped so far.

The technology for small hydropower development is mature and proven. SHP projects are broadly categorised in three types i.e. run of river, dam toe and canal based. Based on head range, SHP projects are also classified as low head, medium head and high head. The low head SHP schemes are generally located on canal falls and small height dams. Medium head schemes are run of river and dam based, whereas high head schemes are mainly run of river. The high head schemes are site specific and installation cost is governed mostly by cost of civil works, thus there is scope for cost optimization in such schemes. Keeping this in view, the present study has been carried out for cost analysis of high head SHP schemes, which are located in the hilly region.

Literature survey reveals that earlier studies were conducted to optimize low head SHP schemes. Studies were also conducted to optimize specific components of SHP schemes. In high head SHP schemes, relatively small discharge is handled, thus the size of machines is small. Due to this, civil works cost contribution is more in the project cost of such schemes. No work has been reported for the cost optimization of high head run of river small hydropower projects. Hence, the present study has been carried out for cost analysis of high head small hydropower installations covering the following objectives:

a. Study of various components of high head small hydro power scheme.
b. Carry out the sizing of components of such schemes.
c. Computation of quantities of different items of civil works components based on determined sizes.
d. Development of correlations for quantities of different items of civil works components using cost influencing parameters.
e. Development of correlations for cost of electro- mechanical equipment using cost influencing parameters.
f. Computation of cost of different components based on developed correlations and prevailing item rates.
g. Cost optimization of various layouts based on developed correlations.

In order to achieve the above mentioned objectives, an attempt has been made to develop a methodology for the assessment of cost of high head SHP project so as to determine its techno-economical viability for investment decision before undertaking detailed investigations. This will enable the planners to consider only feasible projects for detailed investigations and implementation. The cost of such schemes is site specific based on type of components, topography and geology of the site. The basic components of this scheme are broadly categorized into two parts (i) civil works and (ii) electro-mechanical equipment. The components of civil works in high head schemes are the diversion weir and intake, intake channel, desilting tank, head race conduit, forebay and spillway, surge tank, penstock, power house building and tail race channel. Various alternatives considered in the present study are different types of head race conduit, penstock materials, types of turbine and types of generator.

The design and sizing of the various components of civil works have been carried out based on the design discharge of the project. The size of turbine is governed by runner diameter and speed which is determined based on the head and capacity. The head range considered in the study is 100 m to 1000 m whereas capacity range is considered to be 2000 kW to 25000 kW. Two hydro-generating units have been considered with the unit size of 1000 kW to 12500 kW. Based on technical feasibility, different alternatives considered for optimization are given below. The technically feasible types of turbines under the head range considered are Francis, Turgo Impulse and Pelton. Whereas, penstock material considered are steel, Poly Vinyl Chloride (PVC), High Density Poly Ethylene (HDPE) and Glass Reinforced Plastic (GRP).

S. No.	Components	Alternatives
1.	Head race conduit	Channel
		Glass Reinforced Plastic (GRP) pipe
		Poly Vinyl Chloride (PVC)
		Mild Steel (MS) pipe
		Tunnel
2.	Penstock	Poly Vinyl Chloride (PVC) pipe
		Glass Reinforced Plastic (GRP) pipe
		High Density Poly Ethylene (HDPE) pipe
		Steel pipe
3.	Turbine	Francis
		Turgo Impulse
		Pelton
4.	Generator	Induction
		Synchronous

In the high head schemes, water hammer pressure in the penstock due to surge effect is significant. In order to determine the length and the thickness of the penstock to minimise the surge effect, transfer function of the penstock turbine has been used. An electrical analogy of penstock has been used for the development of transfer function by considering penstock equivalent to long transmission line. It has been found that the length of penstock as two and half times of the head is optimum for minimum surge effect.

From the sizing of various components of civil works the quantities of major items (i.e. earth work in excavation, concreting, reinforcement steel and structural steel) have been computed. The cost influencing parameters considered for the development of the correlation for the quantity estimation of major items are head and capacity. The cost of civil works is determined based on the quantities of major items and the prevailing rates of these items. The costs of electro-mechanical equipment have been collected from the manufacturers to develop correlations for the cost.

The cost of civil works components have been computed based on the correlations developed for quantities of various items and the prevailing rates. The total cost of the project depends on the cost of the civil works, cost of electro-mechanical equipment, cost of miscellaneous items and other indirect cost. Establishment related cost including engineering design, audit and account, indirect charges, tools & plants, communication expenses, preliminary expenses on report preparation, survey and investigations and cost of land were considered under miscellaneous and indirect costs. The total installation cost as computed is validated from the installation cost data collected from the existing power stations. A maximum deviation of ±8% has been found for the total installation cost of run of river schemes.

It has been found that the civil works cost constitutes the major portion of the total cost in case of high head SHP projects. As a typical example, considering a plant having the plant capacity of 5000 kW at 100 m head, the cost of the civil works is found to be 59% and about 65% in case of plant having the capacity of 5000 kW at 1000 m head. Cost analysis has been carried out to determine the optimum layout of the high head run of river SHP scheme based on considered alternatives for head race conduit, penstock material, types of turbine and type of generator. Different layouts were evaluated for cost optimization based on installation cost and generation cost. Particle Swarm Optimization (PSO) based technique has been employed to work out the optimal layout of different SHP schemes.

A typical example of SHP project having plant capacity of 5000 kW at 100 m, 500 m and 1000 m heads for run of river schemes have been considered for analysis. It has been observed that the optimum generation cost in case of 100 m head is about Rs. 2.94 per kWh. In this case, results obtained are channel for head race conduit, HDPE pipe for penstock, Francis turbine and induction generator. Whereas, for the same capacity project at 500 m head, the optimum generation cost obtained is Rs. 2.55 per kWh and the alternatives obtained for optimum layout are channel as head race conduit, HDPE pipe for penstock, Pelton turbine and induction generator. Further, in case of same project at 1000 m head, the optimum generation cost obtained is Rs. 2.46 per kWh and the alternatives for optimum layout are channel as head race conduit, steel pipe for penstock, Pelton turbine and induction generator.

The methodology employed for cost assessment and determination of the optimum installation and the nomograms developed for selection of optimum layouts of high head SHP schemes can be used by developers, policy makers and decision takers to plan their investments in such schemes. The financers may also use these cost correlations and nomograms for appraisal of such schemes for financing.