

Analytical Approach for Cost Estimation of Low Head Small Hydro Power Schemes

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ABSTRACT

Increasing global awareness of the negative impacts fossil fuels on the environment has given the boost on the exploitation of available renewable energy resources having obvious benefits for developing countries. Small hydropower is considered to be an attractive source of non-conventional renewable energy as it avoids the pollution associated with burning fossil fuels. However, small hydropower exploitation may not be economically viable as the capacity of hydro plant decreases the generating cost per unit increases. Therefore to make it economically viable the methodology and technology applied must be different from that applied to larger hydro plants rather than having a miniature of large hydro. Under the present paper an attempt has been made to determine the cost of different components of low head SHP schemes. Based on the determined cost, co-relations in the form of cost as function of head and discharge have been developed. The cost based on the developed co-relations, having different head and capacity has been compared with the available cost of the existing hydro power stations. It has been found that these co-relations can be used reasonably for estimation of cost of new low head SHP schemes.

1 INTRODUCTION

Hydropower started with the wooden waterwheel. Waterwheels of various types had been in use in many parts of Europe and Asia for some 2,000 years, mostly for milling grain. By the time of the Industrial Revolution, waterwheel technology had been developed to a fine art, and efficiencies approaching 70% were being achieved in the many tens of thousands of waterwheels that were in regular use. Improved engineering skills during the 19th century, combined with the need to develop smaller and higher speed devices to generate electricity, led to the development of modern day turbines. Probably, Benoit Fourneyron who called his invention a hydraulic motor designed the first hydro-turbine in France in the 1820s. Towards the end of that century many mills were replacing their waterwheels with turbines, and governments were beginning to focus on how they could exploit hydropower for large-scale supply of electricity. The first small hydro project in India of 130 kW commissioned in the hills of Darjeeling in 1897. The Sivasamudram project of 4500 kW was the next to come up in Mysore district of Karnataka in 1902. The pace of power development including hydro projects in India was taken up in the post independence era. 1362 MW capacity (including 508 MW hydropower) installed in the country before independence was mainly coming from small and medium size projects. After independence in 1947, the need was felt for speedy development of infrastructure especially the power sector and the planners choose the large hydroelectric projects to augment the capacity. The establishment of over 20,500 MW of hydro power stations was significant in 50 years compared to 500 MW of previous 50 years [Naidu, 2005]. 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. Thus comes the concept of small hydro. Small hydro technology is extremely robust (systems can last for 50 years or more with little maintenance) and is also one of the most environmentally benign energy technologies available. Out of the all non-conventional energy technologies, small hydro represents highest density resource. Small hydro stands first place in the generation of electricity from non-conventional renewable sources throughout the world. The importance of developing canal falls as source of hydro power generation in India has been well

acknowledged. A number of power stations of this type have been commissioned and more are in the pipe line. The canal fall Hydro Electric schemes are blessed with the advantages of small gestation periods, and are devoid of submergence; resettlement and other problems of environment and ecology [Study, 2002].

2 SMALL HYDROPOWER TECHNOLOGY

Hydro-turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, or other machinery. The power available is proportional to the product of pressure head and volume flow rate. The general formula for any hydro system's power output is given in Eq.(1).

$$P = \eta \rho g Q H \quad (1)$$

Where, P is the mechanical power produced at the turbine shaft (Watts), η is the hydraulic efficiency of the turbine, ρ is the density of water (kg/m^3), g is the acceleration due to gravity (m/s^2), Q is the volume flow rate passing through the turbine (m^3/s), and H is the effective pressure head of water across the turbine (m). The best turbines can have hydraulic efficiencies in the range 80 to over 90% (higher than most other prime movers). Fig 1 illustrates a typical small hydro scheme [Nigam, 1985].

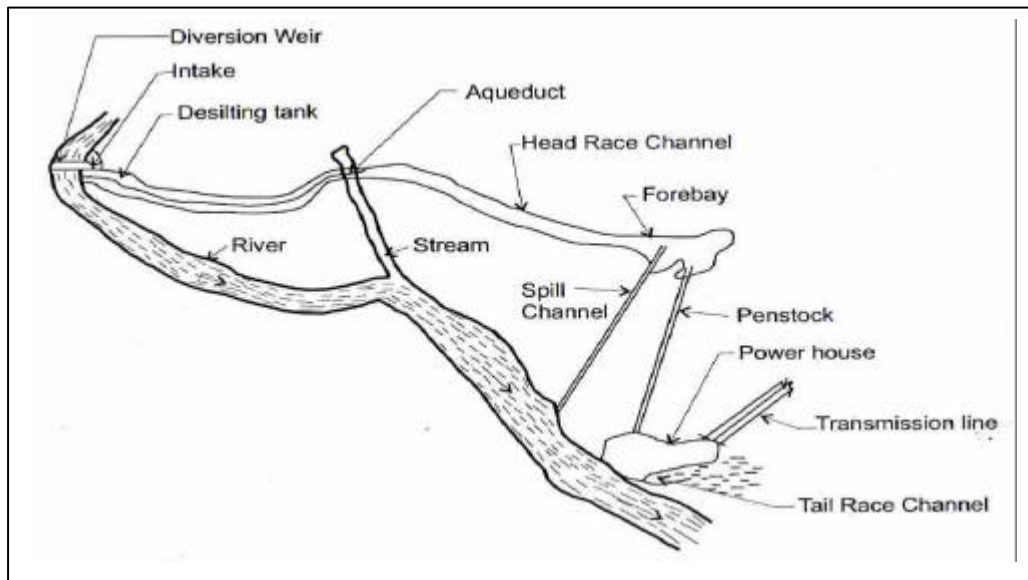


Fig. 1: Typical layout of small hydro power scheme

3 LOW HEAD SHP SCHEMES

Hydroelectric sites are divided into three categories by head as low, medium or high, each category requires different design [Varshney, 2001].

Low Head: 3 to 20 m head. A large number of sites identified for small hydro development normally in irrigation works are in the low-head category.

Medium Head: 20 to 60 head.

High Head: More than 60 m head.

These suggested limits are not rigid but are merely a means of categorizing sites. Low head small hydropower (SHP) schemes upto 20 m head could be run of river, dam based but are mostly canal based schemes. The run of river and dam based scheme components are mostly site specific. We are discussing for canal based small hydropower schemes in this paper. The basic components of canal based low head small hydro scheme can be broadly classified as (i) civil works and (ii) electro-mechanical equipments.

3.1 Civil Works

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 built small hydropower plant while new irrigation channels being planned or built, civil works of small hydro should be taken up side by side to make works economical.

3.2 Electro-Mechanical Equipment

The Electro-mechanical equipment is considered to be the equipment and system required to develop the energy available in impound or flowing water to convert it into electrical energy, to control it and to transmit it to the power grid. The major Electro-mechanical component of power plant is the inlet valve, turbine, draft tube, gates, generator, control and protection equipment and substation for transformation of power to the transmission line. In terms of space requirement and cost the major items are the turbine and generator. Types of turbine and generator used under different operating conditions are available in the literature [S: 12800, 1991]. There are varieties of turbines available in the low head range such as propeller, open pit, tubular, bulb, vertical siphon and Kaplan. Double regulated Kaplan is being used only when there is large variation in discharge and unit capacity are over 1 MW. All active indigenous turbine manufacturers offer these turbines. Tubular turbine is the most commonly used turbine in the low head range.

4 ANALYSIS FOR COST OF SHP PROJECTS

For decision making in development of any 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 rates of various items etc. To know the realistic cost of the project, detailed investigations for topography, hydrology, environment and ecology, geology, construction material are to be carried out in detail. Rate of different items, preliminary layout and drawings of the components of the project and specifications of hydro- mechanical and electrical equipments are also required.

The development of a project involves the following steps.

1. Project formulation and planning.
2. Execution of the project.

4.1 Project Formulation Planning

This is pre-implementation stage. All investigations, data collection, project formulation, feasibility study, report preparation is done during this stage.

4.2 Project Execution

The decision to go ahead for project execution is to be taken based on feasibility report (or detailed project report). Detailed project report is a very important document, which contains, 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 works/ equipments, size of components, cost of materials, economical and financial analysis of the project based on the techno-economical feasibility presented in feasibility report.

It is clear from above that one has to make substantial investment in terms of time, efforts and money cost of project is important to know for this. After, all this exercise, if we find that the project is not techno-economical viable all the investment made will be a waste. So, we have developed a methodology for assessment of cost of the project to know the realistic cost of the project for determination of its techno-economical viability and we are able to know the likely cost of the project before undertaking detailed investigations.

5 METHODOLOGY FOR ASSESSMENT OF COST

The cost of the SHP scheme depends on the physical sizes of civil works and the electro-mechanical equipments. The sensitive parameters are head and discharge. In low head SHP schemes, large discharges are to be handled, thus physical sizes are relatively less. The layout of the scheme and sizes of machine are determined in terms of runner diameter of turbine.

Cost of civil works including all the civil structure such as diversion channel, spillway and power house building. The hydro-mechanical works /equipment includes gates, valves, turbine governor and gearbox etc. The electrical equipment includes generator, electrical control and other accessories. Here we have divided these works / equipment in the categories of civil works and electro-mechanical equipments. Some of the hydro-mechanical equipment such as gates, valves and trash rack are included in respective civil works components and turbines, governor; gearbox is included in Electro-mechanical equipments as per worldwide practice.

The total project cost includes cost of civil works, cost of electro- mechanical equipments and other miscellaneous items. The other miscellaneous items consists of Establishment related cost including designs, Audit & Account etc. indirect charges, tools and plants, communication expenses, preliminary expenses on report preparation, survey and investigations and cost of land. Such cost on other miscellaneous items comes out to be 13% of the cost of civil works and electro- mechanical equipments [CEA, 1982].

We have taken several examples of different head and discharges, having the typical layout of tubular turbine with power house in bye pass channel and main channel used as spillway with gated structure for regulation of flow of water as shown is figure 2. From this layout, quantities and cost of various works based on prevailing market rates are determined and shown in Table -1.

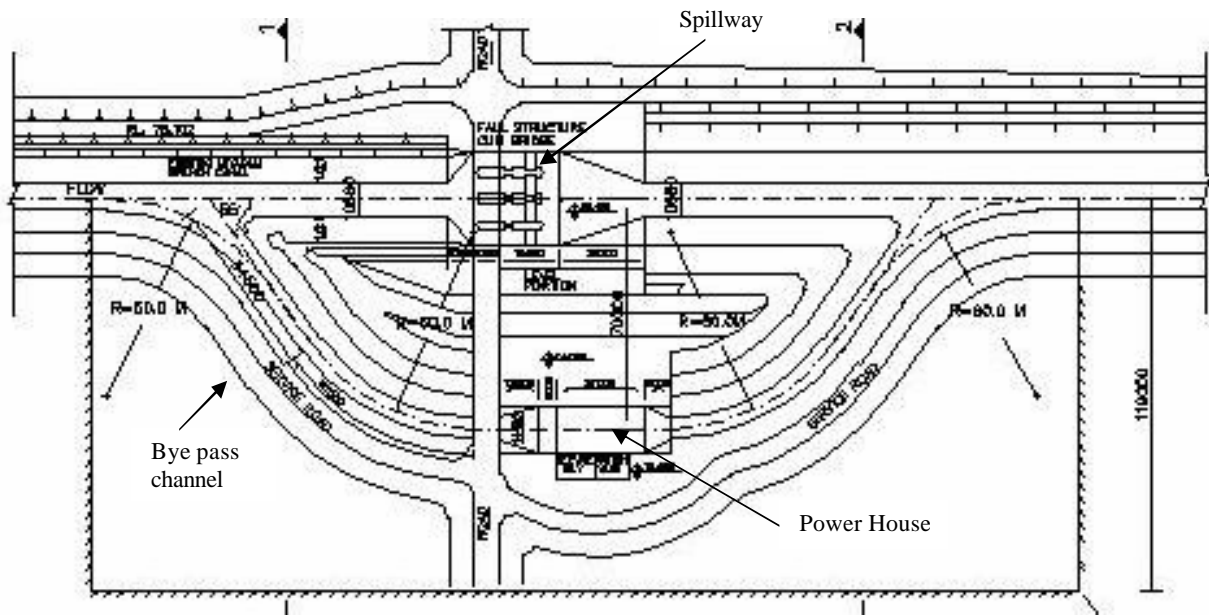


Fig. 2: Typical layout of canal based low head scheme.

Table - 1: Analysed Cost of SHP Schemes

| Head (m) | Capacity (kW) | Runner dia (m) | Total Cost (Million Rs.) | Cost per kW (Rs.) |
|----------|---------------|----------------|--------------------------|-------------------|
| 3 | 1000 | 3.03 | 80.10 | 80103 |
| 5 | 1000 | 2.08 | 74.60 | 74602 |
| 8 | 1000 | 1.50 | 69.23 | 69227 |
| 10 | 1000 | 1.28 | 66.48 | 66477 |
| 12 | 1000 | 1.08 | 64.98 | 64978 |
| 15 | 1000 | 0.93 | 62.86 | 62865 |
| 3 | 2000 | 4.27 | 139.46 | 69729 |
| 5 | 2000 | 2.93 | 128.90 | 64451 |
| 8 | 2000 | 2.08 | 120.63 | 60315 |
| 10 | 2000 | 1.75 | 116.49 | 58246 |
| 12 | 2000 | 1.52 | 113.59 | 56795 |
| 15 | 2000 | 1.34 | 109.66 | 54828 |
| 5 | 4000 | 4.11 | 224.07 | 56018 |
| 8 | 4000 | 2.94 | 208.03 | 52007 |
| 10 | 4000 | 2.50 | 202.21 | 50551 |
| 12 | 4000 | 2.15 | 196.77 | 49192 |
| 15 | 4000 | 1.86 | 190.99 | 47748 |
| 5 | 5000 | 4.62 | 268.87 | 53775 |
| 8 | 5000 | 3.34 | 248.86 | 49772 |
| 10 | 5000 | 2.76 | 241.87 | 48374 |
| 12 | 5000 | 2.39 | 235.21 | 47042 |
| 15 | 5000 | 2.08 | 228.21 | 45642 |
| 5 | 8000 | 5.76 | 389.96 | 48745 |
| 8 | 8000 | 4.16 | 363.26 | 45408 |
| 10 | 8000 | 3.63 | 346.26 | 43283 |
| 12 | 8000 | 3.03 | 341.66 | 42707 |
| 15 | 8000 | 2.60 | 330.76 | 41345 |
| 6 | 10000 | 5.69 | 447.84 | 44784 |
| 8 | 10000 | 4.60 | 433.44 | 43344 |
| 10 | 10000 | 3.91 | 419.82 | 41982 |
| 12 | 10000 | 3.42 | 406.64 | 40664 |
| 15 | 10000 | 2.88 | 393.00 | 39300 |

The cost function has been developed which is sensitive to the installed capacity and head parameters. The exponents for these parameters have been obtained by regression analysis. In the first step, analysis is done between installation cost and installed capacity to find out the exponent of installed capacity. Then results were analysed with the head in second step to find out the coefficient and exponent of head. The developed co-relation is as given by Eq. (2).

$$C = 437403 P^{-0.2206} H^{0.1435} \quad (2)$$

Where,

- C = Cost per kW in Indian Rupees
- P = Capacity in kW
- H = Head in m

The developed co-relation has been verified with cost data of recently completed such power stations as shown in Fig. 3. A maximum deviation of $\pm 12\%$ has been observed which may be considered as a good prediction for cost estimate of SHP projects at the planning stage.

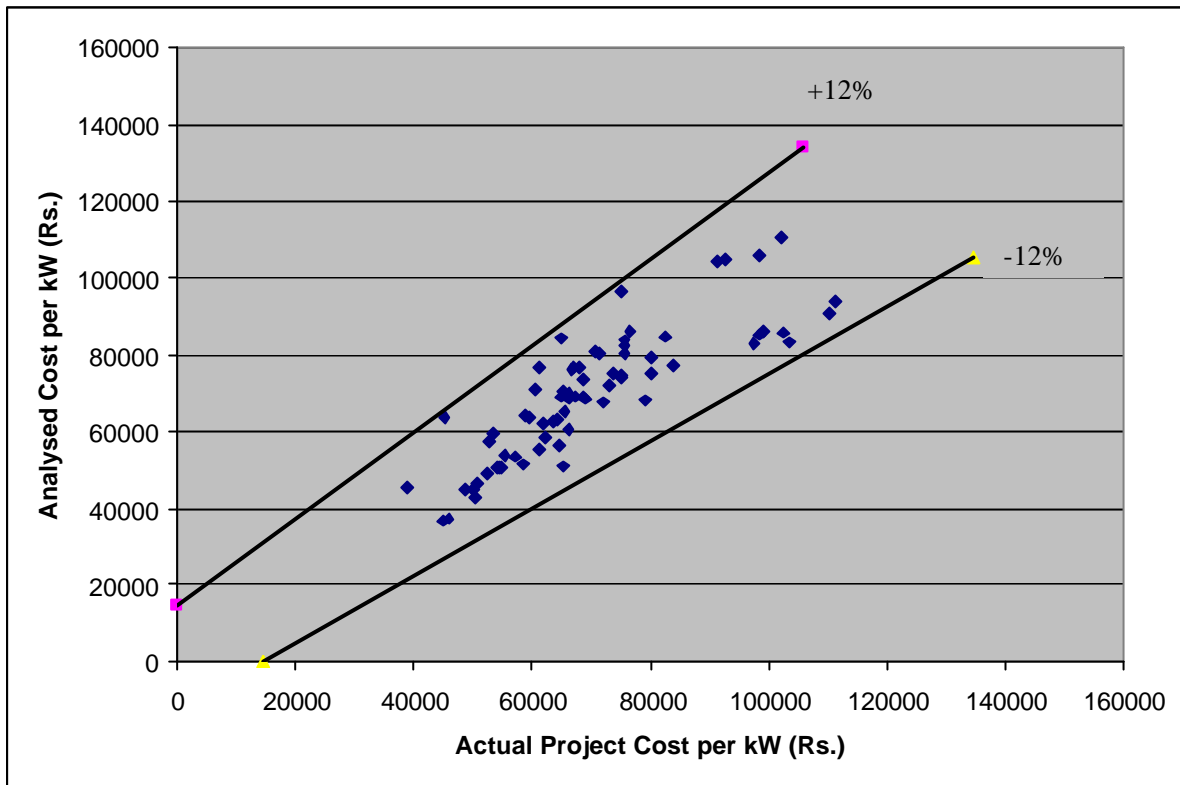


Fig. 3: Comparison of analysed cost and actual project cost

6 CONCLUSIONS

An analysis for cost of canal based small hydropower schemes has been made and co-relation has been developed for estimation of cost, which can be used for predicting the cost of new sites to be developed. This co-relation can give the cost of such schemes with in $\pm 12\%$ accuracy, which could be taken as basis for investment decisions to harness a large potential available on canal falls. The cost worked out from this co-relation may vary slightly for different conditions such as location of site, topography, geological conditions, type of turbine etc.

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