Costing of a Small Hydropower Projects

Sachin Mishra, S. K. Singal, and D. K. Khatod

***Abstract*—Hydropower, large and small, remains by far the most important of the renewable sources for electrical power generation worldwide, providing 19% of the planet's electricity. Small hydro is one of the cost-effective and environmentally benign energy technologies to be considered for rural electrification in less developed countries. The installation cost of the small hydropower project is mainly divided into two parts - Civil works and electromechanical equipment. One of the most important element on the recovery of a small hydro-power plant is the electromechanical equipment (turbine–alternator). The cost of the equipment means a high percentage of the total budget of the plant. The present paper intends to develop a correlation to determine the cost based on the influencing parameters such as power and head. An attempt has been made to develop the trend of the cost of electromechanical equipment with the increase in head of the hydropower plant.**

***Index Terms*—Small hydropower, cost, electromechanical equipment**

I. Introduction

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. Out of the all non-conventional renewable 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 first small hydro project in India having 130 kW capacity was commissioned in the hills of Darjeeling in West Bengal state 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 [1], [2].

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 [1].

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II. 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).

$$P=\eta\rho gQh \quad (1)$$

where, P is the mechanical power produced at the turbine shaft (Watts), h 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 [3].

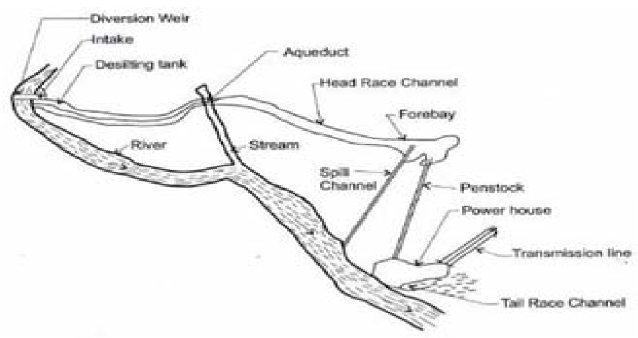

Fig. 1. A typical layout of a SHP scheme [4]

III. Cost Estimation

The basic components of small hydro scheme can be broadly classified as (i) civil works and (ii) electro-mechanical equipments.

A. Civil Works

In 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.

B. 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 electric al 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 [IS: 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 [1], [5].

The cost of the electro-mechanical equipment (turbine, alternator and regulator) means a high percentage of a small hydropower plant budget (around 30% and 40% of the total sum). It stems from this the importance of the determination of that cost, which could directly influence the project feasibility (Fig. 2) [6].

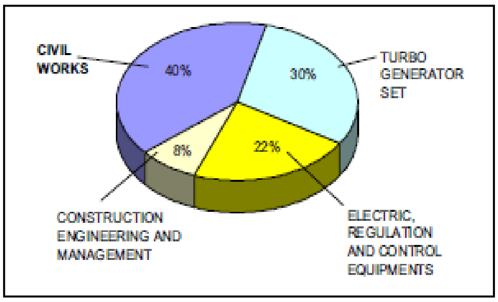

Fig. 2. Distribution of investments on a hydro-power plant [6]

IV. Cost Analysis Methodology

The cost estimation process starts with the collection of data required for this process, which involves various components of civil works and electromechanical equipment of different projects, executed recently. The cost components are then inflated considering inflation rates over the years. This data set is then screened to detect outliners which have unreasonable installation cost. The parameters on which the civil and E ang M cost depends are identified. These are installed capacity, head and year of commissioning etc.

The mathematical model for these costs in terms of identified parameters is selected which is defined as [4], [5], [6]:

$$C_{(a,b,c)} = a \times (P)^{b} \times (H)^{c} \tag{2}$$

where

a, b and *c* are coefficients,

C= Cost in rupees (Rs.)

P = Installed capacity in kilo Watt (kW)

H =Head in meter (m).

A. Cost Estimation at Different Heads

The cost of SHP scheme depends on the physical sizes of electro-mechanical equipments. The cost sensitive parameters are head and installed capacity.

Plots of the Ln (*C*) vs Ln (*P*) for different sets of heads (*H*) were drawn and it was observed that in all the cases, the values of slope of different lines are nearly same while the value of intercept of each line is different. The functional relationship between Cost and installed capacity of the hydropower was found to follow the equation given below [6]:

$$Ln(C) = nLn(P) + A_1 \tag{3}$$

Eq. (3) can be written as:

$$C = A_o (P)^n \tag{4}$$

where, A_o is anti-$Ln(A_1)$

The least square method is used to fit the best curve through the all the data points pertaining to thirty three different installed capacities (Fig. 3) and the relationship obtained is as

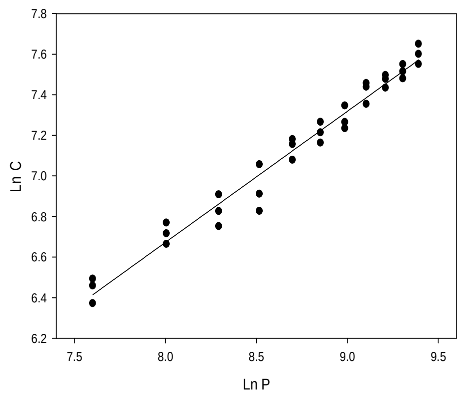

Fig. 3. Plot of Ln (*C*) as function of Ln (*P*)

$$C = A_o (P)^{0.6369} \tag{5}$$

In Eq. (5), the value of constant A_0 is a function of head of the small hydro power plant. As with the effect of increase in the head the cost of the electromechanical equipment decreases. The functional relationship between cost of electromechanical equipment and the Head (*H*) was found to follow the equation given below:

$$Ln(A_o) = nLn(H) + B_1 \tag{6}$$

Eq. (6) can be written as

$$A_o = B_o (H)^n \tag{7}$$

where, B_o is anti-Ln(B_1)

A regression analysis to fit a straight line through data points yields:

$$A_o = B_o (H)^{-0.0782} \tag{8}$$

Eq. (8) can be written as:

$$\frac{C}{P^{0.6369}} = B_o\, H^{-0.0782} \quad (9)$$

Thus,

$$C = B_o\, H^{-0.0782}\, P^{0.6369} \quad (10)$$

where, B_o is anti-Ln(B_1)

C_o is a function of Head and installed capacity of small hydropower plant.

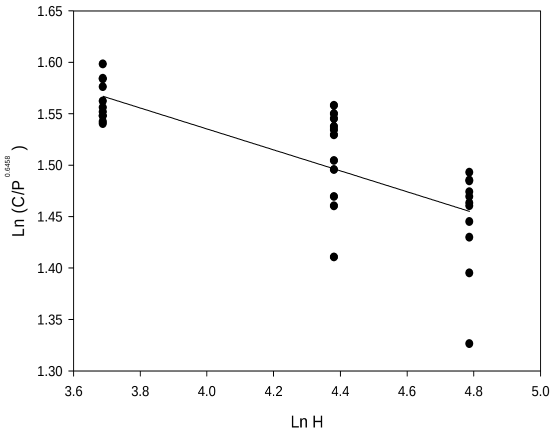

Fig. 4. Plot of Ln ($C/P^{0.6369}$) as function of Ln (H)

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 head to find out the exponent of head. Then results were analysed with the installed capacity in second step to find out the coefficient and exponent of installed capacity. The developed co-relation is as given by Eq. (11).

$$C = 6.882\, H^{-0.0782}\, P^{0.6369} \quad (11)$$

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 through which it has been developed as shown in Fig. 5. A maximum deviation of ±10% has been observed which may be considered as a good prediction for cost estimate of SHP projects at the planning stage.

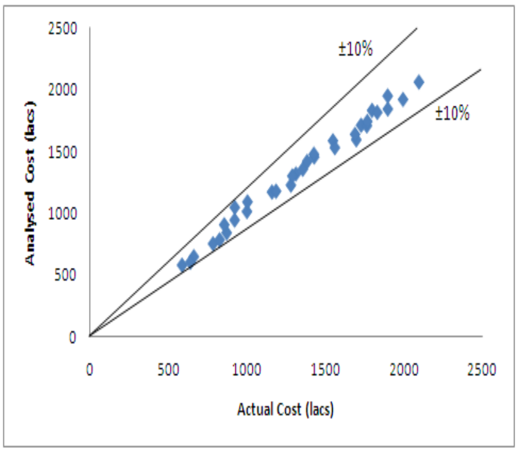

Fig. 5. Error analysis of analysed cost and actual project cost

B. Cost Variation w.r.t Head

As mentioned that the cost of electro-mechanical equipments constitute high percentage of budget of small hydropower plant. Therefore, it is necessary to estimate the cost of the electro-mechanical equipments before construction of the small hydropower plant. In this section an effort is made to analyze the variation of cost per kW with respect to different heads. For computing the cost per kW of a small hydropower the above developed co-relation is used. The variation of cost per kW with respect to the head is shown in Fig. 6.

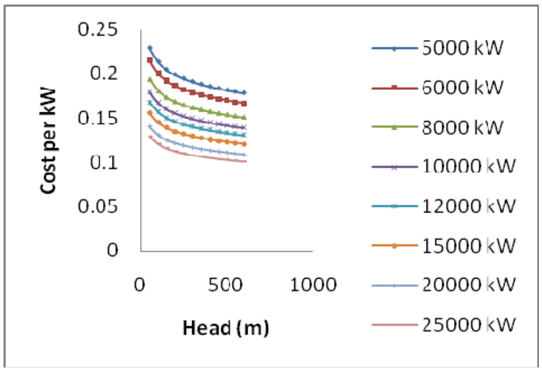

Fig. 6. Vartion of cost per kW with respect to heads

V. Conclusion

An analysis of cost of electro-mechanical equipment for small hydropower has been made and a co-relation is developed to determine the cost of electro-mechanical equipment. This can be useful for the prediction of cost of electro-mechanical equipment for the new sites. This co-relation gives the cost estimation with in ± 10% accuracy. By using developed co-relation it has been found that the cost of the electro-mechanical equipment decreases with increase in the head. This is because the size of the electro-mechanical equipment reduces with increase in the head. That is for high head small hydropower the cost of electro-mechanical equipment will be less as compared to the small head SHPs for the same capacity.

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