

Cost Analysis for High Head SHP Projects

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Abstract. Economic viability of a Small hydropower (SHP) project is very important along with its technical feasibility for taking investment decision. In the present study an attempt has been made to develop the correlations for the cost of SHP projects having high head. The results obtained were verified and maximum error was found $\pm 19\%$. Thus correlation developed may be used to assess generation cost for such projects.

Keywords: Generation cost, high head, installation cost, small hydropower, plf.

1. Introduction

Energy sector plays a vital role in the growth and development of any economy, particularly for a developing country like India. The present installed capacity of power generation in India is 186654 MW; out of which hydropower contributes 20.76%, thermal 65.88%, renewable 10.80% and nuclear 2.6%. The country is still short of power. The all-India average energy shortage is 8.8%, while the all-India average peaking shortage is 12.2% [1, 2, 3]. It is crucial to find sustainable energy generation options with high efficiency and broad applications. Following this criteria there are few possibilities of power generation, such as solar, wind and small hydropower. Out of various renewable energy sources, small hydropower is the source which has sufficient potential to accommodate remote area needs [4, 5].

Under the present study, an attempt has been made to determine the generation cost for run of river (RoR) schemes using Pelton turbine and with different options based on types of penstock material and head race channel/pipe material.

2. Run of River High Head Small Hydropower Plant

In India, hydropower project up to 25 MW station capacity are categorized under small hydropower (SHP) [6]. Broadly small hydropower Schemes are divided into three categories: Run of River schemes, canal based schemes and dam based schemes. Further, small hydropower schemes are classified based on head as low head from 3 to 30 m, medium head from 30 to 100 m and high head more than 100 m. These limits are not rigid [7].

Run of river schemes are developed in the hilly regions, using the natural river flow without any reservoir. A typical layout of such scheme is shown in Fig. 1. The main components of civil works in RoR high head schemes are diversion weir and intake, desilting chamber, intake and head race channel/pipe, forebay and spillway/ surge tank, penstock, powerhouse building and tail race channel.

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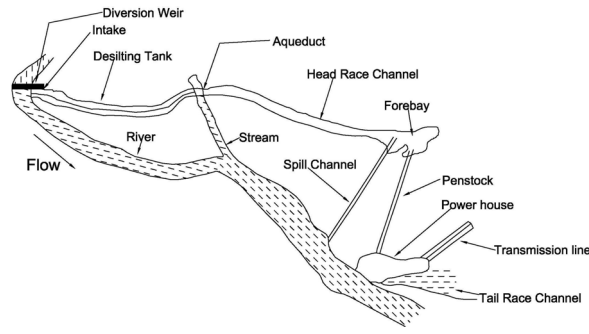


Fig. 1. Typical layout of RoR high head SHP scheme

The electromechanical equipment in such scheme consist of the turbines with governing system, generator with excitation system, switch gear, control, and protection equipment, electrical & mechanical auxiliaries and main transformer & switchyard equipment. Among different types of turbine such as Kaplan, Francis, Pelton and Turgo Impulse, mostly Pelton turbine is used in high head schemes, hence considered in the present study.

3. Cost Analysis

In the present study, an analysis has been carried out for development of correlations for cost of the various items required for the construction of various components of RoR high head small hydropower schemes having two units in the head range 100 to 600 m and unit size 1000 to 12500 kW. The cost has been determined for various layouts having different head and capacity based on actual quantities of various items with prevailing item rates. The correlation for cost as a function of head, capacity and runner diameter was developed by regression analysis for the layouts having Pelton turbine.

1.1. Methodology

The cost of SHP scheme depends on the physical sizes of civil works and electro-mechanical equipment. The correlations for cost or quantity of material required for civil work is given in Eq (1)

$$C = f(w, x) \quad (1)$$

where w, x are the cost influencing parameter. A correlation has been statistically developed for cost per kW or quantity of material required for civil work (C) by regression analysis of the collected data. In order to determine the functional relationship between cost per kW or quantity of material required for civil work (C) and the cost influencing parameter (w), a set of data points for different heads and capacity has been plotted on log–log scale. Plots of the $\ln(C)$ vs $\ln(w)$ for different sets of other cost influencing parameter (x) 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 per kW or quantity of material required for civil work and the cost influencing parameter (w) was found to follow the equation given as Eq. (2) [8].

$$\ln(C) = b \ln(w) + A_1 \quad (2)$$

or

$$C = A_o w^b \quad (3)$$

where, A_o is anti- $\ln(A_1)$

The least square method is adopted for best fit curve through all the data points pertaining to different installed capacities. In Eq. (3), the value of constant A_o is a function of other cost influencing parameter (x). The functional relationship between cost or quantity of material required for civil work and the other cost influencing parameter (x) was found to follow the Eq. (4) given below:

$$\ln(A_o) = c \ln(x) + B_1 \quad (4)$$

or

$$A_o = B_o (x)^c \quad (5)$$

where, B_o is anti- $\ln(B_1)$

From Eq. (3), Eq. (5) can be written as:

$$C = B_o w^b x^c \quad (6)$$

where, B_o is anti- $\ln(B_1)$

1.2. Civil Works

The methodology described in previous section has been used to develop quantities of items required for civil work. From the quantities determined for various components of civil works under different options, the correlation were developed and given in Table 1.

The cost of various items required for the construction of the components under civil works have been determined for different cases based on prevailing rates of civil works for the year 2011. The total civil work cost (C_C) per kilo Watt is given in eq. (7)

$$C_C = C_W + C_{IC} + C_{DT} + C_{HRC} + C_F + C_P + C_{PH} \quad (7)$$

where, C_W , C_{IC} , C_{DT} , C_{HRC} , C_F , C_P and C_{PH} are the cost per kW of weir, intake channel, desilting tank, head race channel/pipe, forebay, penstock and power house building respectively.

Table 1. Correlation for different civil works items

S.No.	Civil Works		ITEMS			
	Components	Earth work in excavation, E/W	Concreting, Conc.	Reinforced Steel, RS	Structural Steel, SS	
1.	Weir	$233.921 Q^{0.9332}$	$609.3683 Q^{1.0004}$	$48.6582 Q^{0.9881}$	$0.7322 Q^{0.9837}$	
2.	Intake Channel (per meter)	$9.2277 Q^{0.9170}$	$1.5033 Q^{0.9931}$	$0.000565 Q^{0.8846}$	--	
3.	Desilting Tank	$870.75 Q^{1.0056}$	$1.87 Q^{0.9803}$	$15.3504 Q^{0.92}$	$0.5839 Q^{1.0047}$	
4.	Head race channel (per meter)	$8.2277 Q^{0.9130}$	$0.1033 Q^{0.9151}$	$0.0000388 Q^{0.8646}$	--	
	MS pipe	$5.6882 Q^{0.9815}$	$0.3735 Q^{1.0078}$	$0.02857 Q^{0.9338}$	$8.1481 Q^{1.2893}$	
	PVC pipe	$5.6882 Q^{0.9815}$	$0.3735 Q^{1.0078}$	$0.02857 Q^{0.9338}$	$0.1085 Q^{0.9815}$	
5.	Forebay and spillway	$545.007 Q^{1.0007}$	$297.3173 Q^{0.997}$	$24.8868 Q^{0.9499}$	$4.1934 Q^{0.9971}$	
6.	Penstock (per meter)	$0.07774 Q^{0.9971}$	$0.09529 Q^{1.0019}$	$0.000582 Q^{1.9921}$	$2.0857 Q^{1.2832}$	
	HDPE	$0.07774 Q^{0.9971}$	$0.09529 Q^{1.0019}$	$0.000582 Q^{1.9921}$	$9.6014 Q^{1.2830}$	
	PVC	$0.07774 Q^{0.9971}$	$0.09529 Q^{1.0019}$	$0.000582 Q^{1.9921}$	$9.0991 Q^{1.2821}$	
	GRP	$0.07774 Q^{0.9971}$	$0.09529 Q^{1.0019}$	$0.000582 Q^{1.9921}$	$0.6486 Q^{1.2822}$	
7.	Tailrace channel (per meter)	$8.2277 Q^{0.9270}$	$0.5033 Q^{0.9011}$	$0.0003 Q^{0.9123}$	--	
8.	Power house building	$2.1913 d^{1.0743} p^{0.0994}$	$2.7467 d^{1.0607} p^{0.0967}$	$0.212 d^{0.9239} p^{0.1397}$	$0.00056 d^{0.108} p^{0.1047}$	

3.1. Electro-Mechanical Equipment

For a range of capacity, head, and runner diameter considered under the present study, cost values of electro-mechanical equipment considering different turbines are determined. Same methodology as used in correlation development for power house building has been employed for the development of cost correlation for electro-mechanical equipment considering different turbines. Therefore, the correlation developed for cost per kW for electro-mechanical equipment ($C_{e\&m}$) using Pelton turbine is given by eq. (8)

$$C_{e\&m} = 40247.3725 d^{0.0282} P^{-0.0391} H^{-0.1266} \quad (8)$$

3.2. Total Cost

The cost of civil works, cost of electro- mechanical equipment, cost of other miscellaneous items and other indirect costs constitute the total cost. 13% of the cost of civil works and electro- mechanical equipment has been taken on account of these miscellaneous and indirect costs [8].

Total cost per kW (C) has been worked out by using following expression.

$$C = 1.13 \times (C_C + C_{e\&m}) \quad (9)$$

4. Financial Analysis

In financial analysis, generation cost has been computed in the first year of operation of plant. The procedure adopted for the computation of generation is discussed as follows [8]:

- Determined installation cost using eq. (9) for known values of head and installed capacity.
- Determined annual energy by using the equation

$$E = P \times 8760 \times \eta_T \times \eta_g \times P_L \quad (10)$$

where E is the energy in kW h, P is the installed capacity in kW, η_T is the efficiency of turbine, η_g is the efficiency of generator, and P_L is the plant load factor.

Determined annual cost and generation cost by using eq. (11 and 12) considering operation and maintenance (O&M) cost including insurance, depreciation, and interest on the capital borrowed.

$$\text{Annual Cost, } C_a = C_{O\&M} + C_d + C_i \quad (11)$$

$$\text{Generation cost, } C_g = C_d / E \quad (12)$$

where, $C_{O\&M}$ is the operation and maintenance cost, C_d is the depreciation cost, C_i is the annual interest, and E is the annual energy.

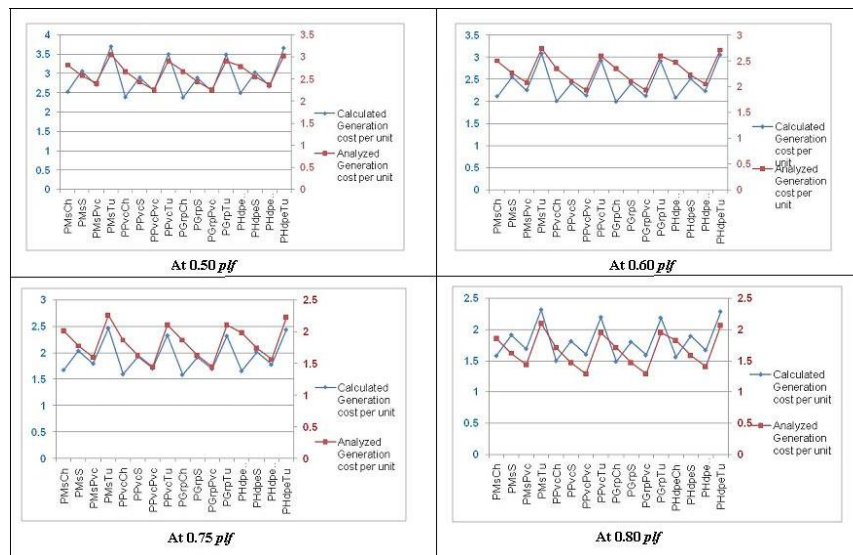
By using above methodology, the generation cost was calculated for different options and the data generated were used for the development of correlation for generation cost by using Minitab software. The correlation developed is given in eq. (13)

$$\text{Generation cost (INR/unit)} = 4.75 - (3.2 * p/f) - (0.000347 * H) - (0.00065 * P) - (0.000228 * n) + (0.0615 * n_j) + (0.278 * (f_i / f_{ms})) + (1.2 * ((n_c / n_{tunnel})) \quad (13)$$

where, n is the speed of the turbine, n_j is the number of jets in Pelton turbine, f_i is the friction loss, f_{ms} is the friction loss in mild steel penstock, n_c is the manning coefficient of channel/pipe used for head race and n_{tunnel} is the manning coefficient of material used in construction of tunnel.

5. Results And Discussions

Table 2. Generation cost per unit for 2 MW and 300m head



In the present study, high head SHP schemes having two generating units have been considered for analysis. The correlations developed for the quantities of various items for different components have been used to compute cost based on the quantities and their prevailing prices. Based on the cost computed from the correlations, financial analysis has been carried out to determine the generation cost for different options using headrace channel/pipe and penstock from different materials having Pelton turbine at different load factors. A correlation for the generation cost has been developed and validated for different layouts of high head SHP schemes. A maximum error of $\pm 19\%$ is observed and the developed correlation can be used to determine the generation cost for different high head projects. Table 2 shows the generation cost based on developed correlation. It is seen that generation cost varies from Rs. 1.30 to Rs. 3.00 per unit where it is

attractive considering selling price around Rs. 3.00 to Rs. 4.50 per unit (1 US\$=50 INR) in different parts of country.

6. Conclusions

The correlations for quantities of various items for various components of RoR SHP schemes were developed by regression analysis. From the correlation of the quantities of various items the cost of various components of RoR based SHP schemes for different layouts were also obtained based on prevailing item rates. Based on developed correlations, installation cost of the scheme has been determined. A correlation for generation cost was also developed at different load factor for different options to assess the same. The developed correlation can be used for planning of future projects.

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