ESTIMATION OF COST OF SMALL HYDRO POWER PLANT USING REGRESSION ANALYSIS

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Abstract
The transition to sustainable energy sources is critical in addressing global environmental challenges and meeting the increasing energy demands. Small hydro power plants (SHPs) have emerged as a viable solution due to their minimal environmental impact, scalability, and potential for local energy independence. This paper provides a comprehensive analysis of the costs associated with developing and operating a small hydro power plant. Through a detailed examination of capital expenditures, including site assessment, civil works, and equipment procurement, as well as operational costs such as maintenance and regulatory compliance, this study offers a thorough cost estimation model for SHPs. The findings highlight the significance of accurate cost estimation in the planning and implementation phases, which is crucial for investors and policymakers to make informed decisions. Moreover, the paper underscores the economic viability of SHPs in comparison to other renewable energy sources, thereby advocating for their broader adoption. Ultimately, this research contributes to the strategic development of renewable energy infrastructure, emphasizing the importance of cost-effective and reliable energy solutions for sustainable development.

Keywords: SHP, Cost, Dam toe, Run of river, Kaplan turbine, Cross flow turbine etc.

Introduction

The cost of the project is dependent on a number of elements, including the location, the length of time it will take to complete the construction, the volatility in the cost of materials, the availability of construction equipment, and the fluctuation in the cost of labour during the building process. The entire cost of the project includes additional indirect expenses, such as the cost of electromechanical equipment, the cost of various miscellaneous items, and the cost of civil works[1]. Indirect costs are defined as those that are not directly related to the project itself. To begin, the installed capacity and head of the scheme are the key elements that affect the cost of components of civil works as well as the cost of electromechanical equipment.[2] This is the case regardless of whether the scheme is electrical or mechanical.

Mainly due to the fact that the cost of the turbine is a bigger proportion of the total cost of the project, in the case of a low head solar heat performance plan. The selection of a certain kind of turbine to be erected at a given location is still another job that is peculiar to the site. Because of the fact that the cost of a solar heat plant (SHP) varies depending on the type of turbine that is selected, it is important to consider the following[3]. In general, the cost of the powerhouse, the cost of the turbine, the cost of the generator, and the cost of the auxiliary will vary depending on the turbine that is taken into account. This is because not all turbines are created equal. On the basis of turbine selection, it is feasible to study a wide variety of turbines in order to obtain the most efficient installation of a solar heat plant (SHP) [3-4].

For the goal of this investigation, a sample site that had certain requirements, such as a head of twenty metres and a capacity of ten thousand kilowatts, was taken into consideration. Additionally, the overall cost of the various turbine systems was investigated. The three types of turbines that have been researched for the purpose of identifying the most ideal installation for the chosen location based on turbine selection are vertical semi-Kaplan turbines, tubular propeller turbines, and tubular Kaplan turbines[5]. The objective of this investigation is to determine which method of turbine selection is the most appropriate.

COST ESTIMATION

On the basis of the analysis that was carried out in ullas.et.al [1], the cost of various components for the site that was taken into consideration with a head of 20 metres and a capacity of 10,000 kW utilising various turbines has been estimated. There have been several cases presented, which are as follows.

BASIC COMPONENTS OF DAM TOE SCHEME

In toe-of-the-dam plans, the power house building is situated at the base of the dam, and the penstock is routed through the dam structure. The fundamental elements of such schemes can be classified into two main categories: (i) civil infrastructure and (ii) electromechanical apparatus. The primary elements of civil works include the intake, penstock, power house construction and tail race channel. The electromechanical components consist of turbines equipped with a controlling system, generators with an excitation system, electrical and mechanical auxiliary equipment, as well as transformer and switchyard equipment. Following are the components:-

- INTAKE
- PENSTOCK
- POWERHOUSE
- TAILRACE
- TURBINE
- GENERATOR
- AUXILLIARY
- TRANSFORMER & SWITCHYARD

TABLE 1 COST CORRELATIONS FOR SHP

SR	TYPE OF COMPONENT	COST CORRELATION
1	INTAKE COST	$C_1 = 17940P^{-0.2366}H^{-0.0596}$
2	PENSTOCK COST	$C_2 = 7875P^{-0.3806}H^{0.3804}$
3	POWERHOUSE COST (TUBULAR TURBINE USED)	$C_3 = 91231P^{-0.2356}H^{-0.0588}$
4	KAPLAN TURBINE USED	$C_3 = 97764P^{-0.2356}H^{-0.0589}$
5	VERTICAL KAPLAN	$C_3 = 83406P^{-0.2353}H^{-0.0588}$
6	**TAILRACE**	$C_4 = 28164P^{-0.376}H^{-0.6240}$
7	TURBINE COST (TUBULAR PROPELLER USED	$C_5 = 61153P^{-0.1961}H^{-0.2111}$

8	TURBINE COST (KAPLAN USED	$C_5 = 70170P^{-0.1853}H^{-0.2053}$
9	TURBINE COST VERTICAL KAPLAN USED	$C_5 = 62902P^{-0.1853}H^{-0.2092}$
10	**GENERATOR & EXCITATION COST**(TUBULAR PROPELLER USED	$C_6 = 78661P^{-0.1855}H^{-0.2083}$
11	**GENERATOR & EXCITATION COST**(KAPLAN USED	$C_6 = 81881P^{-0.1858}H^{-0.2095}$
12	**GENERATOR & EXCITATION COST**(VERTICAL KAPLAN USED	$C_6 = 83091P^{-0.1827}H^{-0.2097}$
13	**COST CALCULATION OF AUXILIARY** (TUBULAR PROPELLER USED	$C_7 = 38328P^{-0.1902}H^{-0.2134}$
14	**COST CALCULATION OF AUXILIARY** (KAPLAN USED)	$C_7 = 41982P^{-0.187}H^{-0.2099}$
15	**COST CALCULATION OF AUXILIARY** (VERTICAL KAPLAN USED	$C_7 = 42332P^{-0.1859}H^{-0.2084}$
16	**TRANSFORMER AND SWITCHYARD EQUIPMENT**	$C_8 = 18739P^{-0.1803}H^{-0.2075}$

CASE 1 The cost of the SHP plant in the first case, when the turbocharger turbine is being used
The cost calculation for different components of a Small Hydropower (SHP) plant using a tubular propeller turbine has been performed according to the methodology described in [1]. The resulting data has been organised and shown in Table 2.

Table 2 displays a number of different cost estimations for the assumed site specification (for the tubular propeller turbine).

TYPES OF COST	COST PER kW	TOTAL COST (Rs)
COST OF INTAKE (C_1)	1697	16977785
COST OF PENSTOCK(C_2)	739	7392007
COST OF POWERHOUSE(C_3)	8734	87345768
COST OF TAILRACE CHANNEL(C_4)	136	1360979
COST OF TUBULAR PROPELLER TURBINE(C_5)	5337	53378987
COST OF GENERATOR &EXCITATION SYSTEM(C_6)	7634	76340485
COST OF AUXILIARY(C_7)	3508	35081354
COST OF TRANSFORMER & SWITCHYARD SYSTEM(C_8)	1912	19124174
TOTAL COST OF CIVIL WORK(C_c=C_1+C_2+C_3+C_4)	11307	113076541
TOTAL COST OF ELECTROMECHANICAL WORK($C_{e\&m}$=C_5+C_6+C_7+C_8)	18392	183925001

CASE 2 COST OF SMAAL HYDRO POWER PLANT WITH TUBULAR - KAPLAN TURBINE
Cost analysis of different components of a Small Hydropower (SHP) plant when a tubular Kaplan turbine is utilised. The calculation has been performed as described in [1] and the resulting data has been organised in Table 3.

Table 3 shows the various cost calculations for assumed site specification (for tubular Kaplan turbine)

TYPES OF COST	COST PER kW	TOTAL COST(Rs)
COST OF INTAKE(C_1)	1697	16977785
COST OF PENSTOCK(C_2)	739	7392007
COST OF POWERHOUSE(C_3)	9357	93572513
COST OF TAILRACE CHANNEL(C_4)	136	1360979
COST OF TUBULAR KAPLAN(C_5)	6884	68841451
COST OF GENERATOR & EXCITATION SYSTEM(C_6)	7896	78961857
COST OF AUXILIARY(C_7)	3999	39992350
COST OF TRANSFORMER & SWITCHYARD(C_8)	1912	19124174
COST OF CIVIL WORK($C_c=C_1+C_2+C_3+C_4$)	11930	119303286
COST OF ELECTROMECHANICAL WORK($C_{e\&m}=C_5+C_6+C_7+C_8$)	20691	206919832

CASE 3: COST OF SMALL HYDRO POWER PLANT WITH VERTICAL SEMI-KAPLAN – TURBINE

The cost estimate of different components of a small hydroelectric power (SHP) plant, using a vertical semi-Kaplan turbine, has been performed according to the methodology described in [11. The resulting data has been organised and presented in Table 4.

Table 4 Displays the various cost estimations for the anticipated site specification (for the vertical semi-Kaplan turbine).

TYPES OF COST	COST PER kW	TOTAL COST(Rs)
COST OF INTAKE(C_1)	1697	16977785
COST OF PENSTOCK(C_2)	739	7392007
COST OF POWERHOUSE(C_3)	8007	80074959
COST OF TAILRACE CHANNEL(C_4)	136	1360979
COST OF VERTICAL SEMI-KAPLAN TURBINE(C_5)	6201	62013890
COST OF GENERATOR & EXCITATION SYSTEM(C_6)	8240	82400148
COST OF AUXILIARY(C_7)	4091	40919859
COST OF TRANSFORMER & SWITCHYARD(C_8)	1912	19124174
COST OF CIVIL WORK($C_c=C_1+C_2+C_3+C_4$)	10580	105805732
COST OF ELECTROMECHANICAL WORK($C_{e\&m}=C_5+C_6+C_7+C_8$)	20445	204458073

MISCELLANEOUS COST CALCULATION

The miscellaneous cost of any small hydroelectric power (SHP) plant is determined by factors such as the scheme type and the type of turbine used. Mathematically, it is estimated that the miscellaneous cost is equal to 0.13 times the sum of the civil work cost and the electromechanical cost.

$$C_{misc.} = 0.13(C_C + C_{e\&m}) \quad (1)$$

Where C_{misc} =miscellaneous cost per kW

The cost of miscellaneous items for various turbines has been computed using Equation (1) and the results are presented in Table 5

Table 5

Types turbines	Head	Power(kW)	C misc(Rs)
Tubular propeller turbine	20	10000	3861
Tubular Kaplan turbine	20	10000	4240
vertical semi-Kaplan turbine	20	10000	4033

TOTAL ESTIMATION OF COST

The total cost will be the aggregate of the expenses incurred for civil works, electromechanical equipment, and other goods, as indicated by the following equation:

$$C_T = C_c + C_{e\&m} + C_{misc.} \quad (2)$$

Through the utilisation of Equation (2), the total cost of various turbines has been computed, and the results have been collated, as can be seen in Table 6.

Table 6: Combined expenses incurred by the plant for the various turbines

Turbine types	Head (m)	Power(KW)	Overall Cost per KW of plant	Total cost of plant (Rs)
Tubular types propeller turbine	20	10000	33561.17436	335611743.6
Vertical type semi-Kaplan	20	10000	35059.67526	350596752.6
Tubular type Kaplan	20	10000	36863.21244	368632124

Table 5 reveals that there is variability in the cost of the plant among different turbines. Figure 1 illustrates the fluctuation in the total cost of a small hydroelectric power scheme based on the toe of a low head dam.

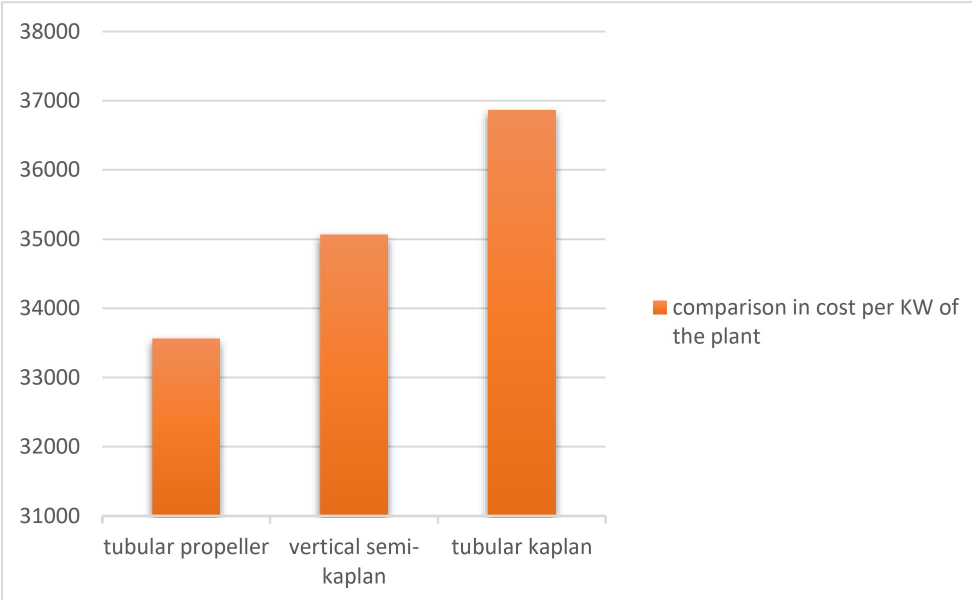

Fig.1: comparison of cost per kW of SHP plant

Utilising a tubular propeller turbine results in the lowest overall cost of the plant when compared to the utilisation of a tubular Kaplan turbine and a vertical semi-Kaplan turbine, as seen in the chart above, which was plotted against various turbines and cost per kW. For this reason, the utilisation of a propeller tube turbine results in a more cost-effective configuration for the plant.

CONCLUSIONS

It has been determined how much various components of civil works and electro-mechanical equipment will cost for a small hydro power (SHP) project that will involve a low head dam. A head of twenty metres and a capacity of ten thousand kilowatts (kW) are also features of the project. Additionally, the research indicates that a hydro turbine would be the most appropriate option for this project, which is a significant recommendation. The results of the inquiry suggest that such a discovery has been made, as shown by the findings.

(1) The cost of a small hydroelectric power (SHP) plant per kilowatt (in Indian Rupees) is 33,560, 35,059, and 36,863 when adopting a tubular propeller turbine, vertical semi-Kaplan turbine, and tubular Kaplan turbine, respectively.

(2) It is feasible to lower the costs associated with the development of a small hydroelectric power (SHP) system that is equipped with a low head dam by making use of a propeller tube turbine so that the system may be used.
In the event that a tubular Kaplan turbine is used, the expense of putting in place a small hydropower (SHP) system that is founded on a low head dam would be at its highest possible level.
Consequently, for the small hydroelectric power (SHP) system that is based on the low head dam, it would be cost-effective to construct a tubular propeller. This is because the attributes of the site would be taken into consideration.

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