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Formulation of Electromechanical Cost Estimation Nomogram for Small Hydropower Project in Nepal

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Abstract
Power generation from flowing water is often known as Hydropower generation. It is one of the major capital-intensive project that requires the detailed technical as well as financial analysis before making investment decision. Cost of Electro-Mechanical (EM) equipment including turbine, generators, controls and autonomous and auxiliaries holds the major portion of the hydropower project budget. Cost of the EM equipment mainly related to the installed capacity and net head of hydropower. This research aims to develop the mathematical relation as well as the cost estimation nomogram to estimate unit cost (per MW) of EM equipment accounting the installed capacity of hydropower plant and available water head. Technical and Financial Details of eighteen hydropower projects with either Pelton or Francis type turbine units were collected and analyzed for the actual unit cost by multivariate linear regression method. Obtained mathematical relationships were then compared against the primary data of actual costs. The developed relations shows that the MAPE (Mean Absolute Percentage Error), Standard Deviation (SD) and R^2 for Pelton and Francis based hydropower yields 5.81%, 6.9%, 78.94% and 8.12%, 10.2%, 83.17% respectively. From the value of MAPE obtained, it can be inferred that the modeled equation provides the excellent accurate estimation. A nomogram for cost estimation for small hydropower plant for Pelton (Head Range = 50 to 800 m) and for Francis (Head Range = 30 to 300 m) has been developed in this article.

Keywords
Cost Estimation Nomogram, Electromechanical, Hydropower, Small Hydropower

1. Introduction

Hydropower is now counted as the largest proven renewable energy resource. It can be stored (Storage and Pumped Storage type plants) to balance the demand-supply cycle which is one of the best opportunities among the other renewable energy resources [1]. Despite huge potential for hydropower generation, only 2190 MW of power has been harnessed in Nepal [2] out of 42,000 MW technically as well as financially feasible potentials. Independent Power Producers in Nepal is generating 1020.52 MW of electricity from hydropower through the 122 hydropower stations and supplied to the power distribution system of Nepal Electricity Authority (NEA) to minimize the domestic power shortage and also facilitating NEA to export power to India (NEA has been exporting up to 364 MW power from six hydropower projects to India in the Day Ahead Market of Indian Energy Exchange) [2]. Out of such 122 power stations, 112 power plant are Small Hydropower Plant (SHP) of installed capacity equal or less than 25 MW [2].

Main components of the run of river (RoR) type hydropower project can be classified in two sub-components i.e. civil works and EM works [3]. The EM equipment denotes all the mechanical, electrical as well as electrical – mechanical coupling/interfacing equipment required to generate electricity on water-to-wire basis. This includes turbines, governors, main inlet valves, turbine and generator shafts, cooling and drainage water systems, overhead traveling cranes, workshops, generators, transformers, earthing systems, control and automation equipment, telecommunication systems, HVAC systems and auxiliary system [4, 5, 3].

Unlike the thermal power plant, hydropower plants are strongly site specific. With reference to particular time of a year, a particular hydropower plant produces a specific amount of the power and energy that other hydropower plants may find hard to duplicate. That means the overall cost of the hydropower project is very much dependent to the project site locations. A site located in relatively remote location may demand higher infrastructure cost, storage cost, transportation cost, access road cost, resettlement etc. [6].

Principally, cost of the EM equipment is function of net head and installed capacity of the plant which are very much site specific. In Nepal, contract agreement between the project developer and the electromechanical equipment supplier is done based on the 'water-to-wire' basis for most of the small hydropower project. Hydropower developers normally assume US$200 to US$240 per kW machine size in general for the estimating and budgeting purpose. This rate is dependent for the machine type, rotation axis, unit capacity, design discharge, manufacturer's profile, country of origin etc. With this rate being assumed for cost estimate purposes, most of the sites have experienced variation of costs during execution phase, which has been prime cause of disputes between contractor and developer and has largely hindered the timely completion of the construction works. This study aims to provide a feasible estimation relationship for the estimating the cost of EM equipment specially for small generation stations in context of Nepal. It is believed that the outcome will benefit many developers in proper estimation and budgeting, thus less disputes during execution phase and hence timely completion of the construction works.

2. Literature Review

The power available to the turbine shaft is directly proportional to the product of water discharge and effective net water head. The available power can be formulated as presented in Equation 1.

$$P = (\rho g Q H)\eta \tag{1}$$

Here, P is power, Q is design discharge and H is net available head. For the determination of tentative cost of the EM equipment, some of the researchers have invented the cost estimation nomogram for the simplification of the process. Since the EM manufacturer/ vendor do not provide any information about the cost, it is very difficult to estimate the budget during study phase of the hydropower project. Construction of hydropower is capital intensive task and requires long lead time [7]. The lead time includes all the project activities form planning to project testing and commissioning. IREA in 2020 published a report 'Renewable Power Generation Costs in 2020' showing the weighted average share of total installed costs in percentage for 25 hydropower projects in China, India and Sri Lanka, as shown in Figure 1, commissioned between 2010 to 2016.

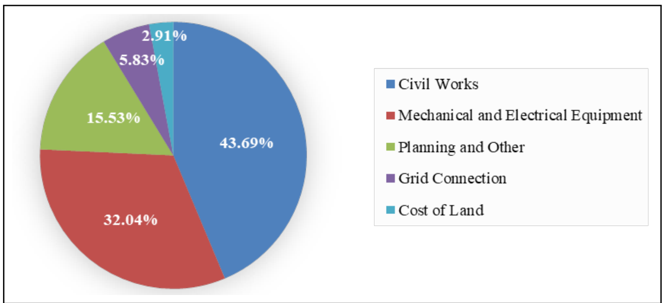

Figure 1: Cost Share in Hydropower Project [7]

S.K. Sangal and R.P. Saini in 2007, analyzed the cost function for the low head hydropower projects and developed a relation to estimate the EM Cost in per kW Indian rupees within the deviation range of ±12% [8]. Cesar Adolfo Alvarado-Ancieta, in 2009 [5] compiled statistical data on costs of EM equipment for 81 selected hydro power projects with net head 9 m to 800 m and installed capacity 0.5 MW to 800 MW in America, Asia, Europe and Africa and generated the cost estimation formula and diagrams which allow a close cost estimation of EM equipment. He further suggested that the diagrams he presented could be used for DDA study, pre- and feasibility study level and need to be updated each year considering the actual price escalation. Sachin Mishra et al. in 2011 analyzed the three main cost estimation methods for EM equipment accounting the power and head as influencing factors [9]. They compared the actual EM cost with the modeled cost calculated by the sigma plot, linest method and logest method to observe the reliability of the methods. They recommended to use either sigma plot or linest plot as the error percentage to the actual cost are relatively small. They developed a correlation equation in terms of Indian Rupees per kW with ±10% accuracy from the actual cost [9].

Giovanna Cavazzini et al. in 2016, proposed a new method for the estimation of EM equipment cost by accounting the design flow rate as well. They observed and compared the results with the cost estimation technique developed by [4] and concluded that the obtained mean errors values were smaller: 9.2% in place of 10.2% for Pelton turbine and 9.8% in place of 11.5% for Francis turbine. Likewise, PRoR or RoR project, Gaydaa AlZohbi in 2018, developed new correlations to estimate the cost of Pelton unit with size $\leq$ 25 MW, Kaplan unit with size 5 MW $\leq$ P $\leq$ 233 MW, Francis Unit with size 1 MW $\leq$ P $\leq$ 32 MW with more than 88% coefficient of determination [10]. He concluded with his arguments, that the cost of EM equipment is very much sensitive to the net head and installed power as the total cost of the EM equipment is positively correlated with installed power and negatively correlated with the net head.

For Nepalese context, Water and Energy Commission Secretariat (WECS) in 2019 recommended to use cost function derived by Alvarado Ancieta [5] and stated that Cost may have increased due to the escalation of the US$ but also may have decreased due to recent advances in the manufacturing technology and competition in the market. No adjustment is recommended to the costs computed by the relation. Some other cost functions, which are found in literatures, devised by the various researcher in past are presented in Table 1.

3. Research Methodology

Figure 2 summarizes the methodology adopted for this study.

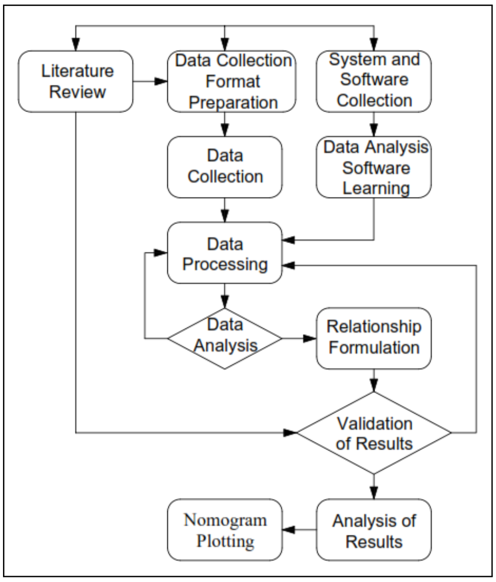

Figure 2: Work Flow Chart for Research

3.1 Sampling Techniques

Population size was identified based on the installed capacity of hydropower plant/project and the developer type within Nepal. Random sampling technique was adopted at which the following points were taken care:

- Each of hydropower to be located within Nepal.
- Each population must be small hydropower plant/project with installed capacity 1000 kW $\leq$ P $\leq$ 25000 kW with Francis or Pelton machine installed as a generating unit.
- The sample selection has been done based on the data availability in such a way that all the provinces of Nepal are represented (except Madhesh Province as no

Table 1: Cost Function Derived and Compiled in Past [11, 10]

Cost Functions	Country	Year	Author
$Cost\ (\$) = 9000P^{0.7}H^{-0.35}$	Canada	1978	Gordon and Penman
$Cost\ (\$) = 97436P^{0.53}H^{-0.53}$	Sweden	1979	Lasu and Persson
$Cost\ (\$) = 9600P^{0.82}H^{-0.35}$	USA	1984	Gulliver and Dotan
$Cost\ (\$/kW) = 31500P^{0.25}H^{-0.75}$	UK	1988	Whittington et al.
$Cost\ (\$) = 40000P^{0.70}H^{-0.35}$	Greece	2000	Voros et al.
$Cost\ ((€/kW) = 103(34.12 + 16.99P^{0.91}H^{-0.14})$	Switzerland	2000	Chenal
$Cost\ (\$/kW) = 12900P^{0.82}H^{-0.246}$	U.S.A.	2003	Gordon
$Cost\ (€/kW) = 3300(P^{-0.122}H^{-0.107})$	Greece	2007	Keldellis
$Cost\ (€/kW) = 3300(P^{-0.122}H^{-0.107}) - Pelton$	Spain	2009	Ogayar and Vidal
$Cost\ (€/kW) = 3300(P^{-0.122}H^{-0.107}) - Francis$	Spain	2009	Ogayar and Vidal
$Cost\ (€) = 1358677.67H^{0.014} + 8489.85Q^{0.515} + 3382.1P^{0.416} - 1479160.63 - for\ Pelton$	Italy	2016	Giovanna Cavazzini et al.
$Cost\ (€) = 190.37H^{1.27963} + 1441610.56Q^{0.03064} + 9.62402P^{1.28487} - 1621571.28$ *-Francis*	Italy	2016	Giovanna Cavazzini et al.

hydropower plants are located in this province now) at which the net available head is medium or high.

Total 36 hydropower project/plants were preliminary identified as the sample size by considering 95% confidence level with 15% confidence interval. Sample size is normally taken as much as possible to represent the behavior of the population. Greater number of sample size always provide the accurate result [12]. Sample size in this research was judged based on the quality of the resulting estimates.

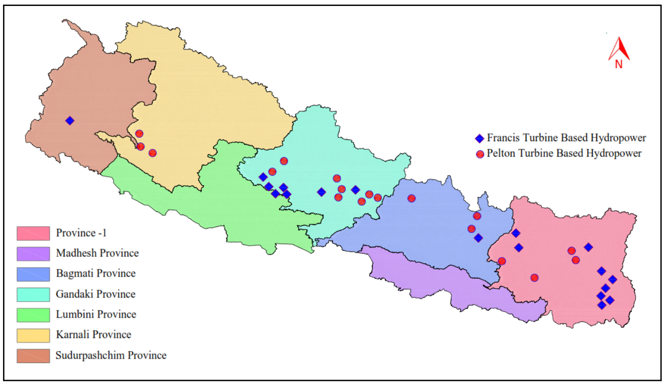

Figure 3: Location Map of Hydropower Considered in this Research

3.2 Data Analysis for Cost Function

Actual cost as well as other technical parameters were collected from the different informants and then preliminary analyzed. Cost of the EM equipment provided in Nepalese Rupees (NPR), Indian Rupees (INR) or Euro were converted into the US$ considering the EM Contract signing date as a base date. https://www.exchangerates.org.uk/ was used to convert the different currencies into US$. Calculated cost in US$ then converted into the unit rate as US$ per kW for the further analysis. Formulation of cost functions have been done separately for Pelton and Francis based hydropower as well as the generalized form by combining both Pelton and Francis. The Cost (C') of the EM equipment is dependent on net static water head (H) and power output (P) as presented in Equation 2.

$$C' = aP^bH^c \tag{2}$$

Here, a, b, and c are constants/coefficients, C' is a dependent and P and H are independent variables. The constants a, b and c were determined by doing the regression analysis [10, 4] of 18 hydropower data for each type of turbine considering net head and power. Multivariate linear regression analysis was done to analyze the Correlations, R^2 and error. Surfaces derived from the Equation 2 were then plotted along with the scatter plot of actual cost to visualize the deviations.

3.3 Validation of Modeled Cost Function

Validation by the primary data of the estimation relationship has been done by calculating the real and simulated costs for small hydropower plants equipped with Pelton and Francis along with the generalized form (by combining both type of turbines). The relation used to calculate the error is presented in Equation 3.

$$Error(\%) = \frac{Market\,Cost - Modeled\,Cost}{Market\,Cost} x100 \tag{3}$$

MAPE, SD and R^2 for all three scenarios were analyzed based on the deviations obtained from the actual cost. Result simulated in this research has also been validated using secondary data derived in past by Alzohbi [10], Ogaryer [4] and Cavazzini [11]. Deviations in unit cost calculated in this research has been compared and analyzed with respect to those relations proposed by three researchers mentioned above for both Francis and Pelton based units and calculated the results as well. The formula used to calculate the deviation is presented in Equation 4;

$$Error(\%) = \frac{Modeled\,Cost - Cost\,Derived\,in\,Past}{Cost\,Derived\,in\,Past} x100 \tag{4}$$

The result obtained from all three data sets were plotted in the line graph showing the deviation in unit cost from modeled value.

3.4 Formulation of Nomogram

After validating the research output with primary as well as secondary data, a cost estimation nomogram has been plotted considering net head 50 m to 800 m for Pelton based and 30 m to 300 m for Francis based hydropower in a single graph. Power considered for both types has been taken 1,000 kW to 25,000 kW. Nomogram has been plotted with H in x-axis and P in y-axis with cost variation 180 US$ /kW to 400 US$/kW with 10 US$/kW interval for easy use.

4. Results and Discussion

4.1 Derivation of Cost Function

Linear regression analysis was done for ln(C) as a dependent variable and ln(P) and ln(H) as the independent variables. 78.94% coefficient of determination (R^2) was obtained from the multivariate linear regression model which shows that nearly 79% of variance in the dependent variable i.e. Unit EM Cost (C) can be explained by the independent variable i.e. Installed Power (P) and Net Head (H). Ogayar and AlZohbi calculated comparatively good value of R^2 as 93.16% and 88.03% respectively for Pelton turbine.The cost function obtained is shown in Equation 5.

$$C_p' = f(P,H) = e^{8.0467} P^{-0.1920} H^{-0.1444} \tag{5}$$

Actual data as well as the modeled surface equation were plotted in the MATLAB and obtained the graph which is shown in the Figure 5.

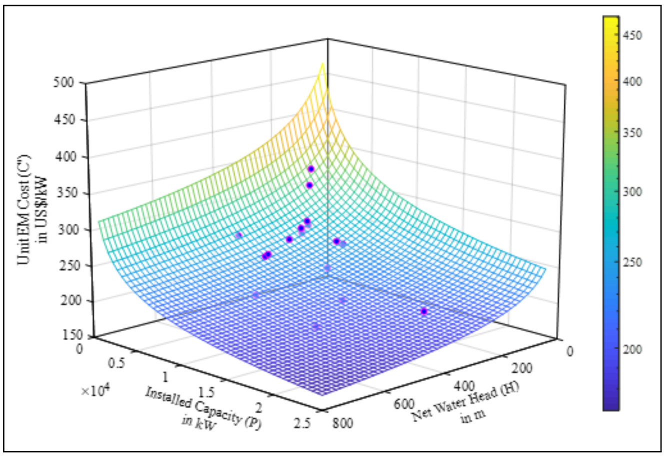

Figure 4: Graph Showing Mesh and 3D Scatterplot of EM Cost for Pelton Units

The scatterplot shows the actual unit cost per kW. However, the 3D mesh plot shows the projected data obtained from the above Equation 4 11. It is clearly visible that the unit cost of the EM equipment for Pelton unit is negatively correlated to the Installed Capacity (P) and the Net Head (H) available. Interpreting the Figure, Unit cost of the EM equipment is remarkably varying for the plant capacity less than 5000 kW and head below 200 m. Using the Equation 3, errors obtained from the actual and modeled unit cost were calculated which is tabulated here in Table 2.

Calculated errors in the modeled unit costs with respect to the actual unit costs has maximum positive and negative deviation 11.2% and -8.3% respectively with error mean 0.2% and SD 6.9%. However, MAPE calculated was 5.81% which shows that the relationship given, provide the excellent accurate estimation. In comparison to the equation derived by the Cavazzini, mean error was comparatively smaller but slightly higher SD were obtained for Pelton units as he calculated the mean error and SD 6.4% and 6.5% respectively. The actual unit cost and modeled unit cost vs. respective hydropower project were plotted in Figure 6.

Table 2: % Errors in Modeled Cost in Projects with Pelton Unit

Project Name	Actual Cost US$/kW	Modeled Cost US$/kW	Error %
Upper Rawa	334.08	324.51	-2.9%
Upper Lohore	317.29	297.84	-6.1%
Suri Khola	281.44	258.24	-8.2%
Rudi Khola-B	275.02	253.3	-7.9%
Dwari Khola	267.61	268.28	0.3%
Upper Machha	263.23	286.07	8.7%
Super Hewa	259.00	255.35	-1.4%
Buku-Kapate	256.93	274.56	6.9%
Upper Hewa	256.00	249.74	-2.4%
Upper Midim	255.18	233.91	**-8.3%**
Padam Khola	255.17	282.7	10.8%
Chepe Khola	250.32	251.95	0.7%
Upper Suri	250.04	237.41	-5.1%
Rudi Khola-A	223.07	242.45	8.7%
Thulo Khola	214.67	198.02	-7.8%
Super Chepe	212.94	219.72	3.2%
Thapa Khola	205.00	213.38	4.1%
M. Mailung	183.08	203.61	**11.2%**

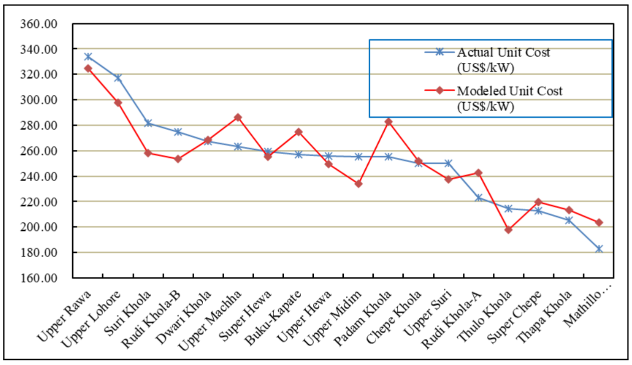

Figure 5: Line Diagram for Actual and Modeled Unit EM Cost of Pelton Unit

Same as for Pelton Turbine, linear regression analysis was done. A relatively good coefficient of determination (R^2 = 83.17%) was obtained from the multivariate linear regression analysis. AlZohbi calculated comparatively good value of R^2 as 92.61% than the Ogayar. (72.26%) for Pelton turbine. That shows the cost relation for Francis, derived in this research, would represent the more sample size than those derived by Ogayer. The cost function obtained is shown in Equation 6.

$$C_f' = f(P,H) = e^{7.8842} P^{-0.2494} H^{-0.0392} \tag{6}$$

Actual data as well as the modeled surface equation were plotted and obtained the graph which is shown in the Figure 7.

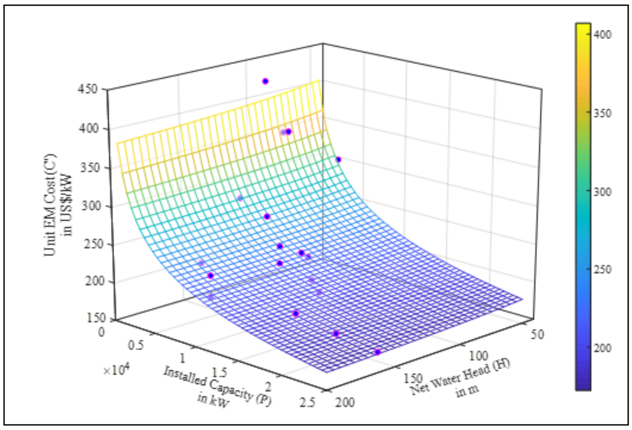

Figure 6: Graph Showing Mesh and 3D Scatterplot of EM Cost for Francis Units

In the Figure 7, the scatterplot shows the actual unit cost per kW of the Francis EM equipment and 3D mesh plot shows the projected data obtained from the above Equation 6. It is clearly visible that the unit cost of the EM equipment for Francis unit is negatively correlated to the Installed Capacity (P) remarkably and the Net Head (H) slightly. Interpreting Figure 7, Unit cost of the EM equipment is strongly varying for the plant capacity less than 5000 kW.

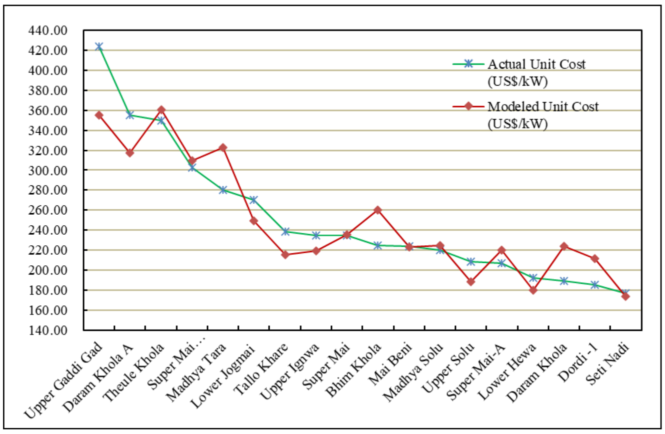

Figure 7: Line Diagram for Actual and Modeled Unit EM Cost of Francis Unit

Using the equation 3 9, errors obtained from the actual and modeled unit cost were calculated which is tabulated here in Table 3.

Calculated errors in the modeled unit costs with respect to the actual unit costs has maximum positive and negative deviation 18.5% and -16.2% respectively with error mean 0.5% and standard deviation 10.2%. The actual unit cost and modeled unit cost vs. respective hydropower project were plotted in Figure 8.

During the error analysis, MAPE calculated was 8.12% which shows that the relationship given also provide the excellent accurate estimation. In comparison to the equation derived by the Cavazzini, mean error was comparatively smaller but higher value of SD ware obtained for Francis units as he calculated the mean error and SD, 10.6% and 4.4% respectively.

Table 3: % Errors in Modeled Cost in Projects with Francis Unit

Project Name	Actual Cost US$/kW	Modeled Cost US$/kW	Error %
Upper Gaddi Gad	424.13	355.52	**-16.2%**
Daram Khola A	355.00	317.2	10.6%
Theule Khola	350.00	360.69	3.1%
Super Mai Cscd.	302.49	309.88	2.4%
Madhya Tara	280.34	322.92	15.2%
Lower Jogmai	269.87	249.03	-7.7%
Tallo Khare	238.80	215.55	-9.7%
Upper Ignwa	235.00	219.14	-6.7%
Super Mai	235.00	235.14	0.1%
Bhim Khola	224.75	260.29	15.8%
Mai Beni	223.58	223.05	-0.2%
Madhya Solu	220.18	224.63	2.0%
Upper Solu	208.74	188.22	-9.8%
Super Mai-A	206.70	219.73	6.3%
Lower Hewa	192.30	180.1	-6.3%
Daram Khola	189.24	224.22	**18.5%**
Dordi -1	185.57	211.38	13.9%
Seti Nadi	176.55	173.98	-1.5%

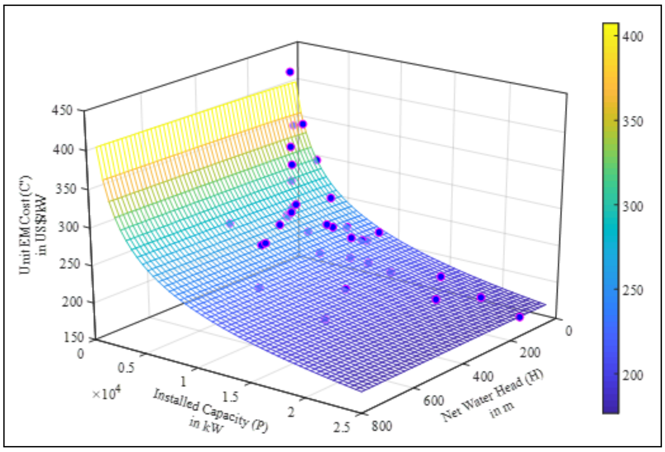

Figure 8: Graph Showing Mesh and 3D Scatterplot of EM Cost in General

To analyze the collective figure, data of all the hydropower with Pelton and Francis units were merged in single sheet and multivariate linear regression analysis was done. Coefficient of determination (R^2 = 88.84%) was obtained which shows that nearly 89% of variance in the dependent variable i.e. Unit EM Cost (C) can be explained by the independent variable i.e. Installed Power (P) and Net Head (H) for the hydropower in general. A surface equation was obtained after analysis as presented in Equation 7.

$$C'_g = f(P,H) = e^{7.7652} P^{-0.2571} H^{0.0031} \quad (7)$$

Actual data as well as the modeled surface equation were plotted and obtained the graph which is shown in the Figure 9.

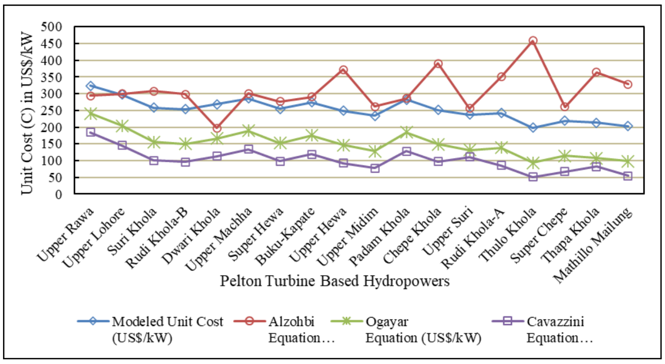

Figure 9: Pelton Unit Modeled Cost Vs. Referenced Past Equation's Cost

In the Figure 9, it is clearly visible that the unit cost of the EM equipment is negatively correlated to the Installed Capacity (P) remarkably but it is positively correlated to the Net Head (H) a little which contradict with the statements established for individual turbine type. Hence, further analysis and validation for the generalized equation was halted.

4.2 Result Validation

Validation of primary data were already done in above sections comparing the value of r, R^2, Mean Error, SD and MAPE which satisfies the result obtained from this research. Outputs from this research were also validated by comparing and analyzing the result with the past researches done by Alzohbi [10], Ogaryer [4] and Cavazzini [11] and validated this research output by adopting the Equation 4 for error analysis. For Pelton based hydropower, deviation of the modeled unit EM cost with respect to AlZohbi's equation were found to be -56.82% to 35.65% maximum with 21.57% SD and 20.38% MAPE. Also, with respect to Ogayar error range found to be 34.48% to 110.88% with 20.68 SD and 71.53% MAPE. Considering the Cavazzini's equation, error range found to be 75.26% to 289.80% with SD 56.01% and MAPE 162.82%. The Table 4 4 below shows the calculations for unit cost validation results for Pelton Units. Analyzing the result obtained above, AlZohbi's equation was found to be fits the newly developed correlation in this research than other. Error percentage with Ogayar's and Cavazzini's equations with comparison to AlZohbi's equation were found to be very high because both the researches were done by considering the relatively small hydropower project with installed capacity less than 1,000 kW.

For Francis based hydropower, deviation of the modeled unit EM cost with respect to AlZohbi's equation were found to be -59.83% to 2.02% maximum with 19.18% SD and 36.42% MAPE. Also, with respect to Ogayar, error range found to be 41.54% to 260.8% with 66.43 SD and 143.89% MAPE. Considering the Cavazzini's equation, error range found to be -12.39% to 49.31% with SD 18.28% and MAPE 28.34%. The Figure 4 14 below shows the calculations for unit cost validation results for Francis based units.

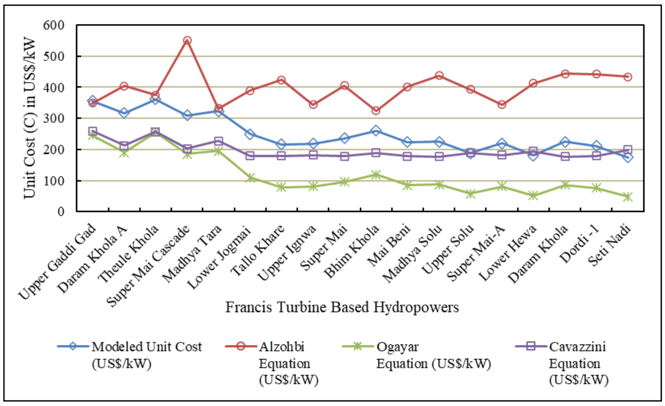

Figure 10: Francis Unit Modeled Cost Vs. Cost Derived in Past

Analyzing the result obtained for Francis unit above, Cavazzini's equation was found to be relatively fits the newly developed correlation in this research than others. Deviations in the modeled cost was observed mainly due to the installed capacity range, operating conditions and country or origin. There are so many other factors like quality of water, requirement of spare parts, transportation cost etc. that are different then Nepal. Ogayar's equations were developed by considering the relatively small hydropower project with installed capacity less than 2,753 kW and that gave higher deviations than Cavazzini's equation.

4.3 Cost Estimation Nomogram

To estimate the EM cost for Pelton or Francis based hydropower project, a nomogram has been formulated (Figure 11) at which net head and installed power to be used as input parameters. Following sequence required to be followed for the cost forecast.

1. Plot the vertical line of net head (H) in x-axis with meter as unit over the Nomogram.
2. Plot the horizontal line of installed capacity (P) in y-axis with kW as the unit of measurement over the Nomogram.
3. Find the intersecting point and interpolate the cost value by considering the above and below unit cost line. That gives the desired unit cost of hydropower EM equipment in US$/kW.

5. Conclusion

In this study, empirical relationship between installed capacity, net head and unit cost (per MW) of EM equipment for both Francis and Pelton based hydropower were developed successfully for the Nepalese context by carrying out the multivariate regression analysis. Also, mesh plot along with scatter graph were contrived and analyzed for their accuracy and reliability. For Pelton based hydropower, value of R^2 obtained was 78.94% with error mean 0.2%, SD 6.9% and MAPE 5.81%. Similarly, for Francis based hydropower, relatively good value of R^2 was found with error mean 0.5% SD 10.2% and MAPE 8.12%. In both the cases, value of MAPE were found to be $<$ 10% that means the modeled equation provides the excellent accurate estimation. Modeling was also done combining the Pelton and Francis based hydropower and analyzed the data and concluded that the generalized modeled equation has generated

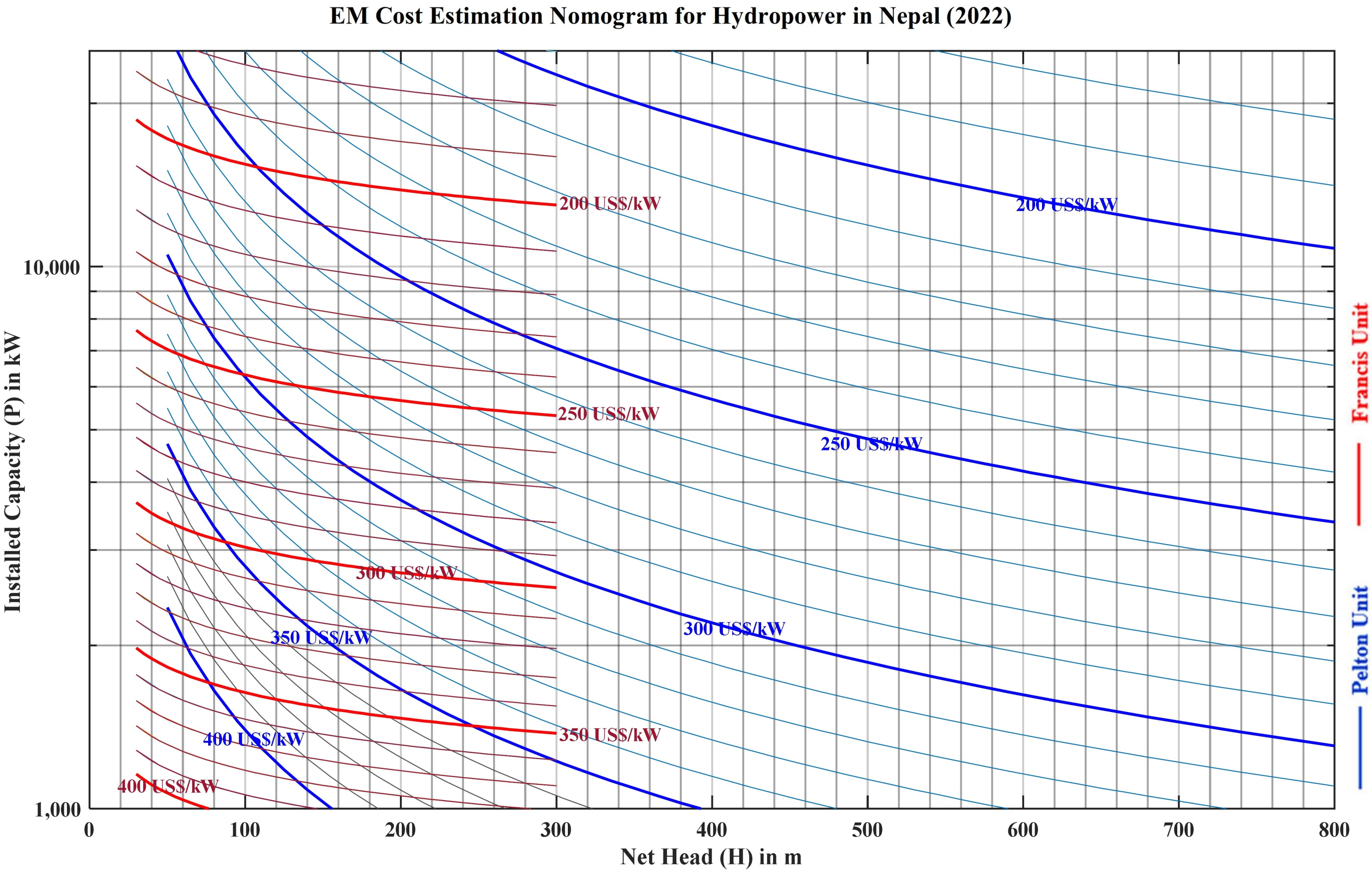

Figure 11: EM Cost Estimation Nomogram

the unrealistic contradictory data. It is recommended for future research to develop a generealizzed model equation. EM Cost forecasting nomogram for both Pelton and Francis based hydropower has been derived and plotted successfully. The developed nomogram gives the EM unit cost for the range of 50 m to 800 m net head for Pelton based hydropower and 30 m to 300 m for Francis based hydropower with installed power range 1,000 kW to 25,000 kW. However, installed power and net head are not only the factors that affects the unit cost of the EM equipment but other parameters such as number of generating units, turbine axis, speed of rotation, extent of control and automation system to be installed, site location, type of switchyard proposed (AIS or GIS), voltage level in transmission lines, turbine manufacturer's goodwill, country of origin etc. also holds the minor impact. It is advised/recommended that the proposed equation be expanded to accommodate more minor variables in further publications.

References

[1] IHA, International Commission on Large Dams, Implementing Agreement on Hydropower, , Technologies Programmes/, International Energy Agency, and Canadian Hydropower Association. Hydropower and the World's Energy Future. (November), 2000.

[2] Nepal Electricity Authority. Annual Report of Nepal Electricity Authority FY 2021-22. pages 1–238, 2022.

[3] S. K. Singal, R. P. Saini, and C. S. Raghuvanshi. Analysis for cost estimation of low head run-of-river small hydropower schemes. *Energy Sustain. Dev.*, 14(2):117–126, 2010.

[4] B. Ogayar and P. G. Vidal. Cost determination of the electro-mechanical equipment of a small hydro-power plant. *Renew. Energy*, 34(1):6–13, 2009.

[5] Cesar Alvarado Ancieta. Estimating the costs of E & M equipment. *Int. Water Power Dam Constr.* ·, (February), 2009.

[6] Upendra Gautam & Ajay Karki. *Hydropower Pricing in Nepal*. 2004.

[7] IREA. *Renewable Power Generation Costs in 2020*. 2020.

[8] S. K. Singal and R. P. Saini. Analytical Approach for Cost Estimation of Low Head Small Hydro Power Schemes, 2007.

[9] Sachin Mishra, Sunil Kumar Singal, and Dheeraj Kumar Khatod. Approach for Cost Determination of Electro-Mechanical Equipment in Ror Shp Projects. *Smart Grid Renew. Energy*, 02(02):63–67, 2011.

[10] Gaydaa Alzohbi. The cost of electromechanical equipment in a small hydro power storage plant. *J. Energy Syst.*, 2(4):238–259, 2018.

[11] Giovanna Cavazzini, Alberto Santolin, Giorgio Pavesi, and Guido Ardizzon. Accurate estimation model for small and micro hydropower plants costs in hybrid energy systems modelling. *Energy*, 103:746–757, 2016.

[12] Simarjeet Kaur. REVIEW ARTICLE SAMPLE SIZE DETERMINATION (FOR DESCRIPTIVE STUDIES) Simarjeet Kaur. *Int. J. Curr. Res.*, 9(3):48365–48367, 2017.