Research Article

VALIDATING TECHNICAL PERFORMANCE OF MICRO-HYDROPOWER PLANTS IN NEPAL

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ABSTRACT

Access to electricity is a major factor for socio-economic development of a country. But providing reliable, affordable and modern energy in rural settlements is a major challenge, especially in the developing countries. Energy service is cost-effective through off-grid electrification due to scattered settlements, whereas micro-hydropower plant (MHP) is an effective complement to grid-based power due to its enormous potential. However, these off-grid MHPs are sometimes debated to be performing below standard which motivated the author to analyze and validate the technical performance of existing MHPs comparing with national standards. This paper presents the performance analyses of 84 MHPs supported by Alternative Energy Promotion Centre (AEPC) in Nepal. The results showed that water-to-wire efficiency mean is 59.2%, performing above designed value. Similarly, electro-mechanical (E/M) efficiency performed above national standard. Water-to-wire, E/M, and turbine efficiencies are positively influenced by increase in plant size, but penstock efficiency remains same, irrespective of plant size. Majority of plants are performing reliably, the plants performing un-reliably is mainly due to insufficient flow. Mean value of plant factor is 27% which is influenced by plant size and energy consumption per household. Lower value of plant factor refers that there is high potentiality to improve energy based economic activities.

Key words: electrification, indicators, performance, plant factor, efficiency

INTRODUCTION

Access to electricity is generally recognized as an important factor for economic and social development(Williams et al. 2015). In 2015, the United Nations (UN) has declared for universal access to affordable, reliable and modern energy by 2030. Electricity is the rising force among worldwide end-uses of energy, making up 40% of rise in final consumption to 2040 (IEA 2017). As per commitment with international agencies, Nepal has formulated two important strategies: National Energy Strategy of Nepal (2013-2030) and Nepal's Energy Sector Vision 2050. These strategiesfocus to reducing energy poverty by increasing access to and ensuring reliable, affordable, modern and sustainable energy for all (WECS 2013).

Providing modern energy access to rural people is a major challenge to all developing countries. About one fourth of Nepalese people who are mainly living in rural area are still out of access to electricity (NEA 2018), (AEPC 2018). It is due to unfavorable geological condition and scattered settlements, extending national grid not feasible solution for providing electricity services to rural people (PwC 2016). Therefore, development of off-grid energy options is the one of complement means to on-grid based option, which is suitable for planning, developing, operating and managing at local level fulfilling the energy need and meeting the national targets of modern energy access to rural people. Consequently, Nepal has adopted on-and-off grid electrification for providing electricity access for rural electrification focusing on fulfilling international commitments and also addressing the need of nation. Off-grid electrification through micro-hydropower is one of the major means of rural electrification widely accepted by the local people. Till the end of 2018 AD, more than 1800 Micro-hydropower Projects (MHPs) are already commissioned for providing modern electricity to rural people under technical and financial support though Alternative Energy Promotion Centre (AEPC 2018). MHP is considered indigenous technology because almost all equipment except generators are manufactured in Nepal (Thapa 2017). In rural and off-grid cases, electric systems are operated in low plant factor, though there is always a debate that whether these off-grid MHPs are able to provide sufficient electricity services to the rural people in order to fulfill their need - reliable energy access to lighting, social services. The main objective of this study was to assess technical performance of installed Micro-Hydropower plants in Nepal, and to validate the performance as per the national standards.

This paper analyses and validates the technical performance of such MHPs by answering the research question: do the plants are able to provide electricity service efficiently, with minimum loss, reliably and relatively better plant factor? The results of these performance parameters include: (i) the efficiencies of different components (penstock, electro-mechanical and water to wire), (ii) reliability, and (iii) plant factor. The analysis and validation was made by excel spread sheet and Statistical Package for Social Science (SPSS) software. To validate the performance data, descriptive statistical tool was adopted.

MATERIAL AND METHODS

Theoretical Framework

An extensive review of analyzing technical performance framework was conducted. Among the many frameworks found in different literatures (Ahmad and Tahar 2014), (Madhuri Y.S. 2017), (IAEA 2005) to analyze the technical performance of off-grid electrification system. We identified three indicators: (i) efficiency, (ii) reliability (iii) energy availability and plant factor. Finally, the technical performance of an off-grid electrification system is defined as the level through which the solution is able to provide electricity service efficiently, with minimum loss, reliably and relatively better plant factor (IAEA 2005).

A brief introduction of identified indicators is presented hereunder:

Efficiency: Efficiency of energy technology is an ability of the system to convert the primary energy source to electricity. The higher of the conversion efficiency of the electric system have, the better are the chances of technical and overall system sustainability (Ilskog 2008;UNDP 2007; Feron 2016). In case of hydropower, the conversion efficiency is overall efficiency of the scheme (known as water to wire efficiency). The water to wire efficiency depends on efficiencies of different components: penstock, turbine, drive/ transmission system and generator.

Reliability: Reliability in sustainable energy system is defined as the system's capability of working in a specific area over its expected lifetime i.e. consistency of the services of system. It is also defined as an ability of system to function/perform according to design condition for a specific period of time and to support failures (Feron 2016), (Wang et al. 2009), (Mainali & Silveira, 2015). In case of off-grid micro-hydro plants in Nepal, the reliability depends on availability of water and ability of electrical power generation throughout the year. As per Nepalese standard, the reliability is ensured if the plants have sufficient design flow and electrical power output at least 11 months in year (AEPC 2008).

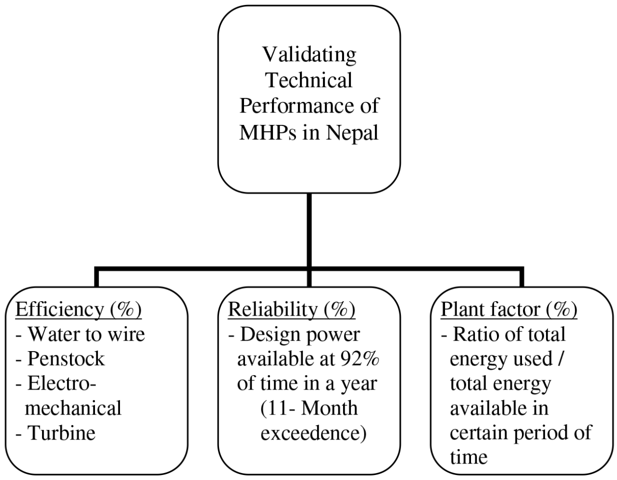

Figure 1. Conceptual framework for validating technical performance of MHPs

Energy Availability and/or Plant factor: Energy availability is a serviceability performance of energy supply to the consumers i.e. amount of electricity provided/ generated from the technical system in a certain period of time. The higher the value of per unit energy availability in a certain period of time, the better is the chance of sustainability of energy system (Ilskog 2008; Mainali and Silveira, 2015).The energy availability can be measured in reference to plant factor i.e. ratio of total energy (kWh) used divided by the total energy available in certain period of time (Harvey 1993).

METHODOLOGY

An extensive review of recent literatures and experiences in off-grid electrification especially related to micro-hydropower in different countries conducted. The review included: firstly, scientific papers, conference papers, theses, books and reports from different organizations. National policies (subsidy and rural energy policy), standards, guidelines were thoroughly reviewed. Secondly, project databases from AEPC, World Bank, and UN were also reviewed. Next, power output and household verification (PoHV) reports of individual micro-hydropower projects are the major source of secondary information for this study. Similarly, SPSS and excel spread sheets were used to analyze the performance data. And descriptive and interferential statistical tool was adopted to validate the performance data by which mean, median, standard deviation and t-test were made to validate the result.

Selection of Indicators:

Criteria and indicators for developing appropriate sustainability indicators were proposed by several authors. According to Hardi & Zdan (1997), the selection of indicators should be based on policy relevance, simplicity, validity, availability of time series data, good quality, affordable data, the abililty of aggregate information, sensitivity to small changes and reliability (Hardi & Zdan, 1997). Whereas OECD (2008) indicates to consider: (i) analytical soundness (i.e. it has scientific/theoretical basis), (ii) measurability (i.e. through data that are readily available, quantifiable and updated periodically), (iii) country coverage (i.e. data are available, comparable across country and also satisfy the country practice) and (iv) ability of describe the performance of electric systems in rural context.

Various authors have identified different indicators to assess technical performance of rural electrification projects (Feron, 2016; Wang et al., 2009; Mainali & Silveira, 2015; Bhandari et al., 2018; AEPC, 2008). Based on the review of these literatures and considering the Nepalese context that satisfies national standards, norms and also in line with international practices; these three indicators were selected in line with the conceptual framework proposed above. A set of selected indicators with relevant definition is presented in the following Table-1 that are adapted to quantitatively evaluate and validate the technical performance of operational Micro-hydropower plants in Nepal. And validation was done comparing the mean values with national standards and/or designed values.

Table 1. Definition of selected indicators for measuring technical performance

SN	Indicators	Definition
A	Efficiency	
a.	Water to wire efficiency (%)	The ratio of electric power output (from generator) and power available at water level.
b.	Penstock efficiency (%)	The ratio of the net head to the gross head
c.	Turbine efficiency (%)	It (η_t) is the ratio of electro-mechanical efficiency and efficiency of generator and drive system $[\eta_t] = \eta_c / (\eta_d \times \eta_{g)}$ ……… (1); Where, η_c = Electrical power output/ power available at turbine inlet (□.g.H_n.Q) ……… (2).
B	Reliability (%)	Electric power availability in 11 month/year i.e. 92% of exceedance. This depends on availability of flow and electric power generation at design flow least 11 months in a year.
C	Plant factor	Ratio of total energy (kWh) used divided by the total energy available in certain period of time

Source: Based on information from (Feron, 2016; Wang et al., 2009; Mainali & Silveira, 2015; Saptalena & Kusch, 2018; AEPC , 2008)

Sampling

The target population of the plants was 283 MHPs in the three provinces that were supported by AEPC (Energy Sector Assistance Program-II phase and National Rural and Renewable Energy Program period) under subsidy scheme. A stratified random sampling technique was applied for the selection of samples. The sampling was performed within 10% desired level of precision and confidence interval of 90 %. Then, the sample size as per Yamane (1967):

$N_0 = N / [1+N.e^2] = 74$ ……… (3)

Where,

N = total population (283 MHPs) N_0 = sample size

e = desired degree of accuracy or error in estimation level (10%)

Total number of plants selected for study was 84. This value is within 9.1% degree of accuracy (error) or at 90.9 % confidence interval which is higher than desired (90%) confidence interval. Therefore, it is expected that the result from the study will represent more than expected result at 90% of confidence interval.

Data Collection and Editing

Necessary data were collected from primary as well as secondary sources. In case of primary data, the researcher visited the project sites along with Power output & Household Verification Inspector (PoHVI)[1] and

1 PoHVI are well trained technical persons for measuring power, voltage, current, frequency, power factor, flow of water (intake and partial flow) and inspect/verify the technical standards of construction/equipment's and household connection.

measured technical data including energy consumption data. Besides visited sites, data were extracted from power output and household verification reports that are prepared by independent consultants (PoHVI) hired by AEPC. Moreover, testing & commissioning, detail feasibility reports and other study reports were also referred to gather necessary information. An excel-based spread sheet is prepared to organize these data.

Data Analysis

Data organizing and graphical analysis was done in excel spread sheets and Statistical Package for Social Science (SPSS) software. After organizing the necessary data, MHPs were categorized in line with Nepalese policies, standards and guidelines as per following manner:

(1) Based on turbine type[2]

- Pelton turbine and Cross-flow

(2) Based on plant size[3]

- Capacity up to 20 kW
- Capacity greater than 20 kW and up to 50 kW
- Capacity > 50 kW

In each category, data were re-organized and analyzed using descriptive statistics and inferential statistics. Statistical mean, standard deviation, regression, correlation and t-test were made to present and validate the results. Regression analysis was done in order to find out variation of different dependent and independent variables from the measured data.

Formulation of Hypothesis

Hypothesis-(1)

Null hypothesis: H_0: $\eta_{ac} = \eta_{dc}$. Actual efficiencies of individual component of studied sites do not differ significantly with the designed and/or national standard.

Alternative hypothesis: H_1: $\eta_{ac} \neq \eta_{dc}$. Actual efficiencies of individual component of studied sites differ with the designed and/or national standard.

Hypothesis-(2)

Null hypothesis: H_0: $\mu_{ar} = \mu_{dr}$. Actual reliability of studied sites does not differ significantly with the designed and/or national standard.

Alternative hypothesis: H_1: $\eta_{ar} \neq \eta_{dr}$. Actual reliability of studied sites differs with the designed and/or national standard.

Hypothesis-(3)

Null hypothesis: Plant factor of studied sites does not influence significantly by plant size.

Alternative hypothesis: Plant factor of the studied sites is influenced by plant size.

The hypothesis is tested at the 5% significance level i.e. comparing critical and statistical t-value at 5% level of significance. The null hypothesis is accepted if the value of $t_{statistic}$ is lower than $t_{critical}$.

RESULTS AND DISCUSSION

Summary of Micro-hydro performance

Mean values of the performance of micro-hydropower plants is summarized in the Table (2). The technical performance of 84 sample plants was analyzed to compare with the designed and/or standard values. The size of the plant varies from 11 kW to 100 kW installed capacity with mean capacity 36 kW whereas actual plant size varies from 9.6 kW to 106.7 kW with mean value of 37.4 that illustrates; actual mean capacity is found to be increased by 1.2 kW.

2 Only two types - cross-flow and pelton are manufactured in Nepal. There are few plants based on francis and propeller imported mainly from China and India. Scope of research is focused on Nepalese turbines.

3 The category is based on differentiation in treating the plants in national standards and guidelines i.e. power output tolerance limit and electro-mechanical efficiency taken during project design (Refer table-3 and 6).

Table 2. Summary of performance for all Micro-hydropower plants (n=84)

	Mean	Min.	Max.	SD	Skewness	
	Statistic	Statistic	Statistic	Statistic	Statistic	St. Error
Plant size (Designed)	36.0	11.0	100.0	23.226	1.402	0.263
Plant size (Verified)	37.4	9.6	106.7	24.158	1.351	0.263
Water to wire efficiency (Designed)	56.1%	43.1%	65.8%	4.46%	-0.279	0.263
Water to wire efficiency (Verified)	59.2%	37.6%	72.4%	5.94%	-0.328	0.263
E/M Efficiency (Designed)	58.7%	45.5%	68.2%	4.67%	-0.373	0.263
E/M Efficiency (Verified)	62.5%	38.0%	75.8%	6.60%	-0.394	0.263
Turbine Efficiency (Designed)	65.2%	51.0%	74.7%	5.06%	-0.443	0.263
Turbine Efficiency (Verified)	69.3%	42.6%	84.9%	7.23%	-0.412	0.263
Penstock Efficiency (Designed)	95.5%	91.1%	98.3%	1.10%	-0.256	0.263
Penstock Efficiency (Verified)	95.0%	87.1%	99.6%	3.34%	2.399	0.263
Watt/HH (Designed)	110.5	63.4	200.0	23.994	1.354	0.263
Watt/HH (Verified)	114.8	64.6	219.6	28.723	1.218	0.263
Household per kW (Designed)	9.4	5.0	15.8	1.920	0.613	0.263
Household per kW (Verified)	9.2	4.6	15.5	2.169	0.596	0.263

Source: Author's estimation

Note: Based on mean value presented in the above Table (2), different form of technical performance is resented in the following sub-sections.

Efficiency

Water to wire efficiency [Overall Efficiency (η_0)]

The mean values of designed and verified water-to-wire efficiencies are found to be 56.1% and 59.2% respectively. From the result of paired sample test at 5% level of significance, critical and statistical t-value is found to be: 1.984 at df 83 and 4.673 respectively. As $t_{statistic}$ is higher than $t_{critical}$, null hypothesis is rejected. Therefore, it reveals that there is significant difference in mean value of designed and verified efficiency. The result implies that the overall actual efficiency is higher than designed value.

Another analysis was done varying the plant size- (1) up to 20 kW, (2) greater than 20 kW to 50 kW, (3) greater than 50 kW. Figure-2 shows the variation of water-to-wire efficiency with the plant capacity. It also shows that the chance of increase in overall efficiency is high in increase in plant size.

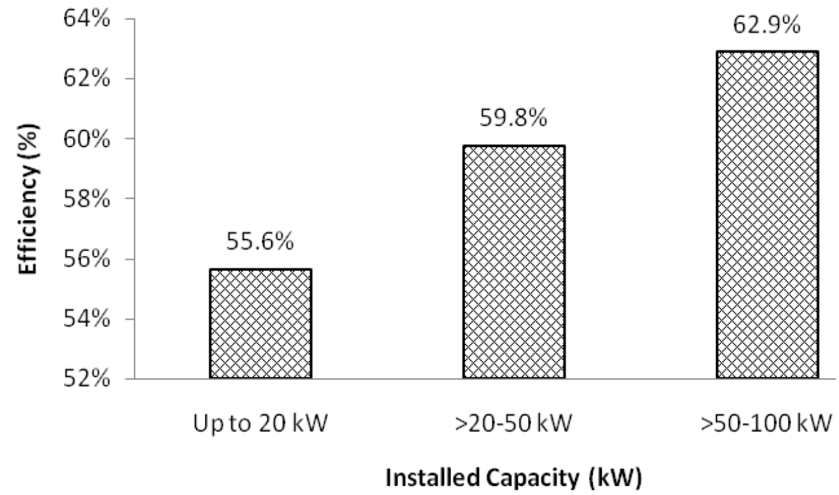

Figure 2. Variation of water-to-wire efficiency with plant capacity (n=84)

Similarly, variation of water-to-wire efficiency with plant size of Nepalese micro-hydro plants was analyzed through SPSS software. Carl Pearson coefficient between water-to-wire efficiency and plant size was found to be 0.408 which shows there is somehow positive correlation between water-to-wire efficiency and size of plant. The variation of water-to-wire efficiency (η_0) with plant capacity (P) is given by regression equation:

$$\eta_0 = 0.555 + 0.0001\,P \;\ldots\ldots\ldots\; (4)$$

From the result of regression analysis at 5% level of significance, $t_{critical}$ and $t_{statistic}$ values are found to be 1.984 and 13.994 respectively. As $t_{statistic}$ is higher than $t_{critical}$, null hypothesis is rejected and alternative hypothesis is accepted. Therefore, it can be concluded that the plant size influences the overall efficiency. However, this finding contradicts with the result of the study performed by Acharaya & Bajracharaya (2013).

Electro-mechanical efficiency

Electro-mechanical (E/M) efficiency is the product of efficiency of turbine, drive system and generator. Therefore, better the efficiencies of drive system, turbine and generator, higher the electrical output. The ratio of electrical output and power available at turbine inlet, electro-mechanical efficiencies of each plant calculated and then analyzed based on turbine type and plant capacity. The summary of the findings is illustrated in the following Table (3).

Table 3. Variation of E/M efficiency with turbine type and plant capacity (n =84)

	Electro-mechanical Efficiency	
Turbine Type and Category	**Verified**	**As per design**
>50-100 kW: Cross-Flow	67.9%	59.4%
>50-100 kW: Pelton	63.2%	62.8%
>20-50 kW: Cross-Flow	63.8%	59.5%
>20-50 kW: Pelton	62.1%	59.6%
Up to 20 kW: Cross-Flow	58.5%	54.9%
Up to 20 kW: Pelton	57.9%	57.9%

Source: Author's estimation

The findings were compared with the value specified in the national standards(AEPC, 2014). Comparing with national standard, all the plants irrespective of installed capacity are found to be performing above national standard. In principle, performance of Pelton based plants should be higher than Cross-flow based plants; but in in this study, electro-mechanical efficiency of Cross-flow based plants is found to be better than that of Pelton based turbine. Similar result is presented in the study carried out by Acharaya and Bajracharaya (2013). It can be concluded that the designers and manufactures of Pelton turbine have sufficient space to improve their quality.

Similarly, year wise variation of electro-mechanical efficiency was analyzed in order to see its improvements in performance over time series. For this, the performance data were compared by splitting the year range in three categories[4]:

(1) Plants commissioned till 2010,
(2) Plants commissioned in between 2011 to 2015,
(3) Plants commissioned in after 2015.

The results show that the performance of Nepalese plants is slightly improved in recent years, which is illustrated in the Figure (3).

4 The category is based on time series. As projects commissioned during ESAP-II phase and NRREP period is considered (i.e. 2007 to 2018) which is ranged in between about 4 year periods.

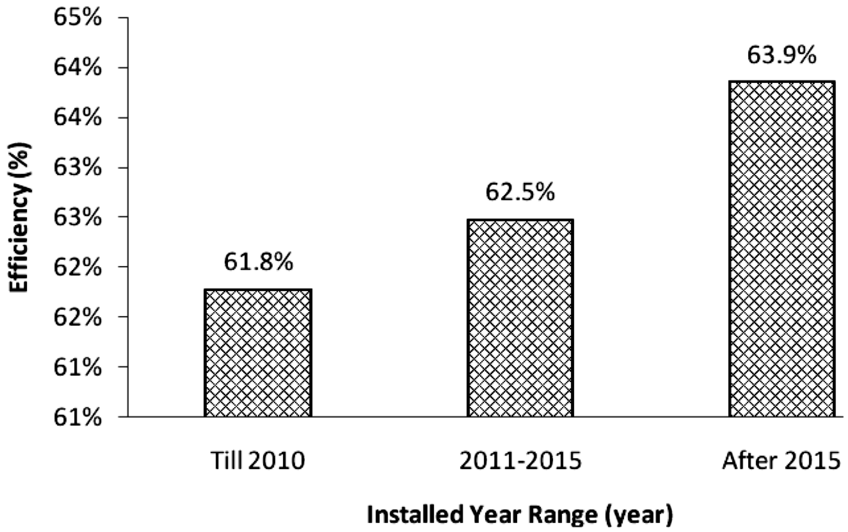

Figure 3. Variation of electro-mechanical efficiency with years

It reveals that average electro-mechanical efficiency is increased from 61.8% to 62.5% and then 63.9% during the three ranges of time series respectively.

Penstock efficiency

Designed and verified penstock efficiencies were calculated and analyzed based on pair sample test. The actual efficiency varies from 87.1% to 99.6% with mean value of 95%. The mean penstock efficiencies based on design and actual is shown in the following Table 4.

Table 4. Penstock efficiency based on descriptive statistical analysis [n=84]

	Mean	Minimum	Maximum	Standard Deviation	Standard Error Mean
Designed	95.5%	91.1%	98.3%	1.10%	0.263
Verified	95.0%	87.1%	99.6%	3.34%	0.263

Source: Author's estimation

After analysis, the mean value of verified efficiency is found to be relatively low compared with designed value and also lower than the value of national standard (i.e. 95%). The verified mean penstock efficiency presented by Acharaya and Bajracharaya (2013) is 94.8% with minimum value of 90% and maximum value of 98%, which is quite similar with the value found from this study.

From the result of paired sample test at 5% level of significance, critical and statistical t-value is found to be: 1.984 at df 83 and 1.523 respectively. As $t_{statistic}$ is lower than $t_{critical}$ null hypothesis is accepted. Therefore, it can be concluded that there is no significant difference in the mean efficiency of designed and verified penstock pipes; as a result, they are performing in line with expected.

Turbine efficiency

All the Cross-flow, Pelton turbine and accessories are designed and fabricated within the country. In order to see the performance of Nepalese turbines, designed and verified turbine efficiencies of the installed plants were analyzed based on pair-sample test at SPSS. The Table (5) shows the result from the analysis. The actual turbine efficiency varies from 42.65 to 84.9% with mean value of 69.3%. The mean value of verified efficiency is found to be relatively higher (4% more) than that of designed. Therefore, it can be concluded that the performance of Nepalese turbines in installed plants is found to be performing better than design.

Table 5. Turbine efficiency based on descriptive statistical analysis [n=84]

	Mean	Minimum	Maximum	Standard Deviation	Standard Error Mean
Designed	65.2%	51.0%	74.7%	5.06%	0.263
Verified	69.3%	42.6%	84.9%	7.23	0.263

Source: Author's estimation

From the result of paired sample test at 5% level of significance, critical and statistical t-value is found to be: 1.984 at df 83 and 5.287 respectively. As $t_{statistic}$ is higher than $t_{critical}$, null hypothesis is rejected. Therefore, it can be concluded that there is significant difference in the mean efficiency of designed and verified turbines, as a result, they are performing in the higher level than expectation.

Mean verified efficiencies of Cross-flow and Pelton turbine is found to be 70.5% and 67.3% respectively; this reveals better performance in Cross-flow than Pelton turbine. Acharaya and Bajracharaya (2013) have illustrated similar result in their studies i.e. performance of Cross-flow turbine is better than Pelton turbine. As per their studies mean efficiencies of Pelton and Cross-flow turbine is found to be 57.4% and 63.1% respectively. In contrast to other countries, performance of Pelton is considered better than Cross-flow. The reason behind the lower performance of Pelton turbine over Cross-flow could be due to problem associated during fabrication and/or installation.

Similarly, year wise variation of Nepalese turbines was analyzed in order to see its improvements in performance over time. For this, the performance data were compared splitting the year range in three categories: (1) Plants commissioned till 2010, (2) Plants commissioned in between 2011 to 2015, (3) Plants commissioned in after 2015

The results show that that the performance of Nepalese turbines is being slightly improved, which is illustrated in the Figure (4).

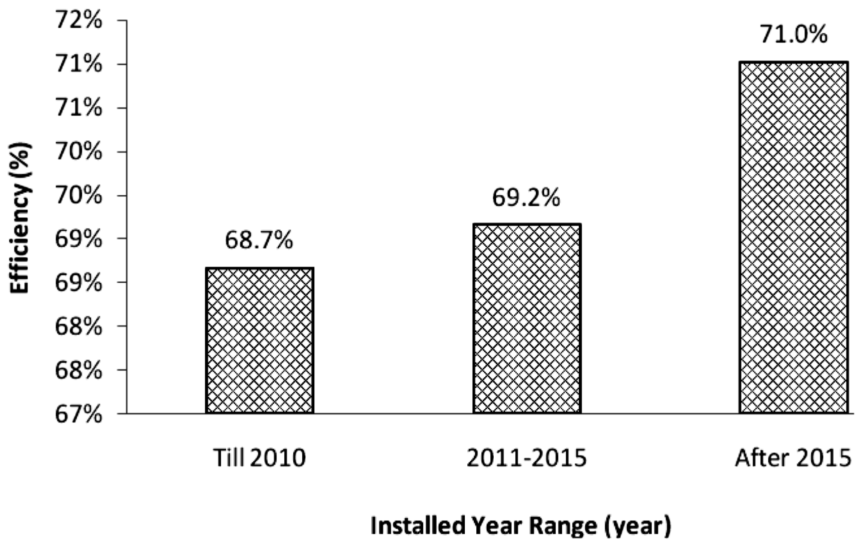

Figure 4. Variation of turbine efficiency with year

It is found that average turbine efficiency is increased by one percentage during three ranges of time series. This may be the results of improvements in manufacturing and installation skills of turbine manufacturers and installers with direct or indirect support from all stakeholders involved for the development of micro-hydro plants in Nepal.

Additionally, mean efficiencies of different components were analyzed with different range of plant size: (1) Water-to-wire, (2) Electro-mechanical, (3) Turbine and (4) Penstock. The result is presented in the Figure (5).

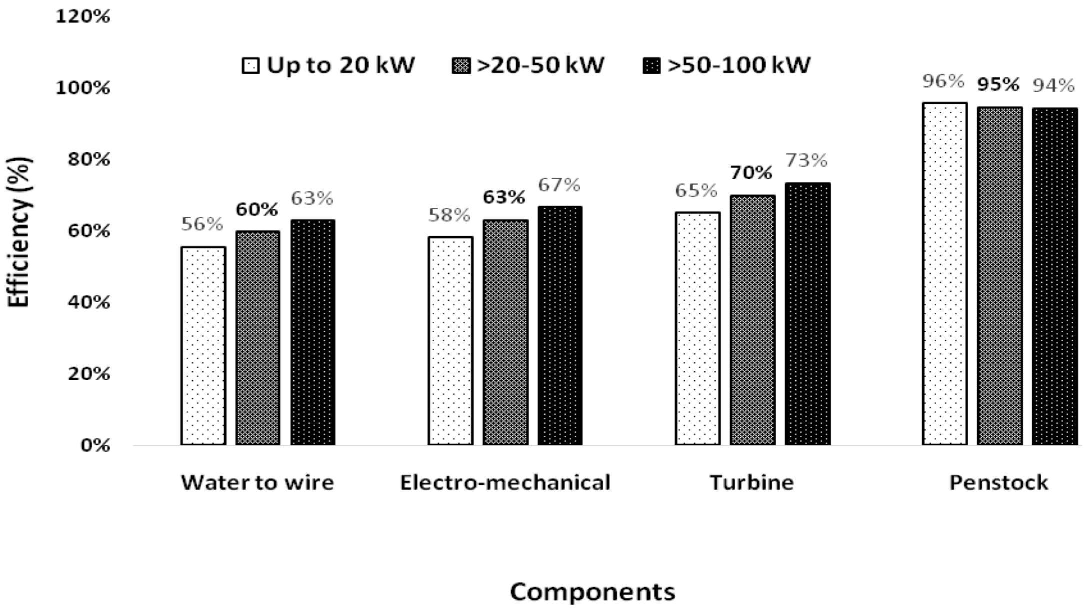

Figure 5. Variation of component mean efficiency with plant size (n=84)

The Figure (5) illustrates that penstock efficiency remain the same irrespective of the plant size whereas mean efficiencies of the rest of the components ascend with increase in plant size.

Reliability

As discussed earlier under theoretical framework, reliability of the Nepalese micro-hydro plants were measured based on availability of flow and electrical power output. Summary of the result in terms of availability of water and electrical power is presented in the Table (6).

Table 6. Reliability of installed plants (n=84)

Parameter	Yes/No	N	Reliability
Water availability (η_w)	No	16	81%
	Yes	68	
Power availability (η_p)	No	7	91.7%
	Yes	77	
Combined ($\eta_c = \eta_w * \eta_p$)	No	22	74%
	Yes	61	

Source: Author's estimation

The result (as presented in above Table 6) shows that majority of installed plants are functioning reliably securing 74% reliability in terms of availability of water and electrical power output. But most of the non-reliability is found due to less amount of flow available in the sites. 16 out of 84 (i.e. about 19% plants) plants are found to be non-reliable in terms of water availability. That means 81% of the installed plants are reliable based on water availability whereas 91.7% of the plants are found to be reliable in terms of electrical power availability. One of the reasons for higher value of electrical power availability could be improvement on the turbine performance (Figure 6) resulting improvements in the overall performance of the plants.

Plant Factor

As discussed under theoretical framework, annual average of plant factor and energy consumed per household (kWh/HHs) were calculated and analyzed with the help of SPSS software to find out arithmetic mean, minimum, maximum, standard deviation and skewness. Summary of these values is presented in the Table (7).

Table 7. Plant factor and energy consumption per households (n = 43)

Parameter	Mean	Minimum	Maximum	Standard Deviation	Skewness
Plant factor	27.2%	2.4%	43.7%	10.4%	-0.767
kWh/ HHs	273.1	23.0	420.5	100.5	-1.080

Source: Author's estimation

Table (7) shows that the mean plant factor of the studies sites is 27% which is considered relatively below for any energy system. Similarly, the mean annual energy consumption per household is found to be 273 kWh which is higher than minimum value (i.e. 250 kWh for rural areas) set by IEA (2015). Similarly, variations of plant factor with plant size were analyzed through SPSS software. Carl Pearson coefficient between water-to-wire efficiency and plant size was found to be 0.0477 which shows there is somehow positive correlation between plant factor and size of plant. The variation of pant factor with plant capacity (P) is given by regression equation:

PF= 0.265 + 0.0001 P ……… (5)

From the result of paired sample test at 5% level of significance, critical and statistical t-value is found to be: 1.984 and 9.28 respectively. As $t_{statistic}$ is higher than $t_{critical}$, null hypothesis is rejected. Therefore, it can be concluded that the plant size influences the plant factor better.

Likewise, analyzing the characteristic of household energy consumption pattern is presented in the following Figure 6, which shows that there is strong correlation between plant factor and energy consumption per household because Pearson's coefficient between plant factor and per household energy consumption was found to be 0.891.

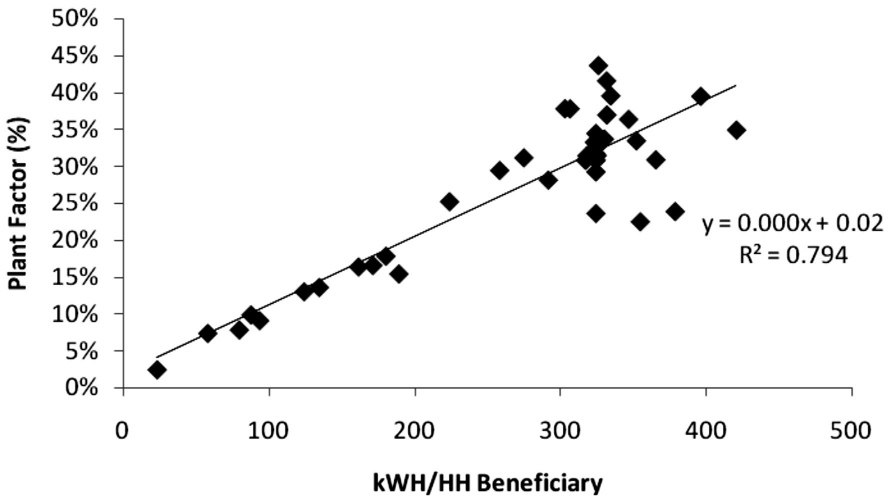

Figure 6. Variation of plant factor with per household energy consumption

From the result of paired sample test at 5% level of significance, critical and statistical t-value is found to be: 1.984 and 17.81 respectively. As $t_{statistic}$ is higher than $t_{critical}$, null hypothesis is rejected. Therefore, it can be concluded that the household energy consumption significantly influences the plant factor better.

LIMITATIONS OF THE STUDY

The designers and manufactures of turbines vary, and there is no standard design of turbine (both pelton and cross-flow). Each manufacturer has own design and practices. Even the materials used are different like mild steel and stainless steel. There is no same level of workmanship during fabrication and installation. The study does not cover the relation of all these factors assuming that irrespective of the different approaches, designs and practice, the overall performance evaluation of Nepalese turbines was performed. This research covers the projects installed in province 1, 4 (Gandak) and 7 (Far-Western). It assumes that most of the installed micro-hydro plants are in these three provinces as a result there will be better chances of representing the scenario of whole country.

CONCLUSION

In conclusion, it is obvious that micro-hydro plants are providing electricity services in the rural part of the country to fulfill lighting, electricity services to social and business activities. Comparing the technical performance of Nepalese plants with national standards, the most of the plants are found to be performing above the national standard. The mean water-to-wire, electro-mechanical and turbine efficiency is above par i.e. 59.2%, 62.5% and 69.3% respectively. And the mean values of electro-mechanical efficiencies of each turbine types and plant size have met national standard. In contrast to other countries, performance of Cross-flow turbines is seen well than Pelton turbine in Nepal. This could be due to some problem in either fabrication or installation or both. Therefore, there is a room to improve the performance of Pelton turbine. However, the performance of Nepalese turbines is found to be in increasing trend.Performance of penstock is found to be less than 0.5% comparing with national standard but as per statistical test (at 5% level of significance) it is within the limit.

In the case of reliability, majority (74 %) of the plants are found to be performing reliably. Few plants performing un-reliably is mainly due to lack of sufficient flow (19%) followed by lower electrical output (8%) to meet the national standard i.e. 11 month availability of design flow in a year.

In regard to plant factor, the plants are performing relatively in low plant factor (i.e. mean value of plant factor is 27%) which implies that there is sufficient room to focus on economic use of electricity in Nepalese micro-hydro plants. The regression analysis refers that the plant factor is strongly influenced by energy consumption per household, and it is slightly influenced by the size of the plant. Therefore, it can be concluded that the higher the plant size, the better is the chance of technical performance and the better is the chance of sustainability as well.

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