Performance Evaluation of Micro Hydro Power Plant using Cross Flow Turbines in Northern Pakistan

Ahmad Jamal¹, Amjad Ullah Khattak²

¹,² Department of Electrical Engineering University of Engineering and Technology Peshawar, Pakistan
engrahmadjamal@gmail.com¹, amjad67@gmail.com²

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Abstract—Micro Hydro-power Plants (MHPs) play a key role in electrification and economic development of remote rural areas where the government grid system power supply is limited. A field study was conducted to evaluate the performance of crossflow turbines in District Shangla, Pakistan during 2019. The relevant data was collected to find the actual and potential power produced, transmission losses, number of households served and installed capacity of MHPs for detailed analyses. A relatively higher power was generated by MHPs with flow discharges ranging from 0.600 to 0.800 m³/s and head of about 10.00 m. The power produced at generation points varied from 8.496 to 48.574 KW with overall average of 25.782±11.971 KW. About two-third of the MHPs performance in term of average overall efficiency (67.56±11.63%) was found higher as compared to the overall efficiency (37.80±8.79%) of the remaining one-third of MHPs where the installation was not according to the site requirements. The number of Households per MHP ranged from 15 to 250 with overall average of 88±55 and energy demand of 1420±474 watts per household. The total transmission line loss in MHPs studied varied from 0.08 to 1.84 per km with overall average of 0.71±0.58 KW per km. With proper design and installation of MHPs more energy can be generated to minimize the gap between demand and supply in the rural areas.

Keywords—Efficiency, Flow discharge, energy demand, Transmission losses and hydro power generation.

I. INTRODUCTION

Pakistan is blessed with enormous natural hydropower resources and possesses potential of hydropower development of 42,000 MW. Out of which small portion of about 7,000 MW (16.7%) has been exploited including 13,000 MW micro hydro power [1, 2]. Energy demand is increasing at the rate of 10% per annum and the gap between supply and demand is increasing day by day [3]. The long hours of power outages have become common place in the country in general and in rural area in particular, which is affecting the economic growth and development. As reported by the Asian Development Bank (ADB, 2019) that due to energy crisis in Pakistan about 2 to 3% of Gross Domestic Products (GDP) was affected. There is a great need for reliable and low-cost electricity which is expected to supports socio-economics development process and can minimize the gap between supply and demand.

In Pakistan’s hilly areas, some of the localities are located outside of the National Grid but there is a great potential for development of micro hydro power [3]. Electricity can be generated from waterfalls that exist in the hilly area which can produced energy with low cost and play a role in economic development of country in general and rural areas in particular. The hydro turbine converts water pressure into mechanical shaft power that can be drive is an electrical power. The cross-flow turbine is commonly used for generation of micro hydropower power with low head and can work under variable flow conditions [4].

The efficiency of cross flow turbines depends on flow discharge, net head, runner, nozzle angle and size, diameter of the turbine, runner length, runner speed, number of blades and other factors. In general, the cross-flow efficiency under various flow conditions 0.4 to 0.6 Q/Qmax ranged from 75 to 80% [5]. Similarly, maximum turbine efficiency of 80% was reported with low head and different flow rate [6].

At present, small micro hydro power systems use impulse turbines and reaction turbine and theses have low efficiency ranges from 30-40% [7]. Agnew Turbine which was modification an axial micro hydro of Kaplan type, and was developed by join research team of university of Glasgow and the Iranian Research Organization for Science and Technology (IROST) and obtained an efficiency of 62%. With slight modification in Kaplan type to Agnew Turbine resulted 23% higher efficiency [8]. In Francis Type Turbine in small hydro system with medium head an efficiency of about 90% can be achieved, while in smaller heads lower efficiencies have been reported [9].

Distribution of electricity from small hydro units, resulting Power losses, Voltage Profile, Power Quality, Excess Voltage, Voltage Fluctuation and Reliability are the major problems that need to be properly investigated. The Power Losses depend on consumers distance from distribution load Centre of the generating units. These are further divided into two classes’ higher reduction of losses and small reduction of losses. In
The water resources are depending on the snow and rain. The annual rainfall is approximately 1,416 mm and snow seasons about 1 to 2 m snow is falling which is the main source of the water and it is used for the domestic, agriculture and also for the hydro power generations in shown in “Figure 1”.

### B. Data Collection

In District Shangla significant number of micro hydro power have been installed by government and non-government organizations during the last decade. Out of these 20 number of micro hydro power were studied in detail is given in “Table 1”.

A structured questionnaire was developed to collect technical data related to micro hydro power installed at different locations in District Shangla as well as detailed information from concerned stakeholders related to number of households served, number of poles, distance between the poles, number and types of energy usage, number of operation hours per day, date of installation, major maintenance problems, size of penstock pipes, total head, types of turbine, year of installation, power generation, the losses in power generation and distribution, development of models for power generation at various operational conditions and the optimum power generation efficiency.

### C. Potential Power (Pn)

For assessment of power generation data related to head and flow discharge, information related to type of turbine, year of installation, potential power produced on the basis of net head and actual power produced data was collected and recorded. Flow discharges were determined through a current meter and head was assessed through GPS and was verified by appropriate surveying equipment. The net head losses were determined from Bernoulli’s equation. The potential power that can be generated is given by equation as follows:

$$P_n = \rho \times g \times Q \times H_n$$

Where $P_n$ is the potential power in watt, $\rho$ is the density of water in kg/m$^3$, $g$ is the gravitational constant m/s$^2$, $Q$ is flow rate in m$^3$/s and $H_n$ represents the flow net head in m.

### D. Actual Power (Pa)

The actual power produced was computed from the current and voltage recorded at the output panel of each MHP. The actual power produced by MHP is given by equation:

$$P_a = 1.73 \times V \times I \times \cos\phi$$

Where $P_a$ is the actual power produced in watt (W), $V$ shows the voltage and $I$ represent the current in amperes which were determined in the field through digital Multimeter, clamp meter and $\cos\phi$ is the power factor taken as 0.8.

### E. Overall Efficiency ($\eta_o$)

The overall efficiency ($\eta_o$) of MHPs were determined from actual power (Pa) recorded divided by potential power (Pn) that can be produced by using the following equation:

$$\eta_o = \frac{P_a}{P_n} \times 100$$


F. Losses in Power Generation and Transmission Line

The power produced at source was found from the voltage and current then at consumers (household’s level) the voltage and current were also recorded as well as the type of wire, thickness and length of the wires to find the losses in power generation and transmission in the systems.

G. Data Analyses

The installed capacity of the MHPs studied ranged from 15 to 50 KW with average of 29.45 KW and with coefficient of variation of 36.01 %. At the site, the available head ranged from3.35 to 19.81 m with overall average of 9.63 ±4.92 m. Accordingly net head varied from 3.20 to 19.80 m with overall average of 9.05±4.90 m. The flow rate varied from 0.070 to1.252 m$^3$/s with overall average of 0.544±0.283 m$^3$/s during the months of July and August, 2019. The Consumers’ Power demand per household in the studied area ranged from 524 to 2637 watts with overall average of 1420±474 watts and coefficient of variation of 33%. The number of Households varied from 15 to 250 with overall average of 88±55 per Micro hydro power plant installed at the site is shown in “Table 1”.

The total length of transmission lines per MHPPs ranged from 2.286 to 7.315 km with overall average of 3.918±1.537 km and coefficient of variation of 39.221. The power produced at generation points varied from 8.496 to 48.574 KW with overall average of 25.782±11.971 KW and coefficient of variation of 46.43%. The total transmission line loss in MHPs studied varied from 0.08 to 1.84 KW per km with overall average of 0.71±0.58 per km and coefficient of variation of 81.16%.

| S. No | Name of the MHP | Capacity (KW) | Flow Rate Q(m$^3$/s) | Gross Head (m) | No. of Households | Demand per Household (Watt) | Total Length of TL (km) |
|-------|-----------------|---------------|-----------------------|----------------|---------------------|---------------------------|------------------------|
| 1     | NAWAZABAD       | 30            | 0.458                 | 7              | 60                  | 1158                       | 2.74                   |
| 2     | MATT AFGHAN     | 30            | 0.500                 | 5.58           | 60                  | 1783                       | 4.11                   |
| 3     | KHWARAH KALLI   | 25            | 0.155                 | 14.8           | 62                  | 1218                       | 2.74                   |
| 4     | KUZZ KANA       | 30            | 0.619                 | 3.96           | 124                 | 524                        | 7.31                   |
| 5     | KUZZ KANA       | 35            | 0.619                 | 4.57           | 133                 | 524                        | 7.31                   |
| 6     | RANEZO          | 30            | 1.252                 | 3.96           | 100                 | 1493                       | 2.29                   |
| 7     | BAR KANNA       | 25            | 0.790                 | 4.82           | 30                  | 1885                       | 4.39                   |
| 8     | BAR KANNA       | 25            | 0.790                 | 4.82           | 30                  | 1911                       | 2.74                   |
| 9     | CHORBUTT        | 15            | 0.070                 | 19.81          | 50                  | 1493                       | 2.29                   |
| 10    | AIMAIR BARAI PIR KHANNA | 40     | 0.672                 | 11.58          | 160                 | 889                        | 6.40                   |
| 11    | LARAI AIMAL KHAN | 20            | 0.640                 | 10.06          | 45                  | 2637                       | 4.21                   |
| 12    | LANDAI KUZ PIR KHANNA | 20     | 0.097                 | 18.29          | 15                  | 1431                       | 2.74                   |
| 13    | TAUHEEDABAD LINOWNAI | 25     | 0.389                 | 13             | 80                  | 1342                       | 2.93                   |
| 14    | SAKHI ABAD BASI | 16            | 0.340                 | 3.35           | 60                  | 732                        | 2.47                   |
| 15    | MATA AGHWAN     | 24            | 0.322                 | 13.72          | 80                  | 1812                       | 2.74                   |
| 16    | BAND KHWARGAE   | 25            | 0.359                 | 9.75           | 150                 | 1500                       | 2.74                   |
| 17    | BAND KHWARGAE MEERABAD | 50     | 0.720                 | 9.14           | 250                 | 1425                       | 5.49                   |
| 18    | DHERIA KAGADAN  | 50            | 0.742                 | 14.32          | 80                  | 1611                       | 5.94                   |
| 19    | DHERIA KAGADAN  | 50            | 0.559                 | 9.14           | 100                 | 1419                       | 3.66                   |
| 20    | PHOSTANO SHELAWAI KUZZ KHANNA | 24     | 0.790                 | 10.97          | 90                  | 1547                       | 2.29                   |

Maximum 50.00 1.252 19.81 250 2637 7.315
Minimum 15.00 0.070 3.35 15 524 2.286
Average 29.45 0.544 9.63 87.95 1420 3.918
STD 10.61 0.283 4.92 54.99 474 1.537
CV (%) 36.01 52.053 51.12 62.52 33.00 39.221
III. RESULTS AND DISCUSSION

A. Actual Power and Flow Discharges

The relationship between actual power produced and flow discharges of 20 MHPs studied is shown in “Figure 2”. It can be seen from the figure that a significant positive correlation was found between actual power produced and flow discharges. In general, the actual power produced increased with flow discharges from 0.070 to 0.800 m³/s beyond that the actual power did not show any significant increase with flow discharges. It can be concluded that flow discharged beyond 0.800 m³/s may not significantly increase the actual power of cross flow turbine which is in conformity with other researchers [21].

B. Actual Power and Net Head

The relationship between actual power and net head of flow is shown in “Figure 3”. A significant correlation was obtained between actual power and net head of R² = 0.3442. It is obvious from the figure that the maximum actual power that can be produced by using crossflow turbine with the net head of about 10.0 m.

C. Potential and Actual Power

“Figure 4”, shows the relationship between actual and potential power. A significant correlation was obtained between actual power and Potential power with R² = 0.6064. The potential power that can be generated by using the available flow and net head ranged from 11.00 to 90.20 KW with overall average of 39.65±21.15 KW with coefficient of variation of 53.33%. The actual power produced by MHPs at the sites ranged from 7.34 to 35.88 KW with overall average of 20.55± 8.67 KW and coefficient of variation of 42.22%.

D. Actual Power Produced and Generator Capacity

The actual power produced and generator installed capacity is given in “Figure 5”. It can be seen from the figure the significant correlation (R² = 0.9023) was found between the installed capacity and actual power produced. It can be concluded that all the generator installed produce relatively better efficiency as desired.

E. Overall Efficiency (η)

The overall efficiencies of the MHP’s studied are given in “Figure 6”. It can be seen from the figure that the efficiencies ranged from 24.76 to 87.31 with overall average of 57.61± 17.95 and coefficient of variation of 31.40%.
Further all MHP’s were divided into two groups. Based on their performance, in Group-1 MHP’s with overall efficiency of greater \( \geq 50\% \) were placed, while in Group-2 consisted of MHP’s with overall efficiency of less than \(<50\% \) is shown in “Figure 7”. A statistically significant difference was found between two groups as per T-Test. In Group-1 the overall average efficiency of 67.56±11.63%. As compared to Group-1, The overall average efficiency of Group-2 was significantly lower (37.80±8.79%) then Group-I. Some of main reasons for low overall efficiency of MHP’s of Group-2 were the turbine and generator units were not proper design as per site requirements. By proper designing and replacement of turbine and generator in Group-2 as per site requirements, the generation’s capacity of the MHPs can be enhanced by one-third.

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**CONCLUSIONS**

The actual power produced increased with flow discharges from 0.200 to 0.800 m3/s beyond that the increase was relatively low. Maximum power can be produced by using cross flow turbine with the net flow head of about 10.0 m beyond or below that head the power produced was lower. A significant correlation was obtained between actual power and potential power, which means that most of MHPs were working according to the design. For the cross-flow turbine a better efficiency was obtained when the flow discharge ranged between 0.6 to 0.8 m3/s. The overall efficiencies of twenty MHPs were found to be 57.61± 17.95%. The annual per capita power demand was four folds more than the energy supply. The micro hydro power plays an important role in energy demand of rural remote areas and should be encouraged.
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