International of Journal Engineering Works
ISSN-p: 2521-2419
ISSN-e: 2409-2770
Vol. 8, Issue 01, PP. 41-46, January 2021
https://www.ijew.io/
https://doi.org/10.34259/ijew.21.8014146

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

Ahmad Jamal[1], Amjad Ullah Khattak[2]
[1,2] Department of Electrical Engineering University of Engineering and Technology Peshawar, Pakistan
engrahmadjamal@gmail.com[1], amjad67@gmail.com[2]
Received: 6 January, Revised: 15 January, Accepted: 20 January

***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 ranged 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 voltage Profile are usually changing at substation transformer by use of voltage regulator and capacitor on the feeder [10]. Power Quality depends on ideal Sinusoidal voltage and current wave form in which current and voltage should in balance [11, 12]. To protect system from degradation in power quality it is important for network operator to minimize short circuit capacity. In Excess Voltage cause the voltage profile of feeder lines to deviate from the desired range [13-17]. While voltage fluctuation in the main distribution system resulting the relative fluctuation in the local lines system. Hence the voltage output changes with short time and this fluctuation cause over or under voltage at the end point of the customers [12, 18-19].

The factors that could affect the power generation of a MHPP are Amount of water flowing in specific time (Water Discharge), the height of water fall (Available Head), Overall Efficiency (Turbine, Drive system, Generator) and Losses (Headrace to End users).The losses that affect the power generation and efficiency of the MHPPs are the channel losses, Penstock losses, Turbine losses, Generator losses, Transformer losses and transmission line and distribution losses [20], H is the available head (meters) and Q is the water flow (m3/sec).

In Pakistan, a significant number of Micro hydro power plants (MHPs) have been installed for provision of electricity to remote rural communities by government and non-government organizations during the last few decades. The cross-flow turbines are commonly used in these MHPs. Out of theses, 20 number of MHPs were selected for detail study during 2019-2020 in which cross flow turbines were used. This research study was conducted to evaluate the performance of MHPs in District Shangla of Khyber Pakhtunkhwa, Pakistan.

II. Research Methodology

A. Study Area:

The study was conducted in District Shangla of Malakand Division of Khyber Pakhtunkhwa, Pakistan. The total geographical area of District Shangla is about 1586 km2, population of 757,810 with total number of Households 64,391, about 8 person per household and consists of three sub division Alpuri, Puran and Besham. Water resources in the district depends on rains and snow. There are about 248 small snow glaciers. The average flow discharge of Shangla river before the water enter into the Khan Khawar dam is about 35 m3/s.

Figure 1: Location map of District Shangla (Adopted from Wikipedia)

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 detail 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:

$$\mathrm{Pn} = \rho \times g \times Q \times \mathrm{Hn}$$

Where Pn is the potential power in watt, ρ 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 Hn 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:

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

Where Pa 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 cosϕ is the power factor taken as 0.8.

E. Overall Efficiency ((η_o)

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

$$\eta_0 = \frac{Pa}{Pn} \times 100$$

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%.

TABLE I. SELECTED PARAMETERS OF MHPS

S. No	Name of the MHP	Capacity (KW)	Flow Rate Q(m^3/s)	Gross Head (m)	No. of House holds	Demand per Household (Watt)	Total Length of TL (km)
1	NAWAZABAD	30	0.458	7	60	1158	2.74
2	MATTA 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	1131	5.49
5	KUZZ KANA	35	0.619	4.57	133	524	7.31
6	RANEZO	30	1.252	3.96	100	953	4.94
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	AJMAIR BARAI PIR KHANA	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].

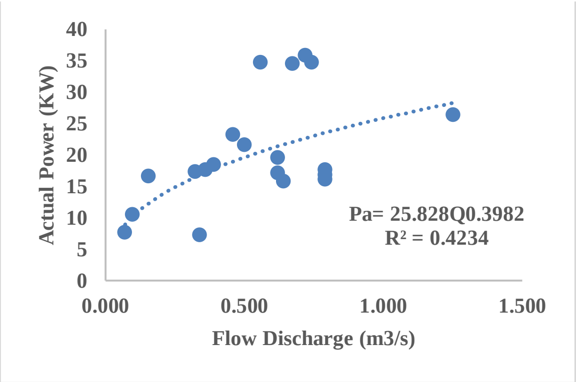

Figure 2. Relationship between actual power and flow discharges

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.

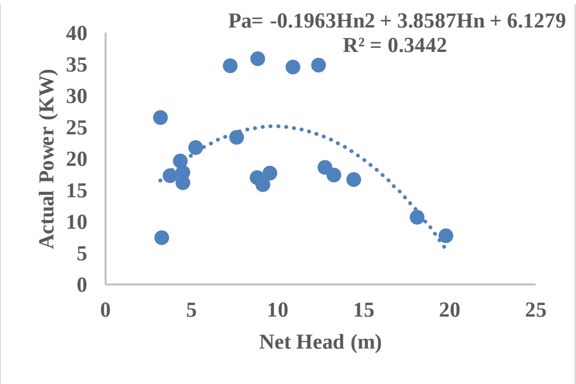

Figure 3. Relationship between actual power and net head.

If the net head is lower or greater than 10 m relatively lower actual power was produced. Similar results were reported by other researchers who found that crossflow turbine is suitable for medium and low head, which is less than 10 m [22].Therefore, it can be concluded that maximum actual power can be produced from crossflow turbine the net head should be in the vicinity of 10 m and net head over or below that range may not produce optimum power.

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%.

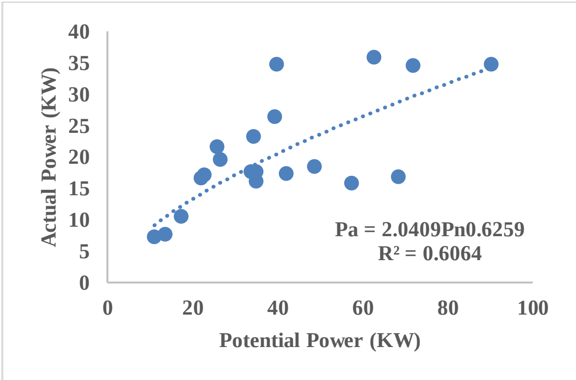

Figure 4. Relationship between Actual power and Potential Power (KW)

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.

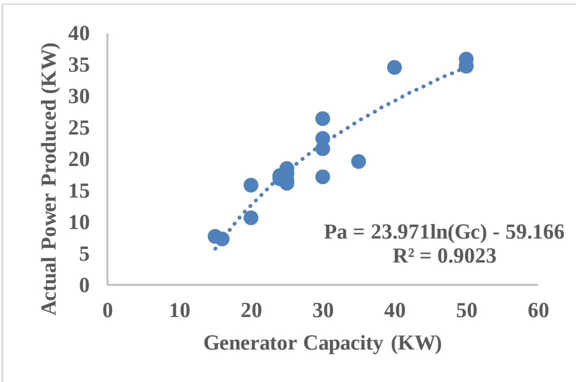

Figure 5 Relation between Actual Power Produced and Generator Capacity (KW)

E. Overall Efficiency (□o)

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%.

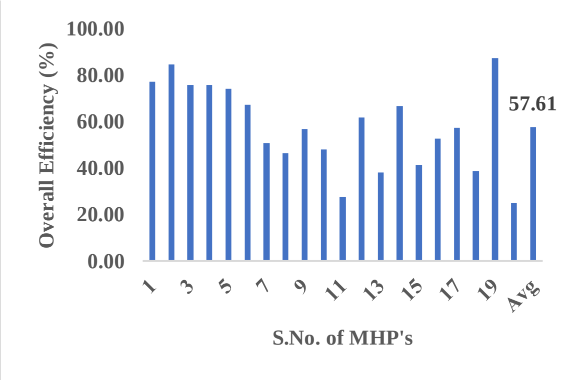

Figure 6: Efficiency of MHPPs

Further all MHP’s were divided into two groups. Based on their performance, in Group-1 MHP’s with overall efficiency of greater ⩾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.

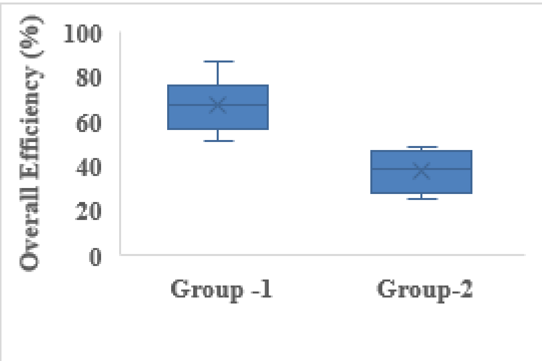

Figure 7: Comparison of overall efficiency of different groups

F. *Annual Power Demand and Supply Per Capita*

The annual power demand and supply per capita of different MHPs is shown in “Figure 8”. The annual power demand per capita of community being served by the MHPs ranged from 574 to 2166 KWH with overall average of 1265±487 KWH. On the other hand, the power supply per capita per annum varied from 42 to 694 KWH with overall average of 291±176 KWH. It can be seen from a “Figure 8” the demand is four folds more than supply. As compare to the annual average consumption per capita in Pakistan of 448 KWH reported by World Bank, 2018. The annual energy consumption in the study area was about half of the electricity used in Pakistan.

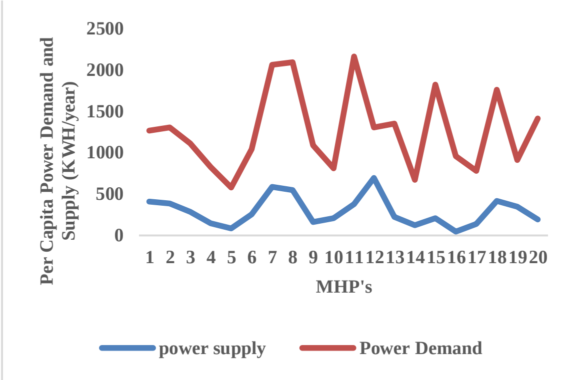

Figure 8. Annual Power demand and supply of MHPs

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.

REFERENCES

[1] Chattha, Javed A., Mohammad S. Khan, and Anwar ul-Haque. "Micro-hydro power systems: Current status and future research in Pakistan." ASME Power Conference. Vol. 43505. 2009.

[2] Chattha, Javed A., et al. "Design of a cross flow turbine for a micro-hydro power application." ASME 2010 Power Conference. American Society of Mechanical Engineers Digital Collection, 2010.

[3] Farooqui, Suhail Zaki. "Prospects of renewables penetration in the energy mix of Pakistan." Renewable and Sustainable Energy Reviews 29 (2014): 693-700

[4] Singal, S. K. "Selection of best Operating Site of SHP plant based on performance." Procedia-Social and Behavioral Sciences 189 (2015): 110-116.

[5] Sinagra, Marco, et al. "Cross-Flow turbine design for variable operating conditions." Procedia Engineering 70 (2014): 1539-1548.

[6] Nasir, Bilal Abdullah. "Design of high efficiency cross-flow turbine for hydro-power plant." Int. J. Eng. Adv. Technol 23 (2013): 2249-8958.

[7] Yassi, Yousef. "Improvement of the efficiency of the Agnew micro hydro turbine at part loads due to installing guide vanes mechanism." Energy Conversion and Management 51.10 (2010): 1970-1975.

[8] Adhau, S. P. "A comparative study of micro hydro power schemes promoting self-sustained rural areas." 2009 International Conference on Sustainable Power Generation and Supply. IEEE, 2009.

[9] Okot, David Kilama. "Review of small hydropower technology." Renewable and Sustainable Energy Reviews 26 (2013): 515-520.

[10] Trebolle Trebolle, David, and Tomás Gómez San Román. "Reliability options in distribution planning using distributed generation." (2010).

[11] Eto, Joseph, et al. Scoping study on trends in the economic value of electricity reliability to the US economy. No. LBNL-47911. Lawrence Berkeley National Lab., CA (US), 2001.

[12] Pepermans, Guido, et al. "Distributed generation: definition, benefits and issues." Energy policy 33.6 (2005): 787-798.

[13] Mathur, H. D. "Enhancement of power system quality using distributed generation." 2010 IEEE International Conference on Power and Energy. IEEE, 2010.

[14] Nagliero, A., et al. "Management of grid-inverter outages and power quality disturbances in distributed power generation systems." IECON 2010-36th Annual Conference on IEEE Industrial Electronics Society. IEEE, 2010.

[15] Singh, Alka, and Bhim Singh. "Power quality issues related to distributed energy source integration to utility grids." 2010 Annual IEEE India Conference (INDICON). IEEE, 2010.

[16] Bojoi, Radu Iustin, et al. "Enhanced power quality control strategy for single-phase inverters in distributed generation systems." IEEE Transactions on Power Electronics 26.3 (2011): 798-806.

[17] Guerrero, Josep M., et al. "Distributed generation: Toward a new energy paradigm." IEEE Industrial Electronics Magazine 4.1 (2010): 52-64.

[18] Marei, Mostafa I., et al. "Hilbert transform based control algorithm of the DG interface for voltage flicker mitigation." IEEE transactions on power delivery 20.2 (2005): 1129-1133.

[19] Woyte, Achim, et al. "Voltage fluctuations on distribution level introduced by photovoltaic systems." IEEE Transactions on energy conversion 21.1 (2006): 202-209.

[20] Uddin, Waqar, et al. "Current and future prospects of small hydro power in Pakistan: A survey." Energy Strategy Reviews 24 (2019): 166-177.

[21] Kaldellis, J. K., D. S. Vlachou, and G. Korbakis. "Techno-economic evaluation of small hydro power plants in Greece: a complete sensitivity analysis." Energy Policy 33.15 (2005): 1969-1985.

[22] Razak, J. A., et al. "Application of crossflow turbine in off-grid Pico hydro renewable energy system." Proceeding of the American-Math 10 (2010): 519-526.

How to cite this article:

Ahmad Jamal and Amjad Ullah Khattak "Performance Evaluation of Micro Hydro Power Plant using Cross Flow Turbines in Northern Pakistan", International Journal of Engineering Works, Vol. 8, Issue 01, PP. 41-46, January 2021, https://doi.org/10.34259/ijew.21.8014146.