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Efficiency Analysis of Hydro Turbine Used in Mini/Micro Hydel Plants: A Case Study of Gilgit-Baltistan.

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Abstract

Hydro power (HP) plants represent the most environmentally friendly and cost-effective means of rural electrification. In areas with mountainous topography, use of mini/micro hydel plants (MHPs) are one of the recommended technology. This facility can serve an isolated community by generating 100 kW to 1 MW of electricity. In majority of the countries including Pakistan no proper attention is paid to the post project evaluation. Performance evaluation of MHP turbines and control equipment are necessary for achieving the most efficient and best results. More than 278 hydro sites have been identified by Gilgit-Baltistan Water & Power Department (GBPWD) and different Non-Governmental Organizations (NGOs), currently 119 hydel plants are functional, producing 148.69 MW of electricity. Approximately 70 % of the region has been benefited with electricity obtained from hydro power plants, the supply demand has been affected by the seasonal variations.

The aim of this research is to evaluate the efficiency of already installed mini/micro hydel plants (MHPs) in Gilgit Baltistan (GB). Through case studies of three (3) different sites, the efficiencies of hydro turbines are presented. The research framework in this paper is that the efficiency of the turbine is compared with international standards. It is hoped that the discussion and results presented at the end will be helpful in future power generation.

Keywords: Hydro power; Turbines, Efficiency; Electricity.

1. INTRODUCTION.

Electricity is an essential stimulator for socio economic uplift of any developing country. Hydro power has become one of the most suitable environmentally friendly and cost-effective means of electrification in rural areas. Nowadays In developing countries, the agencies involved in rural power supply recommend use of Mini/Micro hydel plants (MHPs) as the most robust, efficient and reliable source of off power generation [1]. The employment of MHPs has been recommended by many international organizations such as United Nations Industrial Development and World Bank. The projects developers and implementers are following the standards laid down for setting up MHP installations [2].

In Pakistan natural resources in the form of hydro power is in excess, which can be utilized to produce electricity. Hydropower is the best existing option as it is clean, sustainable and indigenous. About 60 Giga-watt (GW) hydro potential has been estimated to be available in the country. It is therefore imperious to put all efforts towards expansion and development of hydro power without further delay [3].

According to Gilgit-Baltistan Public Works Department (GBPWD) hydro power on main tributaries and Indus River are 40, 000 Mega-Watt (MW) and on sub tributaries the hydro potential is approximately 1,200 MW. In the past several NGOs such as Aga Khan rural support Program (AKRSP) and German Development Organization (GIZ) along with WAPDA and GBPWD have conducted surveys to identify hydro power potential sites. About 278 project sites have been identified; most of them are mini or micro hydel plants (MHPs) having range between 100 kW to 4 MW respectively. The district wise number of hydel plants and their installed capacities are shown in Figure 1.

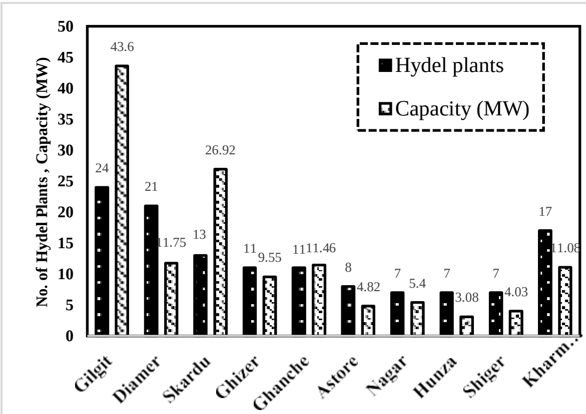


Fig 1 :District Wise Hydel Plants and Capacity in MW (data source: GBPWD)

MHPs Schemes can be used to harness electrical energy for home lightning, industrial and other purposes [4]. Using MHPs with efficient design, especially the turbines, can be perfect solution to overcome the economical and operational problems [1, 5].

Although energy from MHPs are thought as clean and cheap, many of the developing countries that need rural electrification are exposed to economic issues when installing costly hydro equipments [6]. Currently in Gilgit-Baltistan (GB) almost 100 hydel plants are functional, of them, small plants are 22 in numbers with installed capacity of 103.75 MW, 43 of these plants are of mini type having installed capacity of 35.8 MW and 46 micro hydel plants with installed capacity of 8.71 MW shown in the Figure 2.

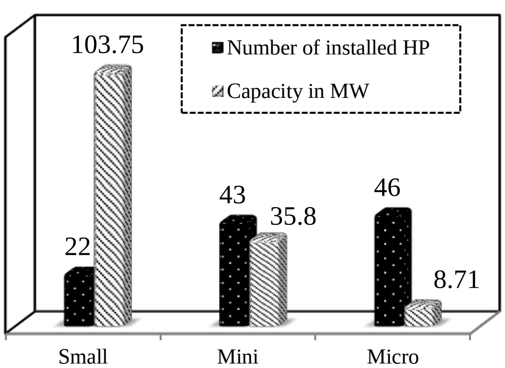


Fig 2: Hydel Plants categories and Installed Capacity in GB (data source: GBPWD/GIZ).

2. GILGIT-BALTISTAN (GB) & HYDRO POTENTIAL.

Gilgit Baltistan (GB) is the situated in between the world highest mountain ranges of the Himalayas, Karakorum and Hindukush in the Northern side of Pakistan. The region is divided into three (3) main divisions (Gilgit, Baltistan and Diamer divisions) and ten (10) districts respectively. Gilgit Baltistan is spread over an area of 72496 sq.km which includes about 27% glaciers, the biggest in the world outside polar region. Its population is 1.4 million as per estimates of 2017 National Census of Pakistan.

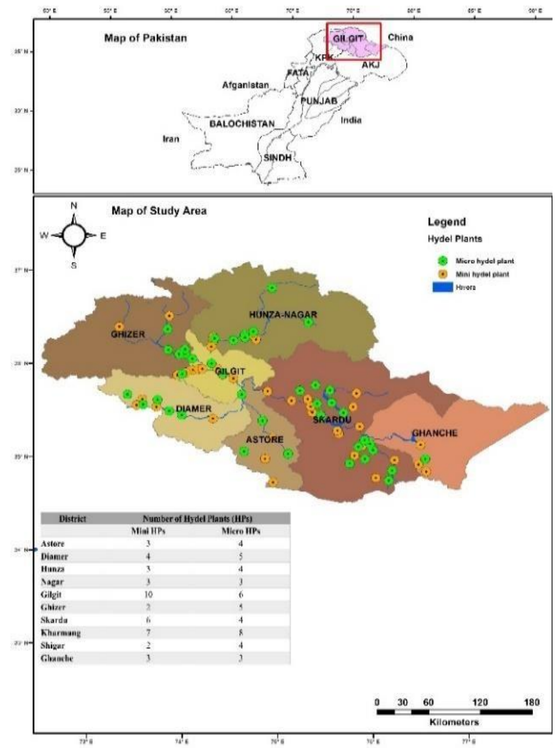


Fig 3: ARCGIS Map of Gilgit-Baltistan (GB) with District Wise Mini/Micro Hydel Plants (MHPs).

The region has bestowed with enormous hydro power potential, which if carefully exploited can ensure future energy security on long term basis. In Gilgit Baltistan the supply of electricity started in 1960s when few micro hydel power stations were developed in the area (Hydro Power and Renewable Policy for GB by GBPWD). This enormous hydro power potential can be exploited to develop mega, small and micro hydel stations in GB to meet the energy requirement. Figure 4 shows year wise generation of electricity from hydropower during the years 1960-2017.

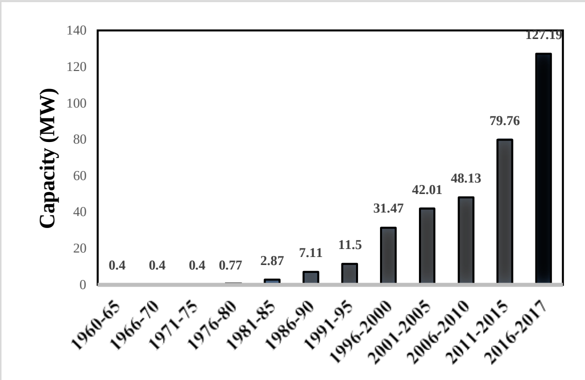
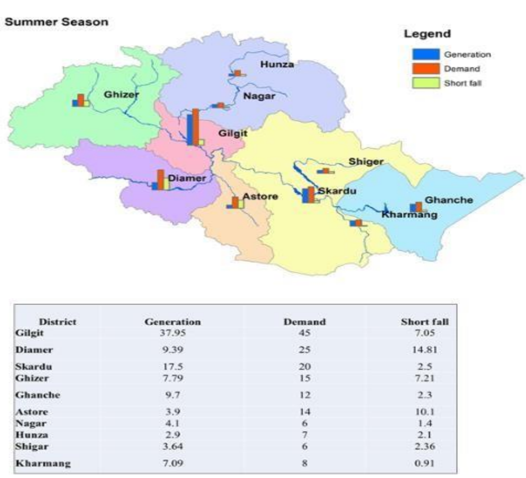


Fig 4: Year Wise Power Generation in GB from 1960-2017 (data source: GBPWD / AKRSP).

3. ELECTRICITY SITUATION.

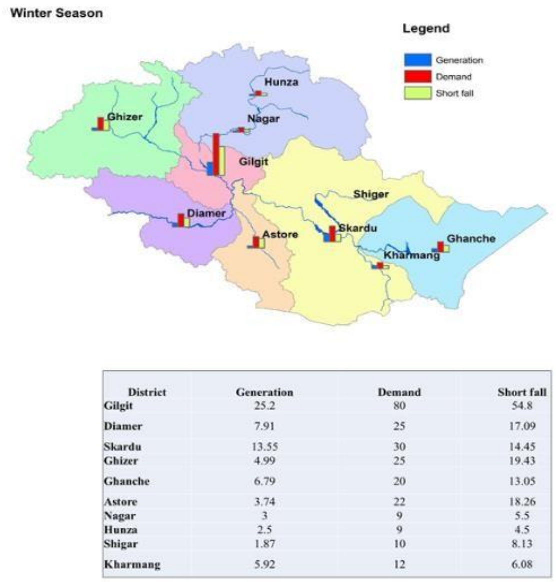
Gilgit Baltistan (GB) is not connected to National Grid because of geographically scattered population and difficult physical infrastructure, the region is lagging as compared to the rest of the country in terms of energy generation. Currently GB Water and Power Department (GBPWD) is the main institution and organization with limited manpower and resources for energy related functions and services. The energy availability varies with seasonal variations, in winters the load shedding last long for many hours especially in main cities of all three (3) divisions (Gilgit city and surroundings, Skardu city and Chilas city). In summer the demand supply gap reduces because of excess availability of water on the hydel plants sites and the region face minimum load shedding.

Figure 5 and Figure 6 illustrates winter and summer situations of electricity availability in Gilgit Baltistan (GB).



District	Generation	Demand	Short fall
Gilgit	37.95	45	7.05
Diamer	9.39	25	14.81
Skardu	17.5	20	2.5
Ghizer	7.79	15	7.21
Ghanche	9.7	12	2.3
Astore	3.9	14	10.1
Nagar	4.1	6	1.4
Hunza	2.9	7	2.1
Shigar	3.64	6	2.36
Kharmang	7.09	8	0.91

Fig 5: Demand and Supply in Summer Season.



District	Generation	Demand	Short fall
Gilgit	25.2	80	54.8
Diamer	7.91	25	17.09
Skardu	13.55	30	14.45
Ghizer	4.99	25	19.43
Ghanche	6.79	20	13.05
Astore	3.74	22	18.26
Nagar	3	9	5.5
Hunza	2.5	9	4.5
Shigar	1.87	10	8.13
Kharmang	5.92	12	6.08

Fig 6: Demand and Supply in Winter Season.

There are some areas in GB like Haramosh, Bagrote, Kharmang, Darel, Tangir and Thore with no load shedding in both summers and winters. Table 1 show the current load shedding situation in three main divisions of Gilgit Baltistan (GB).

Table 1: Current Load Shedding Schedule of GB (data source: GBPWD)

	Division	**Summer**	**Winter**	
			On Hours	**Off Hours**
1.	**GILGIT**			
	City & Surroundings	6 hours off daily	05 Hours	19 Hours
	Juglote Sai	2 hours off daily	12 Hours	12 Hours
	Haramosh & Bagrote	No shedding	No shedding	No Shedding
2.	**SKARDU**			
	Kharmang	No shedding	No Shedding	No Shedding
	Skardu city	2 hours off daily	04 Hours	20 Hours
	Shiger	No Shedding	No Shedding	No Shedding

	Roundu	No Shedding	No Shedding	No Shedding
3.	**DIAMER**			
	Bunner Area	No shedding	16 Hours	08 Hours
	Chilas City & Surroundings	6 hours off daily	12 Hours	12 Hours
	Darel	No Shedding	No Shedding	No Shedding
	Tangir	No shedding	No shedding	No Shedding
	Thore	No Shedding	No Shedding	No Shedding

4. METHODLOGY.

The methodology adopted in this paper is to calculate and plot the efficiencies of these mini/micro hydel plants (MHPs) and compared it with the standard plot. For a hydro power plant, the general formula for efficiency (η_o) calculation is [7].

$$\eta_o = \frac{\text{P(Mechanical power Produced at Turbine shaft)}}{\rho g Q H} \quad (1)$$

where η_o is the turbine efficiency, P is mechanical power produced at the turbine shaft (watts), ρ is the density of water (1000 kg/m^3), g is acceleration due to gravity (9.81 m/s^2), Q is the volume flow rate passing through turbine (m^3), H is effective pressure head across the turbine (m) and Q_o is maximum working flow rate of hydro turbine.

The values of water density (ρ) and acceleration due to gravity (g) are known, so efficiency can be calculated by calculating values of Flow rate (Q), Effective Head (H) and output Power at the turbine shaft (P).

A significant factor which limits the appropriateness of a hydro turbines is the relative efficiencies at design point, head and various flows. For each turbine (Pelton, Propeller, Francis and Cross Flow) its characteristic efficiency at different head and partial flow are different as shown in Figure 7 [8].

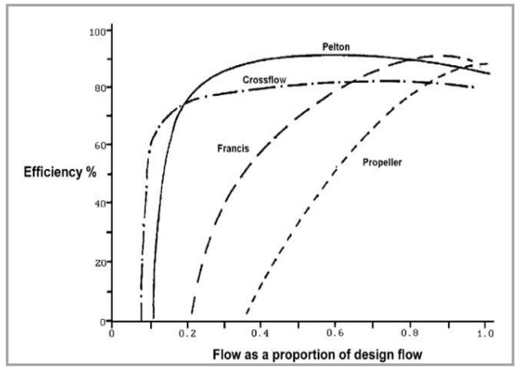


Fig 7: Part Flow Efficiencies [9, 8].

4.1 Calculation of Flow rate (Q), Effective head and Power (P).

To obtain high accuracy of the measurement, proper selection of device range is very important. For calculation of Flow rate, Effective head and power the Electro mechanical devices used are [10].

1- Differential Pressure devices /Pressure time method to calculate flow rate.
2- Electronic Transducers for measurement of effective head.
3- Power meter for calculation of turbine shaft power.

For three sites (Sumayar, Chamugar & Kamri) the parameters are shown in the tables below.

Site 1: 500 kW Sumayar Nagar hydro power plant (Francis Turbine).

Q (m^3/s)	**Q_o (m^3/s)**	**Q/Qo**	**Head** (m)	**Power (kW)**
0.37	0.68	0.54	95	269.83
0.41	0.68	0.60	96	283.20
0.50	0.68	0.73	96	296.25
0.59	0.68	0.87	96	311.28
0.67	0.68	0.98	96	340.34

Site 2: 500 kW Chamugar Gilgit hydro power plant (Pelton Turbine).

Q (m^3/s)	**Q_o (m^3/s)**	**Q/Qo**	**Head** (m)	**Power (kW)**
0.113	0.17	0.66	385	245.41
0.128	0.17	0.75	385	294.21
0.142	0.17	0.83	385	313.81
0.156	0.17	0.91	385	354.31
0.170	0.17	1.00	385	463.11

Site 3: 400 kW Kamri Astore hydro power plant (Pelton Turbine).

Q (m^3/s)	**Q_o (m^3/s)**	**Q/Qo**	**Head (m)**	**Power (kW)**
0.45	0.61	0.74	76.3	231.30
0.48	0.61	0.77	76.3	261.08
0.50	0.61	0.82	76.3	258.91
0.56	0.61	0.92	76.3	241.17
0.61	0.61	1.00	76.3	313.34

4.2 Efficiency Curves.

4.2.1 500 kW Sumayar Nagar hydro power plant:

The project area is in Sumayar valley district Nagar at the left bank of Mamubar Nallah, Hunza river at almost 85 km from Gilgit city. The turbine installed in this site is Francis turbine.

The flow and head are controlled manually and by mechanical load controller (MLC). The maximum efficiency of turbine is 78.25 % at Q/Q_o=0.54. The system must be operated at this condition to get high efficiency. Based on other parameters (head, flow rate and turbine shaft power) the efficiency is calculated and plotted as shown in Figure 8.

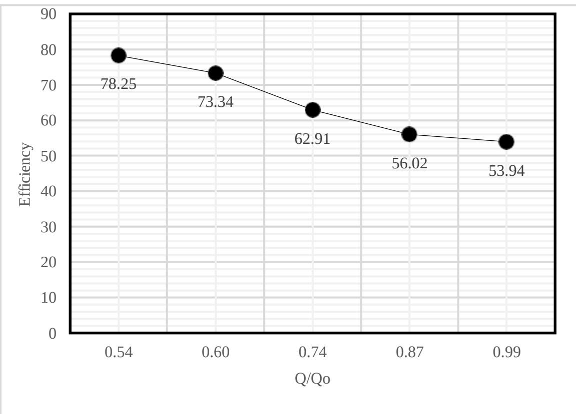


Fig 8: Efficiency Plot of 500 kW Sumayar Nagar HP Plant.

4.2.2 500 kW Chamugar Gilgit hydro power plant:

This site is in Chamugar Nallah, at about 33 km from Gilgit City. An impulse turbine (Pelton wheel) which is highly efficient to generate the required power has been installed in this site. The efficiency curve is plotted based on other calculated parameters (head, flow rate and turbine shaft power).

It has been shown in the Figure 9 maximum efficiency of the turbine is 72.13% at $Q/Q_{o\,=}$ 1. The system must be operated at this point to gain maximum efficiency.

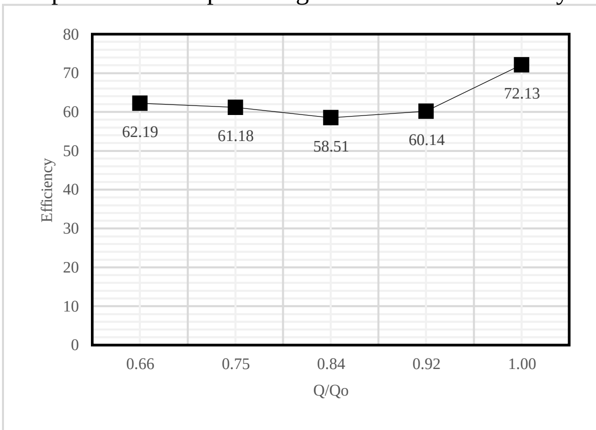


Fig 9: Efficiency Plot of 500 kW Chamugar Gilgit HP Plant.

4.2.3 400 kW Kamri Astore hydro power plant:

The project site is in district Astore on the right bank of Kamri Nallah, at about 120 km from Astore city. Pelton turbine has been installed in this site.

Efficiency is plotted from calculated parameters (head, flow rate and turbine shaft power) as shown in the Figure 10. It has been shown that maximum efficiency is maximum 72.67 % at $Q/Q_{o.}$ =0.77.

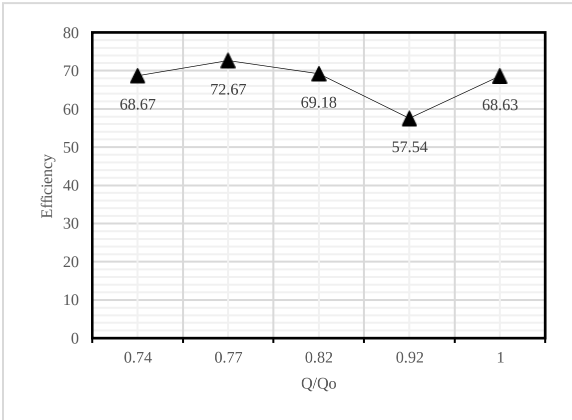


Fig 10: Efficiency Plot of 400 kW Kamri Astore HP Plant.

5. EFFICIENCY ANALYSIS.

Mini/Micro hydel plants generation efficiency is in the range of 60-80% [11].Compared to reaction turbine, impulse turbines have a better performance in low head and high flow sites. The efficiency vs Q/Q_o curves of all the sites have been shown in the Figure 11, to analyze efficiencies of turbines, comparison is made with the part flow efficiencies curve in Figure 7.

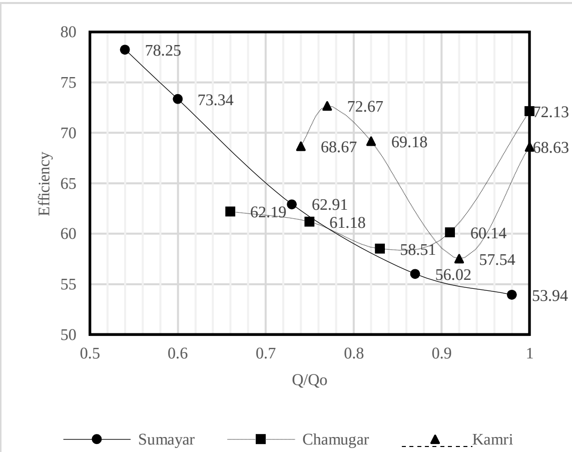


Fig 11: Efficiency curves of three sites.

A Francis turbine is commonly used for hydro plants where head ranges from 1m to 900m [12]. The efficiency plot for Sumayar Site where Francis turbine has been installed shows magnified view of actual curve of Francis turbine in Figure 11, where only portion of flow (Q/Q_o) above 0.54 to 0.98 has been considered.

The plot indicates maximum efficiency of 78.25 % at Q/Q_o=0.54, and then efficiency starts to dip unlike the actual curve in Figure 7 where efficiency goes on increasing up to 90% before dipping to lower value. The deviation from actual curve is because of adjustments of pressure measuring device and electronic transducer. Moreover, silty water and high sediments flow during flood season affects turbine efficiency. Turbine material especially runner which meets virtually any kind of silty flood water needed, nevertheless, a Francis turbine's effectiveness depends upon its runner [13].

For a Pelton turbine used in small scale hydro power development the efficiency range is 70-90% [8] Figure 11 shows efficiency plot of Pelton turbines used in two different sites in Gilgit-Baltistan (GB). For a Chamugar site decreasing where part of flow Q/Q_o above 0.66 has been shown. The actual curve in Figure 7 illustrates Pelton turbines loss efficiency from 90% to lower value., when compared with the curve in Figure 11 the maximum efficiency of Pelton turbines is 72.13% and graph deviates from actual trend. For the Kamri site where also a Pelton turbine has been employed the highest efficiency is 72.67%. The deviation is because of pressure transducer gauge which could not be properly fit on the turbine since there was no proper place to put it.

6. RESULTS & DISCUSSIONS.

This is the first study of its kind to analyze the efficiency of Mini/Micro hydel plant (MHPs) in Gilgit Baltistan (GB) region. It will help to assess the need for improving the design of hydel plants in future. With the time the projects have been unable to meet the energy requirement, because of increase in population and changes in usage patterns (from simply lighting to cooking, heating and supporting small enterprises).

The efficiency plot of the Francis and Pelton turbine used in the three different sites has been compared with actual curve and it has been found that the turbines efficiency is not up to the mark. There is need of adjustment of mechanical and electrical equipments in these sites. Local MHP turbines available in the market have low efficiencies. Project developer used low cost approach in purchase of MHP turbines. Moreover, there is unavailability of trained technicians and lack of facility of efficiency testing at MHP sites.

7. Acknowledgement.

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