

Design Analysis of Mini/Micro Hydro Power Generation Plants in Northern Districts of Khyber Pakhtunkhwa

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Abstract— Energy access in global challenge faced by more than 1 billion people. Pakistan, to address the challenge, has developed access strategy of decentralized energy system. In northern hilly areas of country, Hydel resource has been tapped through mini-micro hydro projects. However, the sites are remote located in hilly terrain, making transportation of machinery a challenging task increasing initial cost. Similarly, loss of head caused by slope in water channels and laborious construction of concrete channel in rigid and sharp rocks further aggravates the situation. This study undertakes case studies of mini-micro Hydel power projects and looks for technically feasible solutions. New design techniques have been revealed relying on piping and pumping of water and construction composition. Concrete channel is replaced by piping structure and water is pumped from intake to fore bay at different angles of inclination and pipe diameters and accordingly the pump power is observed. Due to variation in slope, the net head also varies which has a direct impact on the output power from the plant. The power of pump is subtracted of the power generated by the plant which results in net power. Two actual design examples are considered from a rural area of Pakistan and using statistical analysis techniques the influence on the total output power is analyzed under different scenarios.

Keywords— Pump Power, accessibility, Fore bay, Remote Location.

I. INTRODUCTION

Pakistan is blessed with sufficient Hydel resources, capable to meet the ever-increasing demand of energy. Energy is core commodity required for economic uplift and development of country masses. It's vital role in reducing poverty, enhancing productivity and opportunities cannot be ignored. The government of Pakistan is striving best to fulfill the energy needs across the county. The challenge of access is particularly prevailing in remote and hilly areas, where grid extension is not feasible due to wheeling charges, lower population density and capital infrastructure requirement. However, alternate approach of access through decentralized energy systems has been

adopted. Country wide initiatives has been taken including solar house system, biomass to energy projects, wind projects and hydro projects based on geography of resources availability. In Khyber –Pukthunkhwa, the northern hilly areas are rich in feasible sites for min- and micro hydro-power projects.

The provincial government of KP in its efforts to meet SDG7 target of universal energy access, is taking keen interest to develop the culture of small scale hydro power scheme. The special feature of mini-micro hydro power projects like modular design, ease of maintenance and lower capital cost, make them highly feasible. Therefore, Pukthunkhwa Energy Development Organization (PEDO) under the Energy and Power department is currently doing the hydropower projects in the 12 northern districts of Khyber Pukthunkhwa. These projects are off-grid community based initiatives providing affordable energy to households and local businesses.

In first phase of projects, 356 mini-micro hydro schemes have been completed across northern districts. In construction and commissioning phases, major challenges have been identified. These challenges are both technical and non-technical in nature. The scope of this research is constrained and deals only in technical domains. Therefore, we will only present technical issues faced in first phase of projects.

A. Initial Cost is High

All of the hydropower based projects counts for high starting cost. This high initial cost is categorized as

- Topographic study, feasibility study and the environmental Impacts study cost high.
- Mechanical and Electrical equipment's cost.
- Civil work and infrastructure for site access cost.

The electrical and mechanical equipment's like turbine, generator, transformer cost is not site specific means that it doesn't depend on characteristics of site. While that of civil structure cost mainly varies with site requirements and specifications.

B. Site access and transportation issues

This is one of the main challenges in construction. Most of these MHP projects are implemented in the remote locations of the country. While for high capacity sites the turbine of high discharge and the generator transformer of high rating will be required. So it is difficult to transport this heavy electrical and mechanical setup to targeted location having no proper road and access points. In addition, there is a risk associated with transportation, mainly of damage to machinery and workers physical hazardous.

C. Building Channel in rigid rocks

The civil work in hilly areas in rigid rocky terrain is highly costly, challenging and un-safe. Significant cost is allocated along with machinery and large workforce. Normally, excavation is needed while in some cases the blasting is even required which is costly and danger too. So care is required with enough cost also that is why the alternate options to this channel construction is discuss which is also aim of this research work.

D. Issue of Environment

These hydro power projects are mainly constructed in the northern districts of Pakistan. These northern districts are mostly mountain with altitude of about 4450 meters. The temperature in this region varies from 40 C0 to 15C0 in winter. As the temperature decrease down below the 10 C0 in the month of October to December the setting time for the concrete also increase causing decrease in the strength of concrete channel and thus increasing the delay and cost of the project. The goal of our research is also to introduce new way instead of constructing concrete channel.

E. Power Channel Slope

Water is transported via a channel from canal to the forebay tank with certain velocity. A slope is introduced in the channel in order to make flow possible through simple gravitational forces. However, this in parallel results in losses in available head. For instance, the 500 meter of the channel will be provided with 2 meter of the slope which ultimately will cause the 2-meter decrease of net head. Alternative mechanism with high cost benefit ratio will be investigated in this research work.

II. MODELING AND DESIGNING

A. Analysis Framework

Through analysis framework we will observe the effect of variation in pipe diameter and inclination on the net power and pumping power. Three different cases are considered regarding the position of intake point A with respect to the fore bay point B. The following notations are used representing these cases.

- AB^+ If the forebay point B is at higher level than intake point A
- AB If the forebay point B and intake point A are at the same level
- AB^- If the forebay point B is at lower level than the intake point A

The head loss h_L is identified for various diameters of the pipe resulting in the variation of pumping head h_p and thus pumping power W_p , from which we can identify the net output power of the plant for different diameter and inclination of the pipe. Matlab and Excel will be used for visualization of various effects due to changes in design.

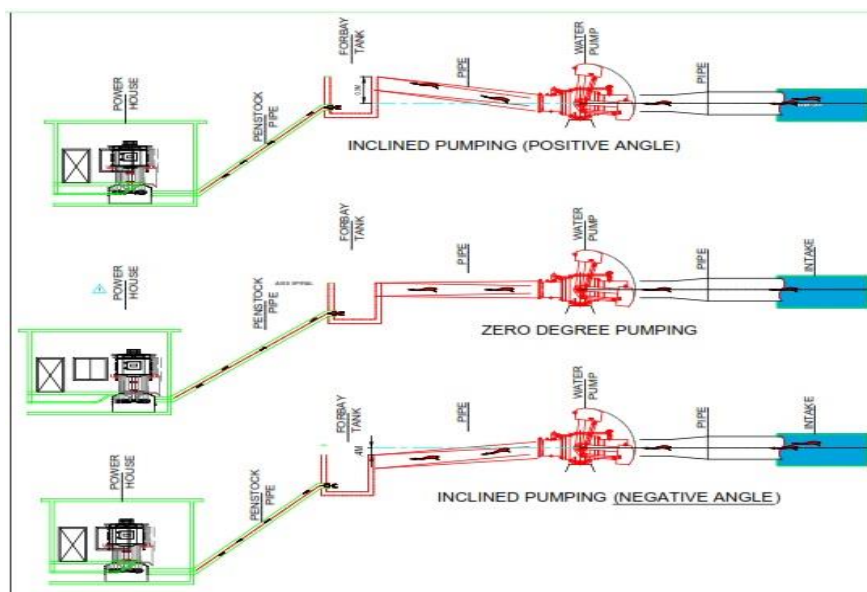


Fig. 1

B. Mathematical Formulation

According to Yunus et al [1], the pumping power required for pumping water of discharge Q can be written as

$$W_p = \frac{Qg\rho h_p}{\eta_p} \tag{1}$$

Where $\rho = 1000 \text{ kg/m}^3$ the density of water is, $g = 9.8 \text{ m/s}^2$ is the gravity acceleration, h_p is pumping head while η_p is the overall efficiency of the pump. If we consider A and B as the intake and fore bay points and $V_A, V_B, P_A, P_B, Z_A, Z_B$, and α_A, α_B as the average velocities, pressures, water heads and kinetic energy correction factors at points A and B respectively, then we can write,

$$\frac{P_A}{g\rho} + \alpha_A \frac{V_A^2}{2g} + h_p + Z_A = \frac{P_B}{g\rho} + \alpha_B \frac{V_B^2}{2g} + h_L + Z_B \tag{2}$$

Where h_p the pumping is head and h_L is head loss given by,

$$h_L = \frac{fLV_{avg}^2}{2Dg} \tag{3}$$

Where L is the length of pipe, f is the friction factor, D is the pipe diameter, g is the gravity of acceleration and V_{avg} is the average velocity of water in the pipe. The relations for friction factor and average velocity are given by,

$$\frac{1}{\sqrt{f}} = -2 \log \left(\frac{2.51}{R_e \sqrt{f}} + \frac{\epsilon}{3.7D} \right) \tag{4}$$

$$V_{avg} = \frac{Q}{A_c} \tag{5}$$

In which A_c is the pipe's cross sectional area, ϵ is roughness coefficient of pipe whose value for different materials is give in the table 3.1 and R_e is Reynold's number given by

$$R_e = \frac{\rho V_{avg} D}{\mu} \tag{6}$$

Where μ is the viscosity of water. The value of kinetic energy correction factor in equation (2) is 1.05 for fully developed turbulent flow and 2 for fully developed laminar flow. The output power of the plant can be computed as

$$P = \rho Qgh \tag{7}$$

While the motor is powered from the same plant, the net output power of the plant can be computed as

$$P_{net} = P - W_p \tag{8}$$

Here we will consider two actual design examples of Pakistan 500 KW Kotkay mini hydro power plant designated by site A and 500 KW Beyari mini hydro power plant designated by site B with design specifications as shown in the table 1.

Table .1

Parameters	Site A Specs	Site B Specs
Discharge (Q)	2.37m ³ /s	1.92m ³ /s

Gross Head (Hg)	30.920m	38.8m
Head Loss in Penstock (Hf)	1.61m	2.04m
Length of Power Demand (L)	336.90m	564.02m
Head Loss due to Slope in Power Channel (Cs)	1.350m	2.256m
Net Head (Hn=Hg-Hf-Cs)	27.96m	34.5m
Total Output Power (P)	500KW	500KW

In this section, mathematical calculations will be carried out for the three different cases as discussed above. The AB^- case will be discussed first taking a 1.3 meters diameter of pipe and with forebay level 0.4 meters down the intake level. From table 3.2 taking the design specifications for site A, the average velocity can be calculated using equation 3 as

$$V_{avg} = 1.8 \text{ m/s}$$

$$R_e = 2317755.474$$

$$f = 0.010122$$

Head loss can be calculated using equation 3 given by

$$h_L = 0.43 \text{ m}$$

Using equation (2) with

$$Z_A = 0.4 \text{ m}, Z_B = 0 \text{ m}, P_A = P_B, V_A = V_B, \alpha_A = \alpha_B, h_L = 0.43 \text{ m}$$

We have

$$h_p = 0.03 \text{ m}$$

Using equation (1), the pumping power can be computed as

$$W_p = 1.05 \text{ KW}$$

Using equation (7), the electrical power of the plant can be computed as

$$P = 516.8 \text{ KW}$$

$$P_{net} = P - W_p = 515.8 \text{ KW}$$

For the case AB with 1.4 meters' diameter of pipe and using design specifications of site A we can write

$$W_p = 11.5 \text{ KW}$$

$$P = 524 \text{ KW}, P_{net} = P - W_p = 512.5 \text{ KW}$$

Taking the AB^+ case with pipe diameter of 1.7 meters and intake level 0.3 meters down the forebay level, the average velocity, friction factor, Reynolds's Number and head loss can be computed as

$$W_p = 16.13 \text{ KW}$$

The output power of the plant and net power can be calculated from equation (7) and (8) respectively as

$$P = 529.4 \text{ KW}, P_{net} = P - W_p = 513.3 \text{ KW}$$

From the above three cases we calculated net output power of the plant and pump power at for the specified diameter of pipe.

III. RESULTS

A. Variation in pump power with varying pipe inclination and diameter

In this section we will analyze the effect of varying slope and diameter of pipe on the net power and pumping power of the plant. This section includes the effect of variation in pipe's inclination and diameter on the pumping power required for pumping water is discussed. The graph shows the relationship between varying inclination (in meters) and pumping power (in KW) where the pipe diameter is kept constant at 1.3 meters. The three portions of the graph (AB+, AB and AB-) represent three different positions of fore bay with respect to the intake. The pump power is zero at the start because of its natural flow under the influence of gravity and hence no pumping power is required. As the fore bay level moves upward with respect to the intake point, the pumping power start increasing for both site A and B. This increase is more for site A as compared to site B and the reason is heavy discharge of site A as shown in the table1.

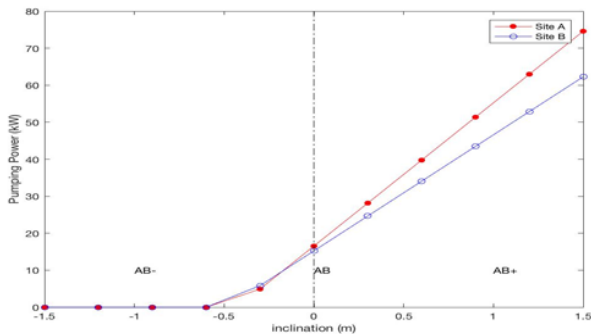


Fig.2

From the graph we can see that as the inclination is varied from -1.5 to -0.6, the pumping power is zero because of natural flow of water due to gravity. Further increasing Forebay level causes pumping power to start developing. Comparing the two graphs for site A and B on certain inclination, Pumping power for site A is high as compared to site B because of more discharge of site A as compared to site B.

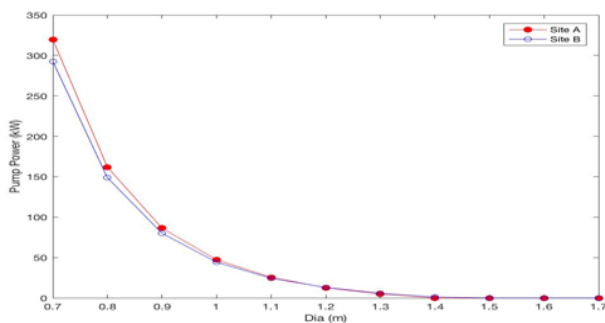


Fig.3

The above graph shows variation in pump power with respect to varying pipe diameter. As the pipe diameter increases, pump power decreases and vice versa. Comparing the graphs of site A and B for a certain diameter of pipe, the pump power for site A is higher than site B due to heavy discharge of site A as compared to site B.

B. Variation in net power with varying pipe inclination and diameter

In the previous section we discussed the pipe's inclination and diameter effect on the pump power. This section will cover the effect of varying pipe inclination and diameter on the net output power output of the plant.

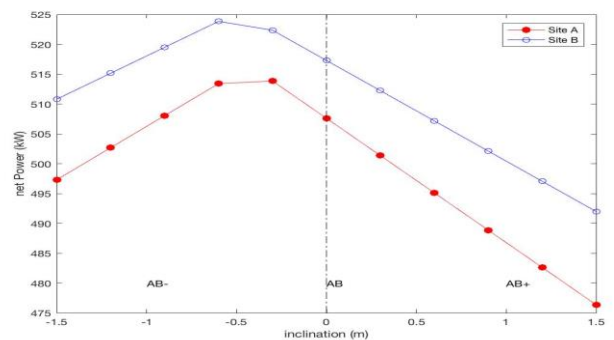


Fig.4

The above graph shows variation in net power with respect to varying inclination. The graph shows that net power is increasing as the inclination varies from -1.5 to -0.6 and then start decreasing. The reason is that as the forebay level rises, the net power increases due to increase in net head but the pump power is also developing and at a certain point the effect of increasing pumping power become dominant as compared to increasing head.

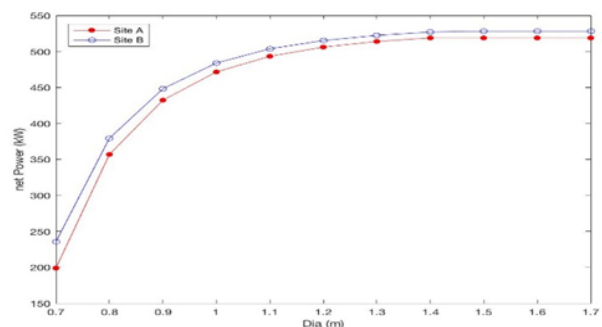


Fig.5

The graph shows variation in net power as compared to varying pipe diameter. The graph shows increase in net power with increasing pipe diameter. This increase is due to reduction in pump power with increasing pipe diameter which causes net power to increase.

CONCUSLION

The head loss and reduced output power in mini/micro hydro power projects is due to slope in concrete channels. The concrete

channel's construction in hard rock is a difficult task as the construction of these channels, especially in case of huge discharge, is a time consuming and difficult job. Significant hindrances are also posed in the transportation of heavy machinery such as hydroelectric power turbines, materials for penstock and generators to remote locations. In this research these problems in relation to the MHP projects are analyzed from the design aspect for two locations in Mansehra district of KP. Novel approaches for design are implemented. The design is based primarily on the process involved in the water pumping operation and pipe placement structure.

Three design techniques (AB, AB-, AB+) were used and the results were plotted using Matlab computer program. Comparing with the conventional design, some extra power was generated in the AB case (pumping water at the same level). The power was observed to increase upon an increase in the diameter of the pipes beyond 1.2 meters; however the concomitant high pump power makes the project cost unbearable (due to installation of such a huge power pump). So, it will also be a matter of concern to give an initial startup for such a high power pump. To overcome this problem, the water was pumped through negative inclination (AB- case) and its effect was analyzed on the pump power, pipe diameter and net power. The results were plotted by varying pipe diameter and its slope. These results were comparatively better as more power was obtained at the cost of less pumping power. Both the problems of initial startup as well as the capital cost can be solved using this technique. Initially pump can be powered from other sources such as battery storage, or through solar power and then shifted to the power obtained from the MHP. The water was then pumped through positive inclination (AB+ case) so that some extra head and thus power could be obtained. Although this technique resulted in the increased power generated from the plant but at the same time the pump power was so high that the net power reduced.

If we compare the results of both the plants (A and B), the net power output of the later one was more than the first one due to the lengthy channel and less discharge of site B as compared to A. So these techniques can give the best results for the plants having less discharge and lengthy channels.

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