DESIGN AND IMPLEMENTATION OF AN EFFICIENT MICRO-HYDROELECTRIC SCHEME FOR LOW HEADS

Gul Rukh*, Iftikhar Khan* M. Naeem Arbab*, Uzma Nawaz*

ABSTRACT

This paper presents a design of a hydroelectric scheme specially proposed for low head applications. After carefully studying the hydrology and geographical conditions of the site, turbine is designed for the heads of 3 to 10 meters obtainable from streams and irrigation channels. The low efficiency in already existing hydroelectric scheme used is addressed and compared with the existing scheme. Using the standard equations, trash rack, penstock and turbine is designed thus keeping the power losses as low as 4%. Hence finally an electrical power of 25kW is produced, suitable to run a farm in villages where electricity supply is not available and where cost of transmission and distribution is high. The location where it has been installed and tested is village Kandar, Tehsil Mathra, Peshawar. The present project is compared with the existing and is much cost-effective and highly efficient.

KEYWORDS: *Hydrology, turbine, generator.*

INTRODUCTION

Most hydroelectric power plants use the potential energy of water stored in a reservoir to operate turbines[1,2]. The turbines are connected to large generators, and can operate on varying volumes of water to adapt to changing demand for electricity[2,3]. Hydroelectric power plant capacity is related to the height and capacity of a reservoir and requires certain conditions in local geography in addition to a water source[1,4]. Hydroelectric power is a clean source of renewable energy where an adequate water source is readily available, and provides inexpensive electricity without environmental pollution such as emissions or waste byproducts as in the case of fossil fuel plants. And, unlike fossil fuel plants, water is not consumed during electrical production, but can be reused for other purposes. Hydroelectricity, in the simplest of terms, is the electricity that is generated using power of water flow, or that water which is stored in a reservoir of dam[5,6,7]. In either case, however, the basic fundamental principle of power generation remains the same.

Recently the government of Khyber Pukhtunkhwa (KPK) decided to launch a program of development in energy sector to cope with the present energy crises in the country. The agricultural community in remote villages is most affected because of infeasibility of connecting these villages to the national grid system through transmission lines. Further long distribution lines connecting these villages to the distribution system is infeasible due to large amount of power losses. The government of KPK therefore decided to fund for the energy system based on solar, wind and hydro so that electrical energy can be economically generated locally, which can be utilized more effectively.

The solar and wind cost is usually comparatively higher than the hydroelectric schemes[5]. Unfortunately most of the water resources available in the settled areas are at low head and therefore methods must be explored to utilize the water at low head efficiently to produce electrical energy.

The objective of the present work is to design and install a hydroelectric scheme that should be more efficient for places where water source is available at low heads. Moreover a comparative study with the existing micro-hydroelectric project is also carried out.

SITE OF THE HYDROELECTRIC SCHEME

The project was undertaken at village Kandar, near Mathra, district Peshawar. The scheme was implemented on Sheikh Nullah from Warsak gravity canal, where already a small hydroelectric scheme has been installed a few years ago producing electrical power up to 10kW to drive a small mill and providing light load to a few houses. The scheme is a low head micro-hydroelectric plant. In the present work the same site is selected with methods of hydroelectric generation utilizing the low head. The location of the scheme is shown circled in Figure 1.

*Department of Electrical Engineering, University of Engineering and Technology, Peshawar, Pakistan

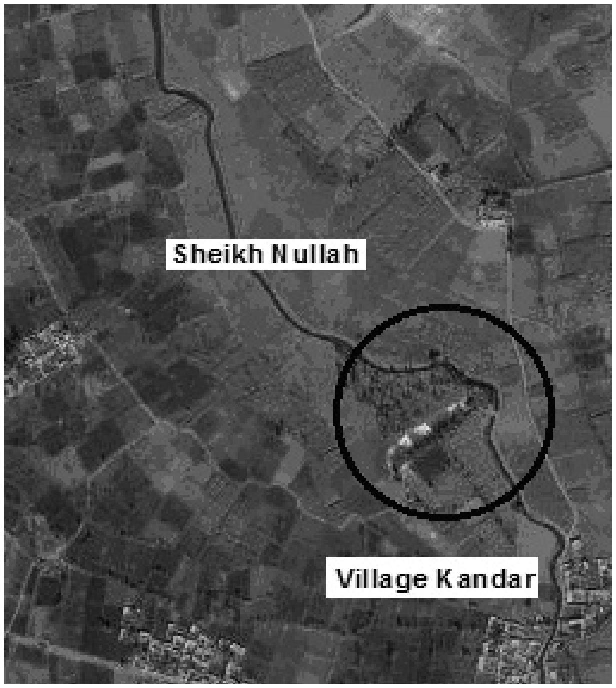


Figure 1: Site (Encircled)

FACTORS FOR SITE SELECTION

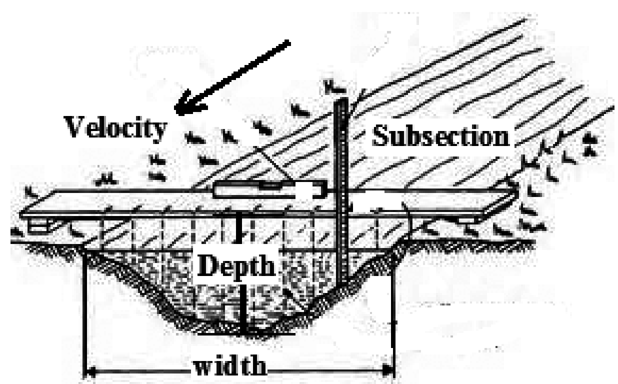
There are two main factors that determine the generating potential at any specific site; the quantity of water flow per unit time and the vertical height (head) that water can be made to fall[3,7]. The gross head is the vertical distance between the water surface level at the intake and at the tailrace for reaction turbines and the nozzle level for impulse turbines. Knowing the gross head, the net head h can be computed by simply subtracting the head losses along its path. The net head is the hydraulic head which is used to determine the amount of potential energy available, once developed, it remains fairly constant[1,7]. Water flow on the other hand is a direct result of the intensity, distribution and duration of rainfall, but is also a function of direct evaporation, transpiration, infiltration into the ground, the area of the particular drainage basin, and the field-moisture capacity of the soil. The planning for a proper site location will include the following[1,3,7]:

1. Water source.
2. Hydrology.
3. Geographical conditions (Terrain).

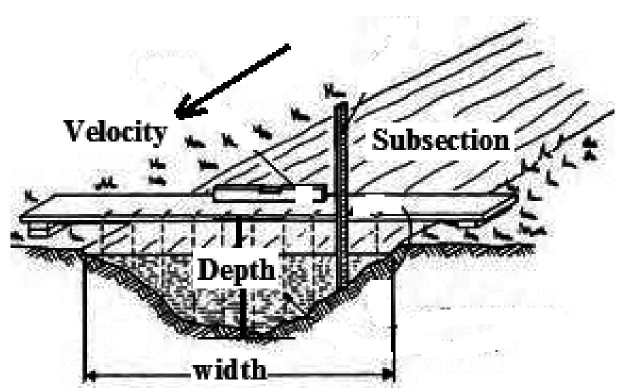
Once water source is recognized, the hydrology of downstream of the river is studied at different locations and a hydrograph is prepared. Data of the flow from the concerned hydrology department must be obtained for at least previous 15 to 20 years[6,8]. Statistical analysis of the water flow is obtained, which provide yearly average flow at selected locations.

MEASUREMENT OF DISCHARGE

The two most important hydro parameters for the purpose of estimating the energy contained in stream or fall is the head and discharge. Head is generally determined from the hydraulic gradient of a river or a stream usually obtained by river gauging[4,7,8]. The discharge is measured by two methods; namely the velocity-area method and the slope area method. In velocity-area appropriate points must be selected on a relatively straight, smoothly flowing portion of the river to be gauged, thus dividing it into subsections. In order to measure the area, the width is divided into subsections or segments. The method is illustrated in Figure 2(a).



(a)



(b)

Figure 2: Illustration of methods of discharge measurement

The slope-area method consists of using the slope of the water surface in a uniform reach of channel and the average cross-sectional area of that reach to give a rate of discharge. This method depends on hydraulic principles and it presupposes that it is practical to drive in pegs or make other temporary elevation marks at water-surface level at the time of the flow measurement, upstream and downstream of the discharge-measuring site as illustrated in Figure 2(b).

HYDROLOGY AND HYDROGRAPH

Hydrology of the site and the source is important in the planning of a hydroelectric power station[2,8]. The best possible site and location of a hydroelectric power station is where continuous supply of water is available throughout the year for the production of electricity. The power capacity of a hydropower plant is primarily the function of two variables[1,8]:

1. Flow rate or discharge.
2. The hydraulic head, which is the elevation difference the water falls in passing through the plant.

The average, maximum and minimum discharge figures for Sheikh Nullah (up-stream) at the selected site was obtained from KPK irrigation department on request. Table 1 shows the minimum, average and maximum values of discharge at Sheikh Nullah, except for the months of de-silting when no water is available.

Table 1: Discharge at Sheikh Nullah

Discharge		
Minimum	Average	Maximum
18.5 cusecs	36.75 cusecs	44 cusecs

HYDRO ENERGY AVAILABLE

The concept of hydro energy available in water at a head can be ascertained by knowing potential energy E_h of mass of water m available at a head h. The electrical energy that can be made available from the potential energy of water is determined by knowing the overall efficiency η of the system. Thus:

$$E = \rho\eta Vgh \text{ Joules} \quad (1)$$

Dividing both sides of Equation 1 by time t, then the left hand side of the resultant expression is the electrical power and using the definition of discharge q (rate of flow), we have:

$$P = \rho\eta qgh \text{ Watts} \quad (2)$$

Where g is the acceleration due to gravity and is equal to 9.81m/s^2. The density of water is ρ (10^3 kg/m^3). For design purpose, both average power and firm power available at a net head is usually determined. Firm power is the power that is always available from the stream, even at times of lowest flow and lowest head and is calculated by using the lowest expected flow in the stream ($\boldsymbol{Q}_{min}$) and the net head *h*. The average power is calculated on the basis of average flow.

SELECTION OF PENSTOCK

Water after passing through forebay is cleared-off with debris at the trash-rack and is admitted to the penstock through intake gate. The trash rack is composed of steel bars, which are spaced at about 2 inches. This is shown in Figure 3.

Figure 3: Placement of trash rack

The trash rack was installed at the intake, 11 meters upstream from the site of turbine installation. The trash rack was fixed between concrete and brick masonry work of a 1 meter wide channel, which is used as a diversion to divert water from the main stream. The flow was directed to the conduit (penstock) through a wooden flume about 1 meter wide and 6 meters in length.

The major losses in penstock are the friction losses, which reduces the head and thereby the efficiency at the turbines. The net head equals the gross head minus the sum of all losses, including the friction and turbulence losses in the penstock, that are approximately proportional to the square of the velocity of the water flow. A simple criterion for diameter selection is to limit the head loss to a certain percentage. Power loss of up to 4% is usually acceptable. Consequently a first approach will suffice to compute the head loss due to friction using the Manning equation[1]:

$$h_f = 10.3L\left(\frac{n^2q^2}{D^{5.33}}\right) \quad (3)$$

Where h_f is the head loss due to friction, L is the length of the penstock, q is the discharge, D is the diameter of the penstock and n is the manning coefficient. From equation (3):

$$D = 1.548\left(\frac{n^2q^2L}{h_f}\right)^{0.1875} \quad (4)$$

If h_f is limited at 4h/100, D can be computed knowing q, n and L, from the modified equation:

$$D = 2.69\left(\frac{n^2q^2L}{h}\right)^{0.1875} \quad (5)$$

Head h = 4.5 m. Length L = 10 m. Choosing the value of Manning coefficient n = 0.012, for average discharge of 36.75 cusecs (1.025 m^3/s), the diameter of the pipe is:

$$D = 2.69\left(\frac{0.012^2(1.025)^2 10}{4.5}\right)^{0.1875} = 0.6\text{m}$$

In the present scheme a concrete pipe with an end section reduced to enhance the velocity of flow to allow more kinetic energy to be produced at the turbine. The reduced section is composed of a cast iron pipe of 6 inch diameter with a flanged bolt coupling to facilitate connection to the valve. In addition it increases the velocity of jet-stream of water directed towards the turbine. The end of the cast iron section incorporates a jet system with 2 inch orifice.

The valve was incorporated to control the flow and to shut down water supply in case of maintenance. The pipe assembly was coupled to a section of cast iron sleeve, which was conveyed on to a concrete penstock connecting the channel to the cast iron pipe. Approach velocity of water in the penstock is given by[3]:

$$v = 0.83\sqrt{2gh} = 0.83\sqrt{2\times9.8\times4.5} = 7.8 \text{ m/s}$$

Where A is the area of cross section of the conduit (penstock), which can be determined from the discharge, already calculated.

$$A = \frac{Q}{v} = \frac{1.025}{7.8} = 0.13 \text{ m}^2$$

The conduit is circular in cross section, the diameter of the conduit is calculated as:

$$D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4\times0.13}{3.14}} = 0.4 \text{ m or } 1.32 \text{ ft}$$

Thus a concrete penstock with a standard diameter of 18 inches was used.

WATER WHEEL (HYDRO TURBINE)

A specially constructed impulse turbine with skewed vanes was used in the scheme (shown in Figure 4), which reduced the effect of back pressures.

The wheel was mounted on steel platform on either side. This type of turbine requires tangential water flow on

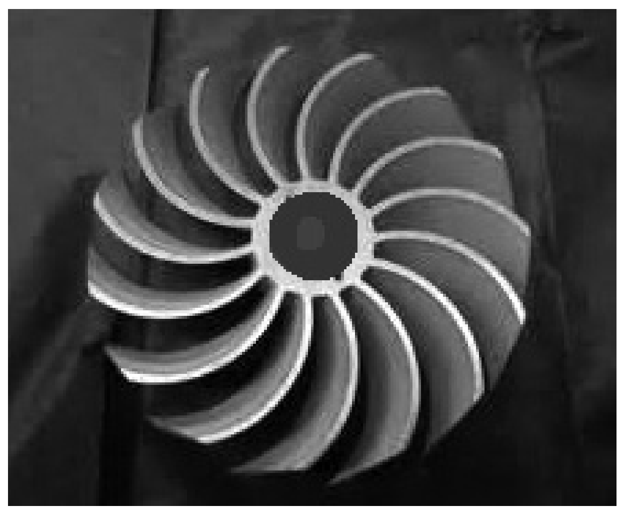


Figure 4: Turbine runner

one side of the wheel. The axes of the jet are in the plane of the runner. In this way the overpressure surge in the pipeline is kept to an acceptable minimum thus increasing the turbine efficiency. The turbine runner is of 0.85 meter in diameter with steel vanes secured by steel rings on either ends. The axle or shaft was passed through the runner via bush bearings. The arrangement was vertical to suit the site conditions. The other end of the steel platform was submerged in water. The torque T necessary for the turbine was determined through a test which produced power at efficiency of 93%. The mechanical power developed by the turbine was then determined. Knowing the torque and mechanical power developed by the turbine during the test, the speed in rpm was then calculated by the expression: $P_m = wT$. Where P_m is the mechanical power output of the turbine and T is the torque. The speed was determined to be about 500 rpm at which the mechanical power output of the turbine was 36 hp (about 26.85 kW).

ELECTRICAL POWER OUTPUT

The electrical power output is determined by knowing the head, discharge and overall efficiency of the system. The generator nameplate efficiency is 95%, the hydraulic efficiency of the penstock with 4% head loss due to friction and bends is 95% and the mechanical efficiency of the turbine is 93% giving an overall efficiency of 83% compared to the existing scheme, which has an overall efficiency of about 70%. For an effective head of h = 4.5m and average discharge of q = 1.02m^3/s, the average electrical power output available is determined by using Equation 2, which is calculated to be 25kW and the firm power at minimum discharge of about 0.5 cusecs is 18.3kW. The arrangement of the micro-hydroelectric system is shown diagrammatically in Figure 5. The system contained a 3-phase, 400V, 50Hz, 30kVA generator. The existing scheme used a generator rated at 230V, 50Hz and 22kVA single phase. The hydro generators have low rpm. Therefore assuming that a typical hydro generator will produce 50Hz at 1000rpm will have 6 poles.

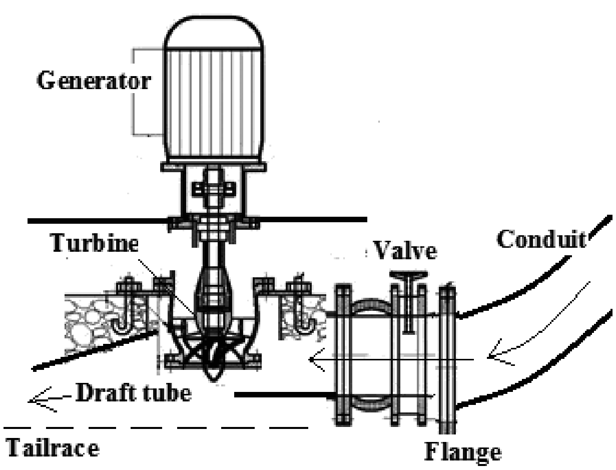


Figure 5: Schematic of the present micro hydroelectric plant

Since the turbine speed at rated horse power is 500rpm, which has to be converted to 1000rpm to drive the generator for generating power at 50Hz. The generator was driven though pulley system with a V-belt arrangement so as to obtain the desired RPM to generate power at 50Hz.

Once the water diverted from the main stream was used in the turbine to convert kinetic energy into useful mechanical work, the water was conveyed through a culvert arrangement, to the tailrace from where the water was allowed to flow into the down stream of the main Nullah.

DISCUSSION AND CONCLUSION

The present project of small hydroelectric scheme was compared with the existing scheme, which is producing about 10kW on the average. This is insufficient to drive the small farm machinery and is mostly used for light loads in the local area. This existing scheme was build in 1998. The scheme utilizes a channel 30 meters in length at a depth of about 0.75 meter with an effective head of 4.5 meters with radial water turbine and horizontal arrangement. The present hydroelectric scheme on the other hand uses a much smaller channel in the form of a conduit of about 10 meters in length with giving an effective head of 4.5 meters. The specially designed vertical type of hydro turbine weighs less and occupies little space. The scheme produces a firm power of 18kW and average power of 25kW sufficient to drive small farm machinery in addition to providing light loads. The total cost on the project was Rs 75,000. Depreciated at 10% annually over the life of the plant, the cost per year on the basis of kW output comes out to be Rs 17500, which is very economical. On commercial basis, the cost of electricity for a load factor of 50%, the cost of electricity from the plant will cost 10 paisa per unit. Table 2 highlights the comparison drawn between the existing and the present schemes.

Table 2: Parameter for existing and present schemes

Scheme	Channel length	Head	Power Output
Existing	30m	4.5m	10kW
Present	10m	4.5m	25kW

Compared to the existing scheme, the efficiency is relatively high about 13% higher. The efficiency of the plant can be further increased by using penstock fabricated from glass fiber so the losses due to friction can be further reduced. Furthermore, the turbine with double jet system can increase the speed and so the efficiency. This might also eliminate the use of extra drives for obtaining the necessary speed for the generator. However, due to lack of funding, these could not be accomplished.

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