Sustainable Resources Management Journal
2017, 2(1) 03-09
http://doi.org/10.5281/zenodo.255257

Micro-Hydropower Plant - Energy Solution Used in Rural Areas, Mozambique

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ABSTRACT

Expanding electricity access and energy in rural area in center of Mozambique is a challenge. Micro-hydropower plant is one of the solutions to provide electricity. However, selecting the power plant size and the turbine type in designing hydropower system is critical. Giving specific site characteristics of head and flow to find specific turbine is necessary to select appropriate turbine. The main objective of this paper is to develop a methodology to select the best turbine that can be used in the micro-hydropower plant at Chimenza river - Manica in Mozambique. Flow duration curve and exceedance probability equation was successfully used to characterize the water flow of the river. The accurate measurement of the head and flow discharge will determine the best type of power plant size and turbine type. According to the result, the optimum flow was 0.29 m^3/s combined with head. The appropriate turbine for this scheme is Pelton type with efficiency of 0.85% and the power capacity will be 157.2 kW.

Keywords: Micro-hydropower plant; Flow duration data curves; Renewable energy

1. INTRODUCTION

The population of Mozambique stands at 23.5 million in 2016 and the total area of the country 786, 380 km^2. Mozambique is one of the fastest growing economies in Sub-Saharan Africa with an average annual growth rate of 7%, 2011 GDP of $9.893 billion USD and $1117 USD per capita (Helder 2010; Miguel et al. 2015). With 18,000MW hydroelectric power potential Mozambique is considered to be one of the highest hydroelectric power potential in Africa (ESHA 2015). Hydropower provides 85% of the electricity needs in the country which is about 14,000MW. The country potential energy resources types and potentials are shown in Table 1.

Table1: Energy resources potentials in Mozambique.

Resources	Potential	Resources	Potential
Coal	20 billion tons	Hydropower	18 GW
Natural Gas	127 billion m^3	Solar Energy	1.49million GWh
Biomass	8.9 million ha	Wind Energy	Speed >6m/s
Geothermal	25 MW		

The increasing population and the country area causing significant challenges to providing electricity access across the country (Aljaradin 2016). While most live along the coast and in the south of Mozambique. The transportation infrastructure is underdeveloped and during the rainy season, heavy flooding results in impassable roads threatening the electricity grid. According to the World Bank, the overall access rate to electricity of about 10 %, with rural access below 5 % (Deloitte 2015).

In response to the large size and disparity between electricity location and load centers, distributed generation, particularly solar, may provide a valuable addition to Mozambique's energy composition. The potential resource for solar, wind, and geothermal are great, but projects have yet to mature in Mozambique. The total installed capacity of solar is only around 1 MW mainly providing electricity to health centers, rural schools, and some homes. Wind and geothermal projects are largely in the research stage in Mozambique. These energy technologies can help Mozambique government meet their policy goals for developing country, affordable energy to expand electricity access in the rural area and promote development. There is tremendous opportunity to leverage renewables to reach the far from the grid rural populations (Armando 2013; Deloitte 2015).

The electricity generation in Mozambique was 16.7 billion kilowatt-hours. The growth in demand for electricity stood on average at 10% per annum between 2000 and 2010, and 13% from 2011 to 2013. It is expected to continue to grow at 8.2% annually for the next 15 years. To be able to meet this demand, Mozambique will need to address its electricity infrastructure challenge (UNIDO 2013; Hélder 2010; Deloitte 2015). In Mozambique, the majority of the electricity sector is run by government-owned entities.

Mozambique is one of 25 countries in the world depending on hydropower for 90 % of their electricity supply. Although Mozambique is one of the largest producers of electricity in Africa, there so many challenges for rural electrification, because most of the energy produced by the largest hydropower plant Cahora Bassa in Tete (2075MW) exported to South Africa, Zimbabwe and Botswana approximately 73%.

Selecting the type of the turbine in designing hydropower system is crucial. There are different turbine types, which operates at different rated flows and netheads. The main objective of this article is developing a methodology to select the best turbine that can be used in the micro-hydro power plant in Manica. A methodology was developed to best evaluate and measure the actual head and water flow of Chimenza River. The accurate measurement of the head and flow will determine the best type of power plant size and turbine type (Bilal, 2014; Yulianus et al. 2014; UNIDO 2013).

1.1. Electrifications of energy from Hydropower

Nowadays, access to electricity is essential to human growth and development, as certain basic activities such as lighting, refrigeration, running household appliances, and operating equipment cannot easily be carried out by other forms of energy. Sustainable provision of electricity can free large amounts of time and jobs and promote better health and education. Electrification can help countries achieve economic and social objectives in rural areas (majority very poor family with basic needed to energy), furthermore, it could play a major role in stopping migration tendency to urban areas (Armando, 2013; Taryn, 2010; Emília 2015).

1.2. Hydropower Turbine

Turbine is a mechanical device that converts the potential energy contained in an elevated body of water for example in river or reservoir into rotational mechanical energy. Giving specific site characteristics of head and flow to find specific turbine is necessary to select appropriate turbine. Usually hydraulic turbine according to energy use classified in two general categories: Reactions turbines, which the energy comes from two effects kinetic energy and potential. Impulse turbine, which flows energy in this turbine, is completely converted to kinetic energy before transformation in the runner. In the river, there are several potential water source points. Each one will have a different elevation and linear distance from the hydro turbine. In selecting the best site, several issues to consider are water availability, access, elevation and topography of the site, distance from the turbine, head pressure, and the volume of water required for the turbine (Bilal 2014; Yulianus 2014).

In such case, you are not as concerned with high heads as with large volumes of water. The turbine is submerged in the water at the end of the open diversion system. With impulse turbines, the water exits the closed diversion system at the turbine so we are only dealing with the head prior to the turbine, or pressure head. With reaction turbines there can also be a closed system for the water exiting the turbine, creating a suction head. The pressure head for open diversion systems is the vertical distance between the water surface above the turbine and the turbine impellers. This distance is usually less than ten feet and is easily measured. If a draft tube is used, there is also suction head for these turbines. The suction head must also be measured. For this reason, selecting the turbine and site is important. The best source point will usually be the one that has the least cost per kWh of electricity produced (Adejumobi and Shobayo 2015).

2. METHODOLOGY

The case used in this study Chimenza river - Manica. According to water availability, access, elevation and topography of the site 18°55'33.4"S 32°47'30.3"E (figure 1) it was selected for the measurement of the head and flow discharge. The flow was measured for one year and annual historical flow data for the last 12 years was supplied by National Meteorological Service of Mozambique. The head was 65m.

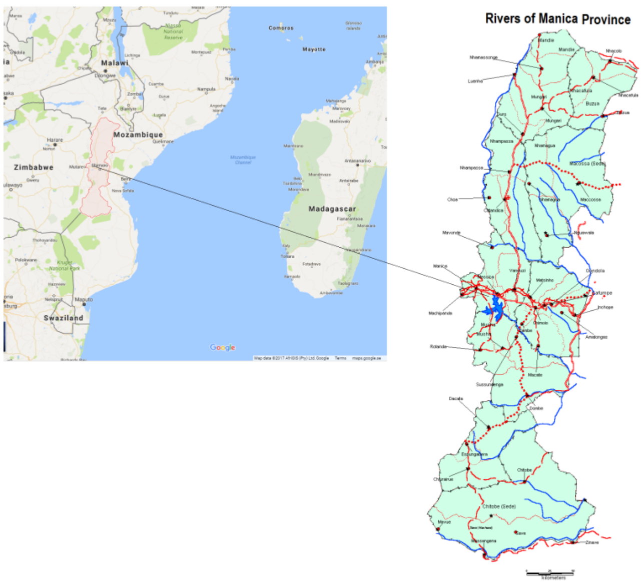

Figure 1: Chimenza river – Manica, Mozambique.

The site with the highest elevation may not be the best, as that site may also have the highest incremental cost of diverting and transporting the water to the turbine.

To measure the discharge, the stream discharge using the float method was used. In this method, the amount of water passing through the point on the stream channel a given time is function of velocity and cross-sectional area of the flowing water, is given in equation 1.

$$Q = A \times V \tag{1}$$

Where Q is stream discharge (m^3/s), A is cross-sectional area (m^2), figure 2. V is the velocity (m^2/s). This method is not expensive and simple to implement. Mean velocity is obtained using a correction factor as show in equation 2 and 3.

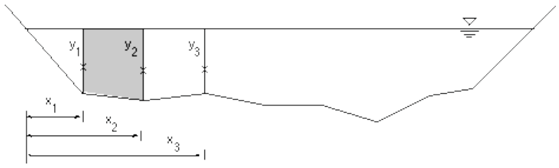

Figure 2: Cross sectional area of the river.

$$V_{surface} = \frac{\text{Travel distance}}{\text{Travel time}} \tag{2}$$

$$V_{mean} = KV_{surface} \tag{3}$$

Where and Vmean is mean flow velocity (m/s), k is friction correction factor, Vsurface = travel distance/travel time k is a coefficient that generally ranges from 0.8 for rough beds to 0.9 for smooth beds (Assuming 0.85 is a commonly used value).

2.1. Flow duration data

Flow-duration data commonly are used to statistically characterize streamflow. Flow-duration data are daily mean flow values measured over a specified time interval that have been exceeded various percentages of the specified time interval. For flow-duration statistics to be reliable indicators of probable future conditions, a minimum of 10 years of record typically are used (Searcy, 1959). The equation used to compute the exceedance probability, is given in equation 4:

$$P = 100^* \,(m/(n+1)) \tag{4}$$

Where

P is the exceedance probability
m is the ranking from the highest to lowest of all daily mean flow for the period of record
n is the total number of daily flow.

The discharge-exceedance probability curves, provides an estimate of the annual probability that any given minimum flow or a greater one occurs in any year. The curve typically has a negative slope when; however, it can also be displayed as a positively sloped curve if the units of measure on the axes are changed. Discharge, shown on the vertical axis, is measured in m^3/s. The horizontal axis shows the exceedance frequency with which a given discharge or greater occurs (Kaveh 2014; Jonsson 2011).

2.2. Flow duration curve (FDC)

FDC curve is the first basic analysis for designing a hydropower scheme for any situations. A flow duration curve shows the percent of time that flow is equal to or more than various rates during the period of study. FDC is defined as a relationship between any given discharge value and the percentage of time that this discharge is equaled or exceeded. It is one of the most informative methods of displaying the complete range of river discharges from low flows to flood events. Therefore, after calculations the annual historical flow in the river was plotted FDC graph to choose the optimum flow to be used in the turbine.

3. RESULT AND DISCUSSION

The discharge data and exceedance probability calculation is presented in table 2. The flow was not uniform according the time of the year and weather.

Table 2: Discharge measurements and exceedance probability.

Measurement	Flow m^3/s	*P*	Measurement	Flow m^3/s	*P*
1	0.9001	7.692308	7	0.1063	53.84615
2	0.6884	15.38462	8	0.1045	61.53846
3	0.458	23.07692	9	0.0925	69.23077
4	0.301	30.76923	10	0.0787	76.92308
5	0.2014	38.46154	11	0.07	84.61538
6	0.1224	46.15385	12	0.059	92.30769

A discharge-exceedance frequency curve is shown in figure 2. The curve typically has a negative slope when drawn as shown.

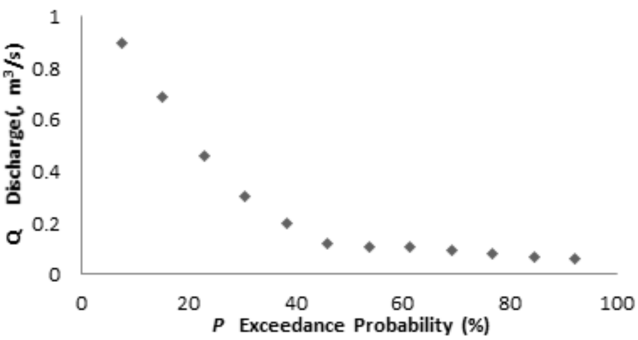

Figure 3: A discharge-exceedance frequency curve.

Usually, the FDC is helpful or important tools for selecting the design discharge flow of the turbine, just considering the reserved flow of a power plant and the minimum technical turbine flow, which given in figure 3. In general, a design flow can defined as a flow, which is significantly larger than the difference between the mean annual flow and the reserved flow. Figure 3 shows the FDC and Flow discharge measurement at Chimenza river in Mozambique. The optimum discharge at Chimenza was observed around 30% equivalent to $0.29 m^3/s$.

3.1. Selection of Turbine

The calculation of capacity of power at Chimenza River or for any similarly plant is consist of mathematical formulations that is product of multiplication of flow measurement and head of the hydropower plant. In this case with a specific site characteristics of head and flow, turbine application range charts have been developed to assist with the selection of appropriate turbine. The charts shown in figures 4 is combination of head and optimum flow that is given in FDC graph, inside of the chart there some range of turbine specific to be select.

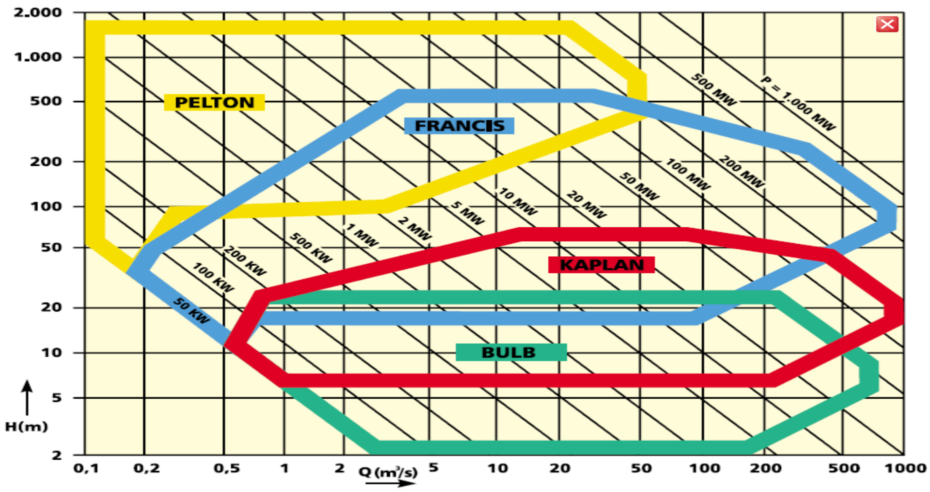

Figure 4: Turbine application range charts.

The net head of the micro-hydropower system at Chimenza River stream is 65m and the design discharge is 0.29 m^3/s; therefore, from turbine chart, figure 4 the appropriate turbine for this scheme is Pelton with efficiency of 0.85% and the power capacity will be 157.2 kW. In this result the general hydropower equations are used.

4. CONCLUSIONS

In general, to select the appropriate turbine it can be long investigations and complex method work, and analyzing hydropower we need exhaust feasibility study and appropriate and good design of hydropower plant. Using flow duration curve and exceedance probability equation was successful in determining the accurate measurement of the head and flow discharge which leads us to select the appropriate turbine for this scheme. With this new power scheme, the power generation of the Chimenza village will increase to 157.2 kW. Hopefully, this sustainable increasing in power generation will help the household to secure their needs. The village is depending on agricultural activities, increasing energy will increase the processing of agricultural products which will provide more food and create more jobs and social stability.

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