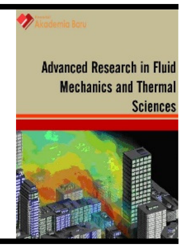
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html

ISSN: 2289-7879



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Small Scale Hydro Turbines for Sustainable Rural Electrification Program

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ARTICLE INFO

Article history:
Received 30 March 2018
Received in revised form 1 August 2018
Accepted 4 August 2018
Available online 10 September 2018

Keywords:
Pico, hydro turbine, head, flow rate

ABSTRACT

Hydropower is one of the world leading green alternative energy to produce electricity besides solar and wind energy. Most potential sites for large hydropower scheme in Peninsular Malaysia have been explored. Due to cabling cost and geographical constraints rural electrification program requires in-situ application which make small hydropower scheme more favourable choice. This run-of-river scheme is environmental friendly as no dam is required. Potential locations in Malaysia have been suggested for small hydro turbine applications, which are ideal for eco-friendly tourist industry and remote power supply. The two such sites are Kg. Tual, Raub, Pahang and Gunung Ledang, Tangkak, Johor. The preliminary studies have been conducted at both locations to select suitable hydro turbine based on their head and water flow rate. Altimeter and water velocity probe are used for data collection. As each location is unique, the correct data are needed to estimate the power production and the turbine type. Kg. Tual scheme is found capable of producing 266.99 kW with cost of energy of RM0.017 per kWh by using Pelton or Turgo turbine. However, Gunung Ledang site is suitable of using Kaplan or crossflow turbine as it is able of producing only 4.75 kW at a cost of RM0.159 per kWh.

1. Introduction

Hydropower is the leading green energy for electricity generation globally. It capable of supplying 71% of all renewable electricity. In 2016 1.064 TW of hydropower has been installed while generating 16.4% of the world's electricity from all sources [1]. However, most of these schemes are large hydropower scheme which requires building of dam.

Rural electrification program must provide in-situ power generation for remote villages in Malaysia [2,3]. Cost of cabling and geographical terrain are the main constraints for providing on-grid power supply [4]. Most of these villages are Orang Asli settlements, which are usually located near a

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river, to provide them daily water supply. Hence for the possibility of using small scale hydro turbine to provide power supply for the limited houses in these villages using micro-grid [5,6].

The classification of hydropower scheme is as defined in Table 1. Depending on the stream flow rate and the available head, micro and pico hydro are two common turbine classes suitable for this type of scheme. Many such hydropower scheme has been successfully installed in South-East Asia region [7,8]. Small hydro scheme potentials are seriously investigated in Malaysia in order to fulfil the rural electrification program [9-11].

Table 1
Classification of Hydropower Scheme

Hydropower Scheme	Capacity	Classification
Large	> 10 MW	Large Scale
Small	< 10 MW	Large Scale
Mini	< 1 MW	Large Scale
Micro	< 100 kW	Small Scale
Pico	< 5 kW	Small Scale

Countries with geographical constraints like Cameroon [12] and Kenya [13] have been adopting the scheme for their rural electrification program to replace the conventional fossil fuel power generation. This scheme will benefit the community socially and financially. In this digital era, electricity is required necessity as pre-requisite for having the electronics devices to communicate, gain knowledge and economics purposes [14,15].

This paper will discuss the preliminary studies conducted at two remote off-grid places in Malaysia for the application of this alternative energy technology. The locations are at Kg. Tual, an Orang Asli village located near Raub, Pahang and another is Padang Batu campsite at Gunung Ledang, of Tangkak, Johor. Measurements of the stream flow rate and the head from the proposed water intake to the proposed power house location are taken to determine the most suitable type of small scale hydro turbine that can be applied at the mentioned locations.

2. Methodology

When designing a hydro scheme, it is best to note that each location is unique due to its head and flow rate. Therefore those measurements are to be undertaken so that the total power generation can be calculated. These parameters are also very important for the selection of the hydro turbine which to be applied at the specific location. The proposed powerhouse for Kg. Tual is located at 4° 08' 30.6" N 101° 38' 52.9" E while the location of Padang Batu campsite of Gunung Ledang is at 2° 22' 24.2" N 102° 36' 27.9" E.

It is critical to decide the locations of water intake and its water outlet to the power house, as these positions will decide the head (pressure difference) for the turbine. The higher the head, the higher turbine output can be expected. The water flow rate at the intake will also influence the power output of the turbine.

2.1 Head Measurement

In this preliminary study, a digital altimeter as shown in Figure 1, is used to measure the head of the proposed powerhouse site. This device is operated based on the technology of electronic bearing sensor as well as barometric sensor and purposely designed for outdoor used. The device is capable to measure the height up to 9000 meters. The altitudes at the propose water intake and at the powerhouse are taken, and the difference is recognized as the gross head.

Fig. 1. Altimeter for head measurement

2.2 Net Head

One of the important component of hydro turbine system is the penstock or pipeline, from the water intake point to the powerhouse. The length, diameter and type of pipe used will determine the losses due to pipe friction. Darcy-Weisbach equation can be used to calculate the pipe friction loss.

$$h_f = fLv^2/(2Dg) \quad (1)$$

where,
hf = pipe friction loss (m)
f = friction factor
L = length of pipe work (m)
d = inner diameter of pipe work (m)
v = velocity of fluid (m/s)
g = acceleration due to gravity (m/s^2)

The difference between gross head and pipe friction loss is defined as net head. Net head is used to calculate the power output of the turbine.

2.3 Flow Rate Measurement

A device called flow velocity probe has been used to measure the water flow velocity. This device is designed for measuring flow velocities in open channels such as rivers. It is capable of measuring the depth of the river (reservoir) based on the scales that has been attached on the probe itself. Figure 2 shows about the overall physical picture of the device.

The measurements were conducted at several points and levels of the river (reservoir) to obtain variable flow velocities and to determine the depth of the river. The width of the river at particular level is also measured. These parameters are used to calculate the estimated cross-section of the river. The flow rate of the water is then can be calculated by using flow rate equation.

Fig. 2. Flow velocity probe for flow velocity measurement

2.4 Flow Rate Calculation

In order to estimate power output, the flow rate of the water should be measured. Data of the flow velocities and the cross-section of the river (the river depth) have been collected by using flow velocity probe. The flow rate of the water can be calculated by using the following equation.

$$Q = AV \tag{2}$$

Where,
Q is the flow rate (m3/s)
A is the cross-section of the river/reservoir (m2), and
V is the flow velocity of the river (m/s).

Figure 3 shows about how the estimated cross-section of the river is calculated based on the collected data.

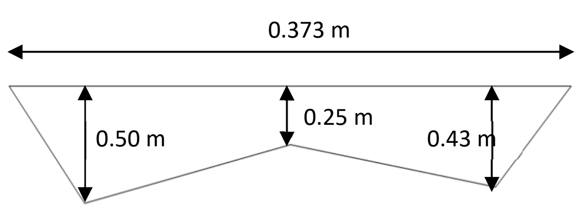

Fig. 3. Cross-section of the river flow area at Padang Batu

3. Results and Discussion

Once the measurements are taken at the two sites, as in Table 2, the estimated power output can be calculated. The power output will decide the suitable turbine which can be used at the site. Then the annual power generation can be calculated and the annualized cost of the hydro system can be estimated. The cost of energy (CoE) of the system can be derived to provide comparison with the tariff of grid-connected electricity.

Table 2
Measurement data at selected reservoirs for both locations

Parameter	Kampung Tual	Gunung Ledang
Flow Velocity (m/s)	0.63	0.1
Pressure Difference (m)	40	8
River Cross Section (m^2)	2.16	1.21
Flow Rate (m^3/s)	1.36	0.121

3.1 Power Output Calculation

Estimate power output produced by the hydro turbine can be calculated by using equation as stated as follows.

$$P = \eta \rho g H Q / 1000 \tag{3}$$

Where,
P is the power output (kW)
η is the turbine efficiency
ρ is the water density (kg/m^3)
g is the gravity acceleration (m^2/s)
H is net head (m), and
Q is the flow rate (m^3/s)

Estimated power for Kg. Tual:

$$P = \eta \rho g H Q$$
$$P = (0.5)(1000)(9.81)(40)(1.36)/1000 \;= 266.99 \text{ kW}$$

Estimated power for Gunung Ledang:

$$P = \eta \rho g H Q$$
$$P = (0.5)(1000)(9.81)(8)(0.121)/100 = 4.75 \text{ kW}$$

(Note: estimated turbine efficiency is 50% = 0.5)

Based on the estimated power calculated for both locations, the estimated power generated for Kg. Tual is around 266.99 kW and 4.75 kW at Gunung Ledang. Based from this amount of power outputs, it is suitable to implement small hydro scheme at both locations. However, in hydro turbine system, losses could occur in generator and cable distribution from the power house to the target locations (the longer is the cables, more losses will occur). Normally, the losses are estimated in the range between 10% and 15%. However, it is predicted that for Kg. Tual case, more losses will produce due to the long distance between the power house and the villages, 1.6 km in one way and 1.0 km in the other, as the power house is located in between the two villages.

It is suggested to use black polyvinyl material pipe as the penstock to flow the water from the intake to the power house where the hydro turbine is located. The used of this kind of material can be long last for at least around five years. Moreover, this kind of pipe material is flexible and easy to bend, indirectly will reduce the set-up time during the initial installation stage.

3.2 Turbine Selection

Figure 4 shows the nomogram for the selection of turbine based on various net head, flow rate (discharge) and power output. At most time more than one type of turbine can be used at a particular location.

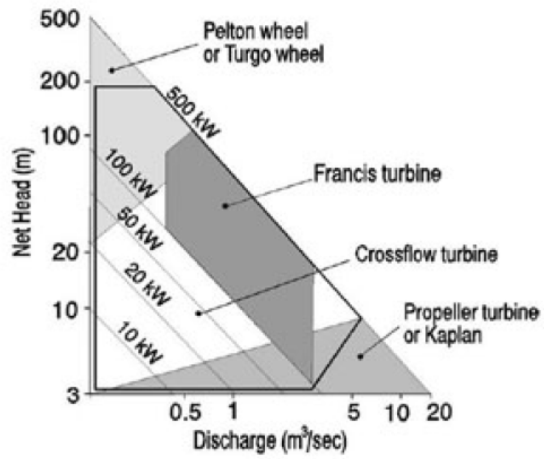

Fig. 4. Turbine Selection Based on Head and Flow Rate [16]

Estimated Padang Batu campsite power generation is less than 5 kW, which falls under pico hydro category. Therefore propeller, Kaplan and crossflow turbines are suitable for low head and low flow pico hydro schemes. Kampung Tual scheme is estimated to generate more than 200 kW, which is in mini classification. Pelton and turgo turbines are the most suitable to be considered for this scheme.

3.3 Cost of Energy (CoE)

In developing the hydropower scheme, the following cost for equipments, civil and electrical works are as shown in Table III. Based on the annualized cost and total annual energy production the cost of energy at both sites can be calculated. Kampung Tual scheme has a lower CoE at RM0.017 per kWh, while Padang Batu campsite of Gunung Ledang has a CoE of RM0.159 per kWh. Both of the tariff are still cheaper than Tenaga Nasional Berhad (TNB) tariff, which average is around RM 0.40 per kW/h.

Table 3
Equipment Cost and Cost of Energy

Equipment	Kampung Tual	Gunung Ledang
Turbine (RM)	70,000	20,000
Penstock (RM)	12,000	3,000
Powerhouse (RM)	18,000	5,000
Electrical (RM)	50,000	10,000
Dam (RM)	35,000	0
Gravel Trap (RM)	5,000	1,000
Cabling (RM)	150,000	15,000
Maintenance - 10 years (RM)	50,000	10,000
Miscellaneous (RM)	10,000	2,000
Annual Cost (RM)	40,000	6,600
Annual Power Generation (kWh)	2,338,832	41,496
Cost of Energy (RM/kWh)	0.017	0.159

4. Conclusions

The preliminary studies show positive results which suggested both locations are suitable to be applied with hydro scheme which is micro type in order to generate the electricity. Based from the estimated calculation, Kg. Tual can be supplied with 266.99 kW of the power output while Gunung Ledang around 4.75 kW. The power is estimated values since the purpose of the investigation as a preliminary study to know the potential possibility and type of hydro scheme that might be applied at both locations. The implementation of devices such as altimeter and flow velocity probe in order to measure the head and also flow velocity (flow rate), was very useful whereby it can saved time in collecting the related data. However, further detail study need to be considered for the next stage before the full installation can be done, such as the size of the power house and its construction, construction of small dam, penstock length, distribution wire length, the necessary equipment of the hydro turbine system, the control panel and related electrical wiring set-up for the power house. The overall costs also need to concern so that the proposed hydro turbine system is the most cost-effective and user friendly.

Acknowledgements
This work is partially supported by the Rural Transformation Program Blue Ocean Strategy National 4 grant Kementerian Pendidikan Tinggi Malaysia. The authors would like to thank Samsung (Malaysia), Orang Asli of Kampung Tual and Taman Negara Johor staff for their supports and help throughout the study.

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