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Design and Development of Run-of-River Hydropower System for a Remote Area

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Abstract

Hydropower is one of renewable energy generation that converts water flow into electricity through an electrical generator connected to a turbine. There are many types of hydropower system with various schemes and generation capacity. Pico-hydropower is a run-off river hydropower system with no water storage that able to generate power up to 100 kilowatt (kW). This study aims to design and develop a run-off-river hydropower system for an indigenous population in Malaysia. Whereas, some areas still have not electrification. However, the remote are typically locates near water source which capable for an installation of small hydropower system. The location selected for this study is Kemensah Orang Asli village since it represents typical economics activities and load profile of indigenous population in this country. This work will focus on data collection alongside design and development of a pico-hydropower system. Initially, crucial data such as potential sites are obtained through topographic maps. Once potential sites identified, the water flow is measures to determine the potential generations at those locations. These data will be used to design an actual pico-hydropower system to be installed at one of the selected sites. The portable and low cost system will be used to supply electricity to several loads comprises of LED lights for lighting the street in the selected area.

Keywords; *Hydropower system, Pico-hydropower, Indigenous Village, Renewable Energy*

I. INTRODUCTION

Hydropower are among the highest renewable energy power producer by providing more than 16.6% of the world's total energy to more than 160 countries globally [1]. Hydropower plants varies according to their generation capacity and architecture. Hydropower can be classified as small (below 10 MW), mini (below 2 MW), micro (below 500 kW) and pico (below 10 kW) [2].

Large hydropower system uses dam to store water. Meanwhile, small hydropower with run-of-river scheme such as micro or pico-hydropower has either small or no water storage. Therefore, it is considered to be the most cost-effective and environmental friendly hydropower technologies [1], [3].

There has been many large hydropower power systems been developed such as in Romania [4], China [5], Africa [6], and Colombia [7]. Meanwhile, small scale hydropower has gain attention among nations where there have been many installations for mini, micro and pico hydropower scheme. To install a small hydropower system for a location, a

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reconnaissance study is needed to ensure optimal power generation. There were several studies conducted to investigate the optimal location and size for small hydropower system installation. For example, Mingyue Pang et al has performed study for a potential installation of small hydropower system for a remote location in Tibet, China [8]. Meanwhile, Jessica Arias-Gaviria et al. conducted an economic study that includes investment cost, infrastructure cost and economic of scale for grid-connected small hydropower system in Columbia [9]. Masahiko Fujii et al. calculated river water levels and discharges to estimate potential power generations for micro-hydropower system for a six rivers in Beppu City, Japan [10]. Erinofiardi et al. provides survey of micro-hydropower system in Indonesia based on turbine types and economics [11]. Additionally, Daniel H.Ngoma and Yaodong Wang conducted a study to determine the best measurement methods for river velocity for a micro-hydropower scheme in Hhaynu, Tanzania [12]. Mattijs Smits and Simon R.Bush investigates the policy and practice of pico-hydropower installation for rural electrification in the Lao PDR [13]. M. R. B Khan conducted a study reconnaissance study based on topographic and hydrological studies to identify the potential installation of small hydropower system in a resort Island in South China Sea [14]–[16]. The study also uses load demand and river flow to estimate potential generations for multiple location in the island.

This study focuses on development of pico-hydropower system. The pico-hydropower scheme resource benefits in term of simplicity and cost compared to other scheme. Therefore, the shows promising results for installation in remote areas to complement or replace the use of diesel generators [17]. This paper presents the design and development of a pico-hydropower system for a remote area in Malaysia. This paper is structured as follows: Section II discusses on the methodology that includes data collection such as load profile and reconnaissance studies. Reconnaissance studies were used to determine the potential hydropower generations on each site and best turbine design. Meanwhile, Section III discusses on the results obtained such as potential locations and power generation. Finally, Section IV summarized the findings of this study.

II. METHODOLOGY

A. Kemensah Orang Asli Village

Figure 1 shows the village location. This village consists of 26 families of various ages. There is one small multi-purpose hall built by the government and some of the house were provided by the authorities. Most of these villagers daily live activities are farming and collection natural resources from the forest such as rattan and bamboo and other stuff such as gaharu and damar as the daily income. Kemensah Orang Asli Village resident have been situated here for the past 60 years without electricity, due to its remote location, the source of light for the people of this village is mainly kerosene lamp, although recently in 2017 the government successfully provide electrical supply for this village but, the cost of this project is high and not suitable for electrification in other indigenous villages in this country.

B. Load profile

The daily load profile for the village for one year were collected based on survey and calculation. Based on the seasonal variation, an estimation of the load profile for Kemensah Orang Asli Village were made in conjunction with the weather forecast. The estimation was made based on the villager’s daily activities, which is spending most of their day in the forest hunting and searching for herbs. Due to this factor, the load profile of this village is divided into two from four different quarters of the year. The load demand during each quarter are shown in Figure 2.

The recorded maximum load demand occurs at 19.00 in all the four quarters of a year, the evening has the highest load demand due to most electrical

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appliances were turned on while the minimum load demand recorded at 10.00 when mostly all villagers were out doing daily activities. The load demand is higher during the monsoon season, due to most of the villagers can't go to the forest and stay in house resulting in higher usage of electrical appliances. Meanwhile, off-season the load demand recorded is lower due to most villagers went to the forest from 8am to 6pm and mostly all the electrical appliances were switched off.

C. Estimation of energy production

From the topographic map study, a total of six sites has been identified to have potential hydropower generation. The potential sites details are shown in Table 1. The potential power was estimated based on hydropower general equation as follows:

$$P = QgH \qquad (1)$$

where P is the power output (kW), g is the gravitational acceleration (m/s2) and H is the net head (m).

Table 1. Potential sites

Site	Head (m)	Distance (m) from village	Expected water flow (L/s)	Type of turbines
1	6.5	325	1.3	- Crossflow - Turgo - Pelton
2	10	330	0.9	- Crossflow - Turgo - Pelton
3	4.5	310	1.8	- Crossflow - Undershoot water wheel
4	2	380	13	- Archimedes - Pelton

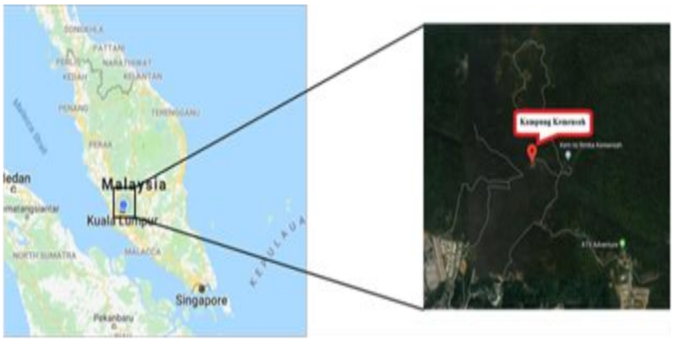

Figure 1.KampungKemensah Orang Asli

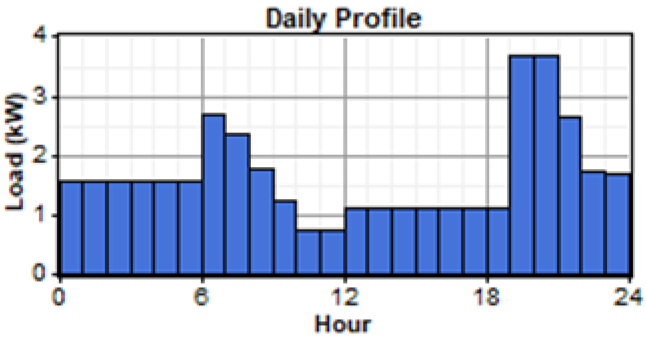

Figure 2. Hourly Load Profile

D. Turbine type selection criteria

The turbine type and size were selected based on net head, Hnet, speed and cost. The preliminary design and selection of a turbine were based on iterative procedures that require evaluation of size, cost, and speed.

E. 2D Modelling of the Pico-hydropower system

The turbine selected is Pelton and the model is shown in Figure 3.

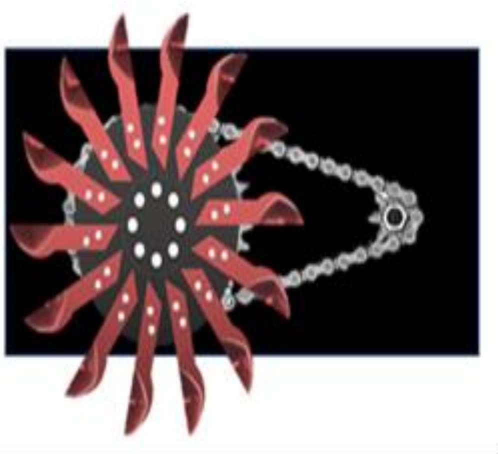

Figure 3. Turbine model (front view)

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F. Block diagram

The system comprises of turbine, generator, battery and three loads. The system block diagram is shown in Figure 4.

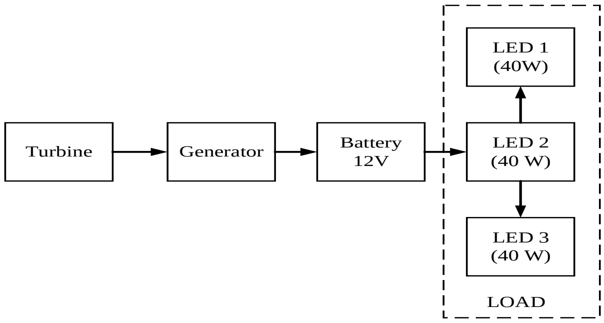

Figure 4. Block Diagram

The turbine prime mover is water flow. Turbine will drive the generator to rotate and produce electricity that charges the battery. The battery was used as backup power when hydropower system unable to provide enough power.

G Flowchart

The methodology for design and development of the pico-hydropower system is shown in Figure 5.

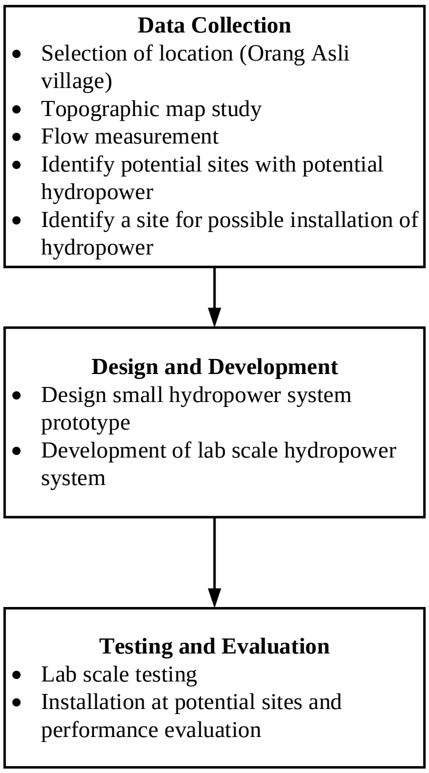

Figure 5. Methodology

III. RESULTS

A. Run-of-river hydropower location

The river running plant produces energy from the accessible stream and the natural elevation drop of a river. It is suitable for all year-round rivers with a minimum of water flow. The water drop from the height head and hit the turbine to rotate the returned to the river.

B. Net Head

The net head is very crucial parameter for identification of potential hydropower generation. The net head for the sites were identified from site visit and topographical map. Figure 6 shows gross head for a selected potential site at the village.

Figure 6. Gross head for a selected site

This site has only 2 meters of head. In this study, a chain and gear mechanics was used for optimal power generation.

C. Flow Measurement

A flow meter was used to determine the available flow for power generation. Three sites have potential for pico-hydropower on the village. The flow profiles for the sites are shown in Figure 7.

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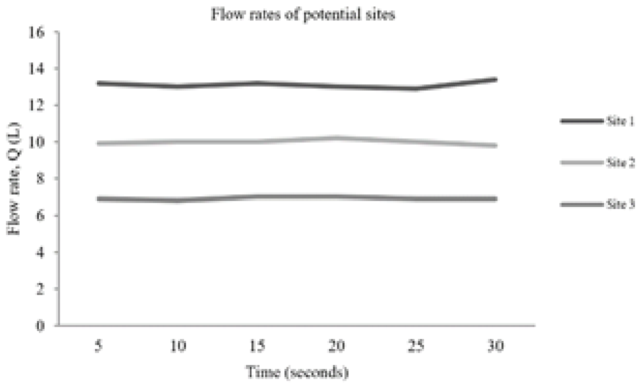

Figure 7. Flow profile for potential sites.

The y-axis is the flow rate for in liters per second. When the flow duration curve is draw, all the flow rate data will be sorted in constant in horizontal line. The flow rates are plotted on the left progressively create stable reading flow rates to the right. The x-axis is the time in seconds. In this study, the flow rate only be taken for a period of 30 seconds to measure the characteristic the flow rate of run-of-river. The flow rate at three different locations shows that run-of river site have stable flow rate.

The flow duration is plotted to identify the location's flow characteristics. The mean flow, Qmean, were calculated for the locations. Table 2 shows the available sites at the village within one km radius to limit power losses.

Table 2. Site in 1 kM radius at village

Time (s)	Site 1	Site 2	Site 3
5	13.2	9.9	6.9
10	13	10	6.8
15	13.2	10	7
20	13	10.2	7
25	12.9	10	6.9
30	13.4	9.8	6.9
Average (Qmean)	13.11	9.98	6.92

D. Pico hydropower system

The laboratory scale pico-hydropower system prototype developed shown in Figure 8.

Figure 8. Pico-hydropower prototype

The turbine rotates based on water flow. Then, the driver comprises of gear and chain transfers the rotation energy to the generator. The generator produces DC current that is connected to controller. The battery storage system connected to a controller and loads (LED lamp) via 12V bus. The Pulse Width Modulation (PWM) controller will manage the generated power to the loads and charges the battery with excess power

E. Power output

Power output for the prototype were calculated based on performance testing at selected sites. The pico-hydropower has been installing at three different locations to measure the voltage and current. The performance testing results is shown in Table 3.

Table 3. Power output prototype at site

	Voltage, V	Current, A	Power, W
Site 1	13	0.14	1.82
Site 2	10.3	0.11	1.133
Site 3	7.6	0.08	0.608

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IV. CONCLUSION

This study presented optimal location and size of a pico-hydropower system for an indigenous village in Malaysia. This hydropower scheme able to provide distributed generation without the needs for grid-connectivity.This scheme also suitable for indigenous villagers whom located at hilly regions with nearby river. This project outlined the methodology for site survey and turbine selectin. for low-cost pico-hydropower system.

A detailed overview of the different elements of Pico-hydropower, including its classification, components, performance evaluation, and efficiency was discussed.

The selection of turbines highly dependent on the flow and head of the water. Therefore, it is crucial to determine the availability of flow and head to estimate the potential power. Moreover, distance to village also important to minimize power losses.

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