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PRELIMINARY STUDY OF RENEWABLE PICO-MINI HYDRO ELECTRIFICATION IN ROYAL BELUM, PERAK

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ABSTRACT

PV/Diesel Power Generation Scheme was adopted to replace the stand-alone diesel power generation system in rural villages and schools in Malaysia. As the diesel fuel costs fluctuates over the year and the PV module showing inefficiency and incapability to totally replace diesel generators, hydro power is identified as an essential add-on power sources to the current PV/Diesel system. Hence, this paper studies the preliminary elements and analyse the potential for PV/Diesel/Pico Hydro hybrid system to be applied in SK Sungai Tiang in Royal Belum, Perak. The comparison between PV/Diesel hybrid and PV/Diesel/Pico Hydro hybrid with emphasis placed on the amount of fuel savings and total cost needed to implement the PV/Diesel/Pico Hydro hybrid based on capital cost and operational & maintenance cost (O&M).

Keywords: PV/diesel/pico hydro hybrid system, PV/diesel hybrid system, operation & maintenance.

INTRODUCTION

In Malaysia, there are many rural areas within Peninsular Malaysia as well as Sarawak and Sabah where the local natives have no access to electricity. Tenth-of-thousands of households were tapped into the national grid through the Government Transformation Programme (GTP). However, SK Sungai Tiang and the local communities of Royal Belum area was not among those who were fortunate to enjoy the benefit due to the claim by the country's main electricity provider. Tenaga Nasional Berhad (TNB) which stated that the terrain conditions do not permits grid connection as it would involve high cost of implementation. [1] Power supplies are much needed to power up water filtration system to provide clean drinkable water to the community. Apart from that, power is also required to provide communication service for safety purposes.

SK Sungai Tiang which has around 25 staff and students have to rely mainly on the diesel generators provided by the Ministry of Education to be able to power up the basic appliances like fans and lights so that the students can study with comfort. Diesel generators are only short term solution.

The installation of the diesel generators alone can cost up to USD 4,000 to USD 12,000 per units and the operating cost which includes the diesel fuel, maintenance and fuel transportation costs are estimated to be around RM431,578/ year. The diesel generators are giving out significant carbon emissions into the area which concerns the officials of Royal Belum State Park (RBSP) where the protection of the biodiversity is at utmost importance.

Figure-1. An overview of SK Sungai Tiang, Royal Belum.

Solar energy to generate electricity could not operate alone as it could not provide sufficient energy during night time or rainy days. Hence, to ensure consistent electricity supply, the diesel system is still required to cover the inefficiency of the solar system. The main overall problems are the capital expenditure (CAPEX) and operating expenditure (OPEX) are very costly.

Figure-2. SK Sungai Tiang solar hybrid station.

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In conjunction with the Government's Eleventh Plan and state park effort to promote renewable energy sources [2], this project will study the potential of integrating the current PV/Diesel hybrid system with a 100% environmental friendly and cheap hydro power source [3]. The PV/Diesel/Pico Hydro Scheme is assessed based on the amount of diesel fuel saving as well as the overall cost to implement this tri-hybrid system.

Hydro power plant

In order to differentiate the size of the hydro power scheme, a prefix system was needed. There was no official system released by the officials, however, according to the Renewable First UK, a hydro and wind company, the hydro scheme can be categorizes as shown in the table below:

Table-1. Hydro category table based on power range.

Hydro Category	Power Range
Pico	0 kW – 5 kW
Micro	5 kW – 100 kW
Mini	100 kW – 1 MW
Small	1 MW – 10 MW
Medium	10 MW – 100 MW
Large	100 MW +

In all hydro systems, the electricity production is done by harvesting the natural flow and elevation head of the river. In some cases, where the system has "pondage" to temporarily store water, it allows the regulation of flow to some level and shift the generation of electricity to meet peak hour demands. On the other hand, when there are no pondage, electricity production timing cannot be scheduled as it follows the river flows and hence, peak demand might not be fulfilled. If there are no damn utilized, a small part of the river flow might be channelled through a penstock where it will be guided into the turbine.

Run of River (RoR) hydro schemes are more favourable in some cases where environmental impacts are of big concerns. This is because comparing to bigger scale hydro projects where dam will need to be built, the RoR type only has a small barrage, usually just a weir, where there are minimal or no water stored [4]. RoR hydro schemes are also more conservative towards the environment as marine life are less interfered, less risk towards sedimentation issues and costs lesser than the larger plants with dam also stated than in RoR hydro projects, the social and environment implications are also considerably low as there is no need for big reservoir which might transform a river into a lake as pondage for the hydro generation purpose. [5] [6] Regardless of the size of RoR projects, its impacts towards the ecosystem of the natural river flow will be lower compared to those of large dams. [7]

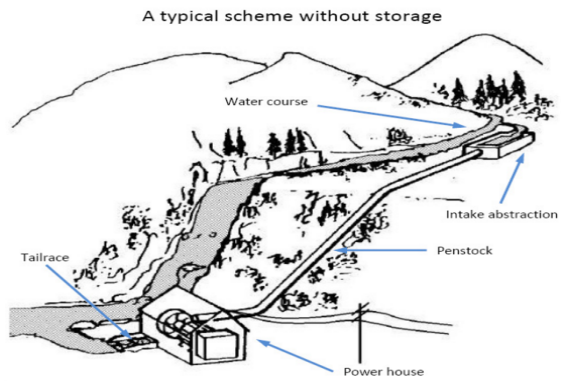

Figure-3. A typical RoR scheme without pondage/ storage capability (Credit to: Universiti of Strathclyde, UK).

A preliminary measurements and site testing was done in Sungai Mes, Royal Belum. There is consistent water flow with potential of implementing a typical Pico hydro scheme without storage. Further survey and measurement will be conducted to provide sufficient data for actual installation. Other potential sites are also surveyed for the same Pico hydro scheme.

Figure-4. Run river cross flow turbine operating under a waterfall.

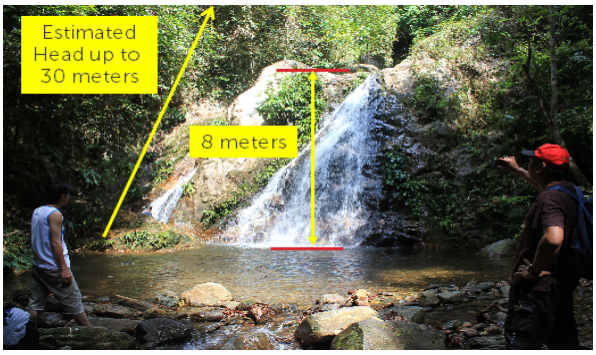

Figure-5. Sungai Mes waterfall site survey.

SITE ASSESSMENT

In order to estimate the power generation potential in a river, it is essential to be able to measure the flow rate and also the head of the river. Flow rate is defined as the amount of water flowing past a certain point in a given period of time. The unit for flow rate is litre per second. Meanwhile, the head of water refers to the vertical height (unit: metres) measured from the turbine level up to the level where water enters the penstock or a stream. The horizontal distance or the penstock length does not contribute to the pressure increments. This head is important as it is needed to compute the current water pressure or the potential water pressure in the river or stream.

Flow rate obtaining procedure

For ease, the measurement of flow rate can be done by using a stopwatch and a 10 litre water bucket. The flow rate (unit: litre per second) can be obtained by dividing the 10 litre bucket volume by the amount of time needed to fill the bucket completely. The method is only applicable when the opening of the river is narrow or through a weir of pipe when the flow is at a maximum rate.

In the case where the bucket method cannot be applied, the flow rate can be obtained by using a float or a buoy. The speed at which the float travels is equivalent to the river flow rate. The average speed of the river however, can be calculated by multiplying the speed of the float by a certain factor:

$$Q\left(\frac{Litre}{sec}\right) = A * S\left(\frac{m}{sec}\right) * 1000 \quad (1)$$

Where:
Q= Flow rate (litre per second)
A= Correction Factor (0.8 for a concrete channel, 0.7 for earth channel, 0.5 for rough hill stream)
S= Speed of float (metre per second)

As for streams which has average depth of less than 15 centimetres, the following formula is used to estimate the flow rate up to an accuracy of 80 %:

$$Q\left(\frac{litre}{sec}\right) = \frac{D_{float}(m) * Avg\ Depth(m) * Avg\ Width\ (m)}{Time\ taken\ by\ float\ (s)} x\ 1000 \quad (2)$$

Where:
Q= Flow rate (litre per second)
D= Distance travel by float (m)
Avg Depth= Average depth of stream (m)
Avg Width= Average width of stream (m)

Head obtaining procedure

There are several methods at which the head can be obtained:

- Using pressure gauge: Connecting a pipe from the water intake location to the potential turbine location and attach a suitable range pressure gauge at the end of the hose.
- Using contour map: The head can be identified by comparing the height of the water source and also the potential site at which the hydro scheme will be set up from the contour map.

POWER ESTIMATION

The power output from a hydro power plant can be estimated by using the head and river flow rate measured. The formula to be given is:

$$P = Q * \rho * h * g \quad (3)$$

Where:
P= Power (kW)
Q= Flow Rate (m^3/s)
ρ= Density of water (1000 kg/m^3)
h= Head (m)
g= Gravitational acceleration (9.8 m^2/s)

By taking into account η (Efficiency) of the whole system which ranges from 0-1, the revised version of the power estimation formula will be:

$$P_{actual} = \eta * Q * \rho * h * g \quad (4)$$

Where:
P_{actual}= Actual Power (kW)
η= Efficiency (%)
Q= Flow Rate (m^3/s)
ρ= Density of water (1000 kg/m^3)
h= Head (m)
g= Gravitational acceleration (9.8 m^2/s)

TURBINE SELECTION

A turbine is a device that extracts the potential energy of running water, stream or river and converts into mechanical energy in the form of rotating shaft power.

Preliminary turbine selection is depending on the head and also the flow rate of the river selected as the water source. At different net head and flow rate, there is a different turbine that is suitable for the application. Typical river with high head will utilize Pelton turbine whereas Banki/ Cross Flow and Kaplan turbines are suitable for river with low head.

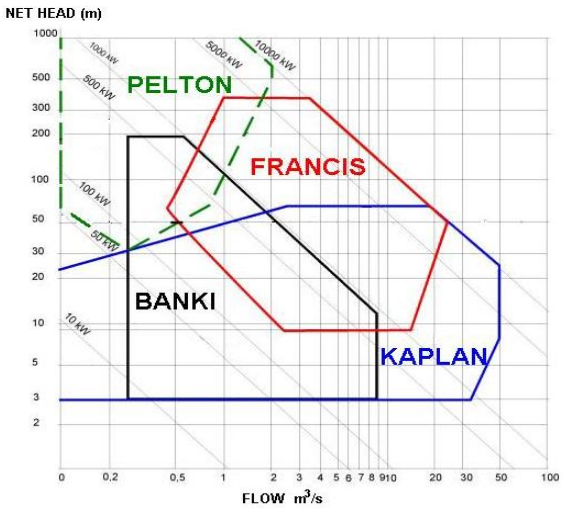

Figure-6. Turbine application range graph (Source: International network for sustainable energy, 2008).

Other criteria which includes: overall system cost, overall system size, environmental considerations (regulatory, weather, location suitability), unit portability, unit reliability, required civil works, design modularity, and also maintenance & serviceability were also considered.

SYSTEM COMPONENTS

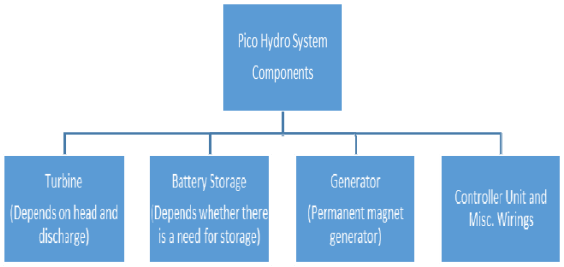

Figure-7. Proposed system components for the pico hydro system.

a) Turbine

All turbines have its own power-speed characteristic and its efficiency-speed characteristic. They will operate most efficiently in a certain head, flow and speed. Different turbines are chosen for different heads as the shaft speed for electricity generation is needed to be as close to 1500 rpm in order to reduce the speed change between the generator and also the turbine. The speed of all turbines will decrease with proportion to the square-root of head, hence, low-head sites needs turbines which is relatively fast under given operating condition.

b) Battery storage

In order to ensure continuity of supply of electricity, a battery storage is normally used. It also functions as a storage bank for the excess electricity generated by the PV module when the load demand is not that high. Typically, deep cycle batteries are used. Deep cycle batteries are designed to be able to handle regular charging and discharging without affecting their lifetime. The capacities of these batteries normally ranged from 2V to 12 V DC.

c) Generator

A generator will be used to convert these mechanical energy generated from the turbine unit and turn them into electrical energy. Typically, permanent magnet generators are used. Permanent Magnet Generators (PMG) normally does not need a gearbox like what the generators required as PMG are designed to be directly coupled with the turbine and are capable of producing high power output at low RPM.

d) Controller unit and misc. wirings

A controller unit is a logic controller used to control the flow of the electricity generated. When there is demand higher than the amount of power generated, the controller will utilise the power available in the battery storage. In the case where the storage is empty, the controller acts to initiate the diesel generators to generate power to cover the excess demand.

METHODOLOGY

Site assessment (Suitable turbine location)

In our case, the location of Royal Belum has been identified as our datum. However, we need to assess any nearby waterfall or river that meets our requirement for pico to mini hydro plant suitability. For instance, we need water source that has constant flow and does not dry up during the dry season; we need water source that is close to the target population to reduce the need for power transmission line; we need to have suitable turbine installation location where the nature of the reserve will not be disturbed.

Maximum hydro power potential calculation

The maximum amount energy that can be harvested from a hydro system can be estimated by calculation using the values of head and flow rate obtained from the water source.

Power demand estimation & current PV/diesel system contribution

To understand the amount of electricity needed, we have to estimate the power load needed by each household in the area. Since we are targeting the orang asli community for this project, we have to estimate the power

consumption and also the breakdown of the current power generation system supplied to them.

Turbine type identification

After considering the available head and the flow of water source, the suitable turbine shape can be selected using the relevant chart or graphs. Estimated operating efficiency can also be determined.

Turbine designing & fabrication

Since the turbine type that is to be utilized is determined, the turbine can now be designed by using the appropriate formulae. The 2D and 3D drawing will be presented by using Solidworks software for latter fabrication process. Details like the guide vanes angle, overall dimensions, number of blades has to be taken into account.

Overall hydro system details identification

Other components of the hydro system like penstock dimension, forebay dimension, water jet diameter, generator type, battery storage, logic controller, inverter has to be identified in order to set up complete system for hydro generation. Penstock length and diameter must be appropriate in order to reduce any unwanted head losses in the penstock. Forebay dimension must be designed as limited size might hinder the water supply towards the turbine especially when river water level is not optimum. Appropriate water jet dimension will determine the efficiency of the turbine; while the need of having a generator has to be considered in the case where the rotational speed of the turbine does not match with the rotational speed of the generator shaft.

RESULTS

The waterfall located is originated from Sungai Mes which is near Sungai Kejar. The waterfall is of four stages, with each stages around 10-20 feet in height, the overall waterfall head is roughly around 60-80 feet (22m in average). The flow of the waterfall is estimated to be around 0.5 m^3 to 1.0 m^3.

By using the turbine application range graph, the suitable turbine for the application of pico-mini hydro power generation for this case is Banki Turbine or also known as Cross Flow Turbine. The possible power output is around 200 kW.

The maximum power output without considering efficiency is:

$$P_{theoretical} = (Q * \rho * h * g)$$
$$= (1.0*1000*22*9.81)$$
$$= (215.82kW)$$

Considering a system efficiency of 60% to account for losses in the system,

$$P_{expected} = (\eta * Q * \rho * h * g)$$
$$= (0.6*1.0*1000*22*9.81)$$
$$= (129.49kW)$$

CONCLUSIONS

With the power output expected to be around 129.49 kW, the waterfall identified is a good source of hydro energy. However, the waterfall site has to be further assessed in other aspect such as whether the location is easily accessible for transportation and maintenance purposes, etc. If all the criteria are fulfilled, the waterfall will bring significant hydro power from the pico-micro hydro system to help achieve the aim of reducing the time needed for diesel generators operating to fulfill the electricity demand, thus, reducing the diesel fuel consumption and carbon emissions from the generator sets.

NOMENCLATURE

PV Photo-Voltaic
RM Ringgit Malaysia
UK United Kingdom

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