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Pico-hydro Electrification from Rainwater's Gravitational Force for Urban Area

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Abstract

The demand for electrical energy is increasing in most areas in the world. Unstable fossil fuel price and its rapid depletion have led to an intensive research on new energy source and energy conversion. This paper presents the performance of the energy harvesting which focuses on the experimental work to emulate energy harvesting from the rainwater by utilizing a Pico - hydro approach installed to a high building. NACuM core DB-370F DC generators, 1000 litres water tank, 0.5 inch diameter piping system used in two different configurations with three different head setups. The result shows a huge energy harvesting potential obtained from the system and rainwater with maximum 261 milliwatts despite the hardware's limitation in the setup. Hance, contributes to the cost-efficient due to its small in size, environmentally friendly, and hassle-free maintenance.

***Keywords**: Pico-hydro, gravitational, rainfall*

1. Introduction

In the new millennium era, ever since the electricity was found more than a century ago, it has become one of the most valuable commodity. To provide the sufficient electricity with lower cost is a challenging demand in many years to come especially in urban areas. The continuous growth of the numbers of populations, skyscrapers, factories as well as the residences has made the electrical energy demand become more critical.

In Malaysia, hydropower plant, gas-based power plant, coal power plant continues to dominate the power generation sectors [1]. However, gas and coal-based power plant depends on the availability and price of the fossil material. Large hydropower plant requires huge capital and land [2]. As a result, this opens for an opportunity for a new research in renewable energy and energy conversion field. Pico-hydro technology with a capacity less than 5kW has become popular recently due to its flexibility and cost effective to be applied in small-scale power generation [3]-[5]. Still, an appropriate and effective setup is essential to produce higher efficiency of energy conversion.

Geographically, Malaysia is located near to the equator that is known to have a huge amount of rain yearly. Peninsular Malaysia and Malaysian Borneo side receive around 2500 millimeters and 5080 millimeters of rainfalls, respectively in average each year [6]. Kuching, Tawau, Kota Bharu, Kuala Lumpur, and Taiping are among the highest receiver of rainfall. Therefore, pico-hydro generation is feasible at these locations as they are considered as the dense cities with higher number of populations and various buildings. By using rainwater as a prime agent, authors aim to see the potential of harvesting a useful energy by converting the gravitational force and water flow of the rainfall water in the pipe to an electrical energy. Two setup was established for the experimental work to determine the most efficient way in producing electrical energy with pico-hydro.

2. Small Scale Hydro

Hydropower is very common in Malaysia. It has become one of the major energy contributors to the nation via electricity generation in several dams all over the country. There are several classifications related to hydropower in terms of the generated power. It starts from

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as small as milliwatts to as big as Megawatts. Figure 1 illustrates the classification of the hydropower family.

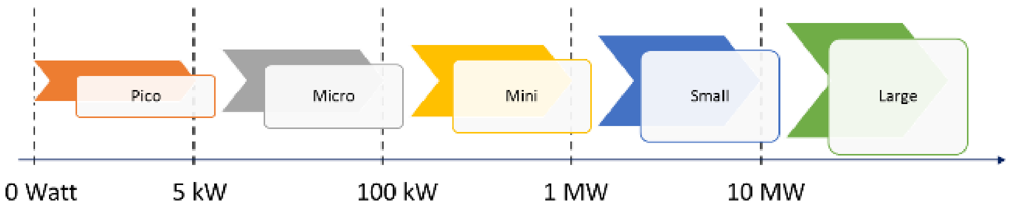

Figure 1. Classification of Hydropower

Based on the classification, Pico-hydro is a subset of hydropower family-tree that is capable to produce power as low as milliwatts to a maximum number of 5kW [7]. Pico-hydro is based on the simple concept of kinetic to electrical energy conversion. The moving water spins the turbine that drives the generator and hence, produces the electric energy. However, to harness the kinetic energy of the water flow to generate electricity, several factors have to be considered such as water power, head, and flow. Head and flow play a big role and electricity will not be able to be generated if these two variable are omitted [8].

2.1. Pressure Head and Potential Power

Generally, potential power from the hydro system is proportional to the water pressure head and its flow rate. The higher the flow rates and the pressure head, the higher it will able to produce the kinetic energy that flows into the generator to start rotating and generate electric energy [9]. There are two head types to be considered in determining the heads which are gross head and net head. The gross head is defined as the vertical distance between the penstock and point at which the water leaves the generator. While net gross is the value of gross head minus the losses due to friction and turbulence [8].

There are many methods that can be used to measure the water head [10], however, in this work, head measurement is straightforward since it is can be easily measured due to its vertical setup. The amount of output power produced is depending on the vertical drop of water flow (H) in the pipeline and the water flow rate (Q) [11]-[12]

$$P = Q \times H \times g \quad (1)$$

Where,
P = Potential Power (watts)
Q = Volumatric flowrate (litre/sec)
H = gross head (m)
g = gravitational constant ($9.81\ m/s^2$)

The power equation is then modified by an efficiency factor (η):

$$P = Q \times H \times g \times \eta \quad (2)$$

Where, η = efficiency (%)

The aforementioned equation is necessary to provide a reasonable estimation of the output power to be produced by the system regardless of its generator size and rating.

2.2. Generator and Turbine

Generally, the electric machine is divided into two categories i.e. electric motor and generator. The fundamental operation is based on rotational movement which involves current and voltage to produce or to consume power. There is no tangible difference between those two, except for the direction of power flow [9,13]. In this project, the prime agent is the water flow in the pipeline. The energy conversion is based on the production of motionally induced Electromotive Force (e.m.f). The working principle is based on Faraday's law; whenever a conductor is moved in a magnetic field, the e.m.f is induced and yield current movement in the conductor closed circuit. In this work, DB-370F generator with NACuM core generation type is used. The selection of this generator is due to its compact size which suited with the experiment apparatus design. The mini generator was constructed with the coil fixed inside its housing. An exciting magnetic field and current are induced when the magnetic body is rotating by means of water flow.

Figure 2. NACuM DB-370F Generator

Table 1. NACuM Generated Power at Several Flows (100 Ohm Resistor) [14]

Flow (LPM)	Voltage (V_DC)	Current (mA)	Power (mW)
2.7	3.4	34	115.6
3	3.5	35	122.5
4	3.6	36	129
12	3.66	36.6	133.9

3. Experimental Work

The experimental work was done at a three-story building located in the Faculty of Electrical Engineering, Univerisiti Teknikal Malaysia Melaka (UTeM). The work emulates a condition where the rainwater is captured and stored in a 1000 litres water tank before it is released to the generation system via 0.5 inch diameter piping. The generatation system is powered by a pico-hydro generator. The generator has a capability to generate 3.7 Vdc output with 129 milliwatts rating power. An overview of the framework of this research is illustrated in Figure 3.

Finding the best configuration to generate maximum harvesting capacity from the rainwater is the main focus of this work. Three pico-hydro generators were utilized in the experiment, and were set into two configurations. Configuration A uses all three generators at once as depicted in Figure 4. Three heads were set in this configuration i.e. H1(head 1), H2(head 2) and H3(head 3) with a value of 0.57 meter, 2.57 meter, and 4.57 meter respectively.

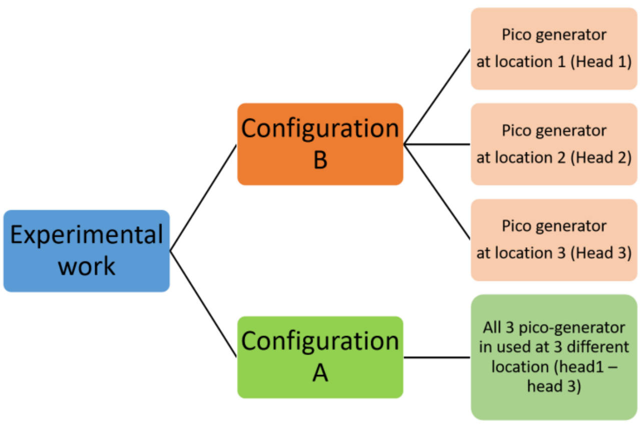

Figure 3. Experimental Frame; Two configurations with Four Different Setups

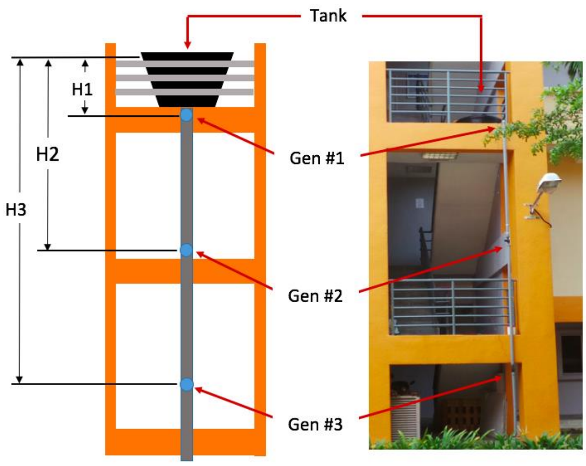

Figure 4. Experimental Setup for Configuration A

On the other hand, configuration B uses one generator at a time. As such, it has three experimental works for different locations of the generator. The first generator is located 0.57 meter from the head, the second and the third generator positioned are 2.57 meter and 4.57 meter from the head respectively.

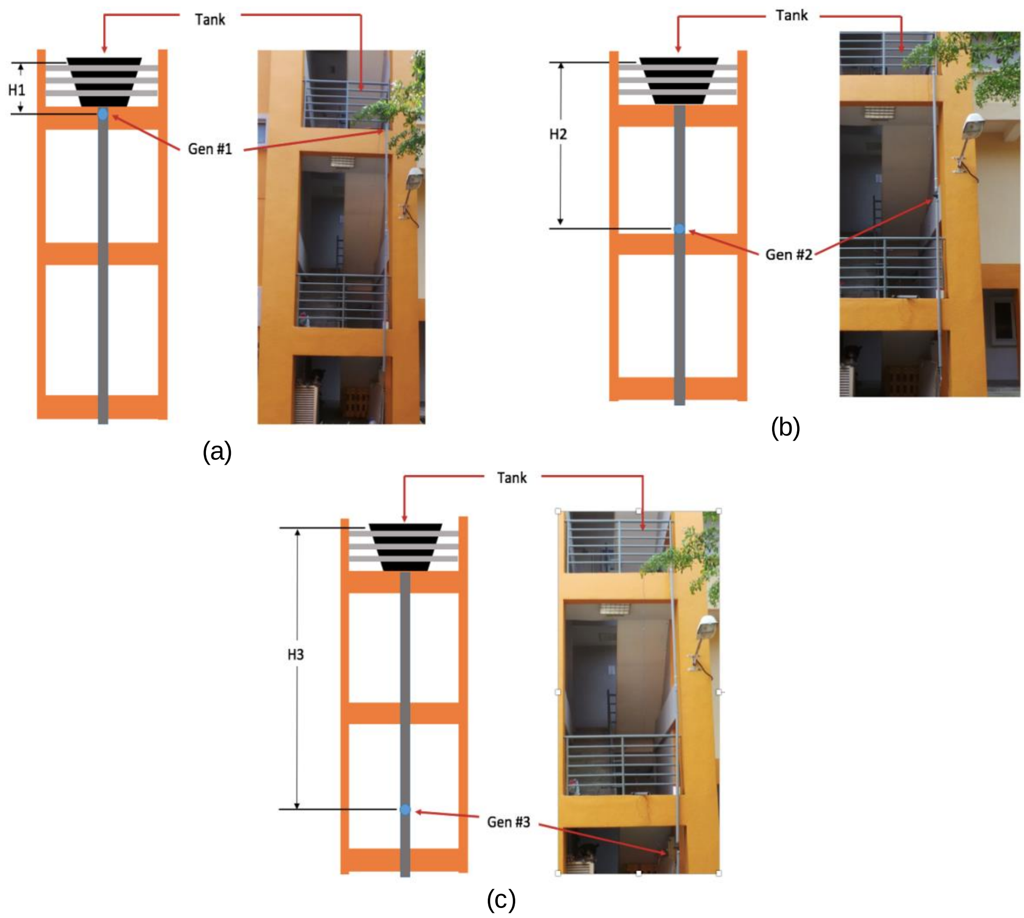

Figure 5. Experimental Setup for Configuration B; (a) Generator #1 (b) Generator #2 (c) Generator #3

4. Results and Analysis

An open circuit test outcomes in Table 2 and Table 3 present the water flow rate, head value, current, voltage, and power after 10 times sampling process. The corresponding data are accordingly plotted in which it compares the results between configuration A and configuration B. With an accumulated average power of 261 milliwatts, it is clearly seen that configuration B yields 88% far better result over configuration A. This can be visually noted in Figure 6.

Table 2. Average Result of Configuration A with 10 Attempts

Flow (l/s)	Head (meter)	Variables of Configuration A Generator	Current (A)	Voltage (V)
0.0786	0.57	#1	0.01	0.38
0.0478	2.57	#2	0.01	1.42
0.0367	4.57	#3	0.02	1.56

Table 3. Average Result of Configuration B with 10 Attempts

Flow (l/s)	Head (meter)	Variables of Configuration A Generator	Current (A)	Voltage (V)
0.0786	0.57	#1	0.01	0.38
0.0478	2.57	#2	0.1	2.49
0.0367	4.57	#3	0.1	2.61

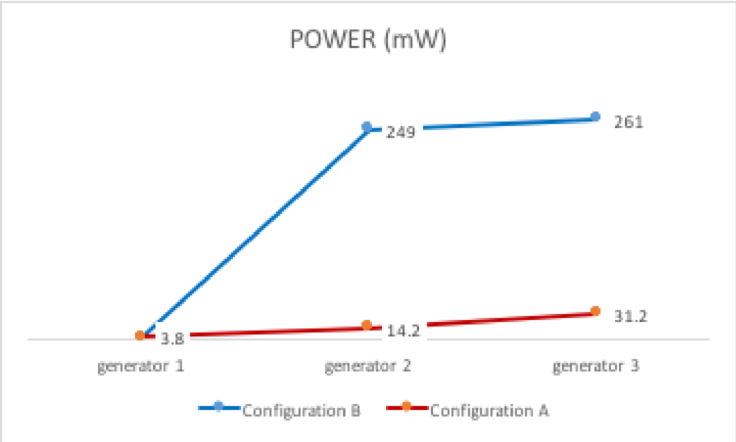

Figure 6. Output Power (Configuration A versus Configuration B)

Generally, the results shown in Figure 6 are the net power generated by the systems. Since the generated power has a close relationship with voltage, these results deliver an initial information that the system follows the general output power indicated in equation (1). From equation (1), a potential power of configuration A at third generator is;

$$P_{out\,(config\,A)} = Q \times g \times h$$
$$= 0.0497 \times 9.81 \times 4.57$$
$$= 2.228\ \text{Watt}$$

Since the highest net power produced by configuration A is 31.2 milliwatt, therefore, from equation (2);

$$\eta_{config\ A} = \frac{31.2\text{mW}}{2.228\text{W}} \times 100$$
$$= 1.4\%$$

1.4% is the maximum efficiency that configuration A can achieve. Obviously, the setup with three generators simultaneously has contributed to extra losses due to fractions, thresh rack and entrance losses. As for configuration B, the potential power at setup 3 (generator #3) is also 2.228 Watt. However, the net power generated is much higher. Thus, contributing to its higher efficiency compared to configuration A.

$$\eta_{\text{config B}} = \frac{261\text{mW}}{2.228\text{W}} \times 100$$
$$= 57.9\%$$

The actual efficiency is noted to be lower compared to the estimated figure. This is due to the hardware limitation such as generator capability, friction losses in Pico-hydro system, entrance losses and thrash track. However, its efficiency is much better compared to the system developed by [10] where water distributed to the houses was used as a prime agent.

5. Conclusion

As a conclusion, it should be noted that there is a huge prospect to acquire energy from the gravitational force of the rainfall's water with an appropriate apparatus and method. With the proposed method, clearly that the energy conversion is feasible with the presence of skyscrapers in an urban area. With a right placement of generator at an optimum head distance, the maximum efficiency of energy conversion rate can be tremendously obtained, in this case, 57.9% (in milliwatt). Pico-hydro implementation in the research contributes to the cost-efficient due to its small in size, environmentally friendly, and hassle-free maintenance.

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