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Experimental Study for the Double-Stage Savonius Blade with Different Overlap Ratios for Rain Water Harvesting (RWH) System

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ABSTRACT

The energy demand kept increasing, in line with the increment of world population. The price of fossil fuel is kept rocketing. Renewable energy is the alternative that had been approached to make sure the sustainability of the energy. The example of sustainable energies is rain, solar, tides, wind, biomass, and hydro. In general, the climate in Malaysia is characterized as high rainfall throughout the year. The collection of rain water can be used to generate an electricity under the concept of rain water harvesting (RWH) system. The purpose of this study is to vary the overlap ratio, β (0.15 and 0.3) of the Savonius blades in the proposed RWH system. From the analysis, it is shown that for the Double-Stage Savonius blade rotors, higher electricity can be generated when β is increased. From the finding, it is found that the Double-Stage Savonius blade rotor of 0.15 β produces power output of 0.12 Watt while 0.3 β produces 0.13 W, respectively.

Key Words: Savonius blade, double-stage, overlap ratio, rain water harvesting.

1. INTRODUCTION

The energy demand kept increasing, in line with the increment of world population. The price of fossil fuel as a primary energy resource is kept rocketing. Various efforts had been done in searching for the best feasible alternative energy that can be used due to the depleting amount of the natural fossils fuels, the growth in energy consumption and the raising the awareness of global warming [1]. Renewable energy is the alternative that had been approached to make sure the sustainability of the energy and continuously giving the good quality of life. In addition, it also can generate approximate the production from conventional fossil fuel without releasing carbon emission or radioactive wastes to the surrounding [2]. The examples of sustainable energies are rain, solar, tides, wind, biomass, and hydro. Each of renewable energies has prosequences and consequences. Wind power, solar power and micro hydro share the most common form of alternative energies used in residential area.

Malaysia is the country that has exceptionally rich with natural resource. In fact, Malaysia has a climate that flourish with many fundamental elements. The most precious natural resource that most people overlook its beauty as one of the renewable energy sources is water. Basically, the lake, river and also rain water are where the water resource in Malaysia comes from. In general, the climate in Malaysia is characterized as high rainfall especially the climate of West Malaysia and the atmospheric temperature is uniform throughout the year. The mean rainfall in Malaysia is 2500 mm and the average temperature is 27 °C of a year [3]. Rainwater can be valuable not only as a source of renewable energy but also, it can be drank safely when stored in a nicely installed water storage system. Furthermore, it can be very useful especially during the dry season mainly at the outskirts of towns and cities where the water is not easily accessed [4].

The data from Malaysian Meteorological Department [5] reported that on the early of the year until the middle of March 2014, Malaysia experienced dry condition with a very little amount of rainfall. In contrast, most area in Malaysia experienced the wet condition after Mid-March 2014.

Exploiting energy from rain water is one of the initiatives that can be made and has a huge potential on being implemented in Malaysia. A systematic development is needed for better performance of this invention. This invention will be referred as rain water harvesting (RWH) system. The principle of the system will be explained in this paper. Basically, generating electricity by using rain water can be applied with the harvesting method. In concept, the rain water will be collected and stored after harvesting from a certain area such as a rooftop. By implementing RWH system, a fresh and new energy resource can be created. High total precipitation amount of rain water will add up the relevant of implementing RHW system in Malaysia. For that, this study will emphasize on the principle work of the system and the modification of the system in order to enhance the performance of the system.

2. RESEARCH METHODOLOGY

The work has been started doing a thorough literature review to investigate and compile the valuable information that needed. Then, then design in terms of system structure, type, design, size and scaling are carried out. An estimation of scale design was executed to obtain 0.3 watt of generated output power to light a 03 watt LED lamp. After that, a preliminary design was done to build a prototype of the proposed RWH system. The performance of the early design then is analyzed before designing the actual RWH system. Once satisfied, the actual design is built and further analysis has been executed as explained later in the next section.

2.1 The design and experimental procedure

The design process is executed by following a designed method flow. Process had been started by determining the appropriate design of the pipeline sizing. First, the crossover area section of the pipe is determined by surveying the available sizes of the pipe dimension in the market. Then, process is followed by determining the appropriate design of the micro-sized turbine rotor before determining the appropriate design of pipeline length and water tank size. To obtain the appropriate designs and fabrications of mentioned components of the proposed RWH system, 2 type of experiment has been set. For the first experimental, the water in the tank is released when the amount of water in 30 litres. Then, experiment is followed by doubling the amount of water to 60 litres. In each experiment, different length of pipeline (between the bottom level of the water tank and the height of the mounted turbine rotor) were used. The generated current, voltage, blade speed rotation and the time taken for the water flow from bottom water tank to rotor are measured. From these experiments, the optimum design of the RWH is determined.

2.2 Schematic diagram of RWH system model

The proposed RWH system model as depicted in Figure 2 has the following components:

Filter: To filter the rainwater from the rooftop from the rubbishes, leaves, debris, and etc. For the proposed system, a double-layer filter is used to ensure that the water from the roof is proper filtered before releasing the water flow through the pipe. The first layer is used to filter the big contaminants such as rubbish, leaves and others whilst the second layer is used to filter the micro and small contaminants such as sands, stones and others.

Water storage tank: The water storage tank is used to collect the filtered rainwater that was flow from the rooftop. The storage tank which has a capacity to store water up to 60 litres was selected and used for the proposed RWH system. The storage tank was placed 2.75 metres from the ground, as illustrated in Figure 2.

Figure 2: Block Diagram of the Proposed Electrical Generation System using RWH System

Piping: Designed and fabricated to fix the suitable size of the proposed micro Savonius turbine that could provide optimum water flow rate, pressure and velocity. Water will be released from the collected water tank when water reached a certain measurement level (30 and 60 litres, depends on the set carried out experiment). The rectangular shape was chosen for the pipe compare to the circular one in order to provide smoother blades rotation and appropriate space for the blade rotor. The chosen geometry size for the pipeline is 4 inches times 2 inches, with height of 1.0, 1.5, 2.0 and 2.5 metres. This geometry sizes were chosen to find the best optimum water flow velocity in order to power 0.3 watt LED light bulb. The generated power by the blade rotor can be calculated using equation (1). Then, the estimation of the optimum water flow velocity can be estimated by rearranging equation (1) into equation (2).

$$P = \frac{1}{2}\rho A C_p U_{opt}^3 \quad (1)$$

$$U = \left(\frac{2P}{\rho A C_p}\right)^{\frac{1}{3}} \quad (2)$$

where P = power output, C_p = power coefficient, p = density of water = 999.97 kg/m³, A = area of rotor and U = velocity of water. Assumed that C_p = 0.4.

By considering the available pipeline in the market (4 inches by 2 inches) and by manipulating the parameters of pipe's height and the pipe's surface area, the instantaneous water volume and the water flow rate can be estimated using equation (3) and (4), respectively. Hence, the instantaneous water velocity can be estimated by rearranging equation (4) into equation (5). Power then can be estimated by suing equation (6).

$$Vol = A \times h \quad (3)$$

$$Q = \frac{Vol}{t} = \frac{A \times h}{t} = A\bar{v} \quad (4)$$

$$\bar{v} = \frac{Q}{A} \quad (5)$$

$$Pg = V \times I \quad (6)$$

where Vol = water volume, h = water height, t = time (assumed as 2 seconds) and $\bar{v}$ = velocity of water with the specified water height, Pg = generated power , V = measure voltage and I = measure current.

Generator: To generate electrical energy when connected to the micro-sized Savonius turbine via shifting components. A 6 Volts DC motor (from a used toy racing car) has been used as a generator to convert the mechanical to electrical energy, as depicted in Figure 3.

Blade rotor: The micro-sized three-bladed Savonius VAWT rotor is mounted into a shaft shifting system to enable the connected generator produces electrical signal when the shaft is rotating. The micro-sized Savonius blades were designed and built using an aluminium sheet with an aspect ratio (AR) of 2, with height (h) of 9 cm and diameter (d) of 4.5 cm, as shown in Figure 4. The blades were separated by 180 degrees from each other.

Rotor dimension: Length = 0.08 m, diameter = 0.045 m

3. RESULTS AND DISCUSSION

In this section, results will be divided into two subsections; overlap ratio set at 0 and overlap ratio set to 0.3.

3.1 Overlap ratio at 0

Table 1 shows the collected data when the overlap ratio of the blade rotor is set at 0. The measured data when water volume in the tank is set at 30 and 60 litres is compared. Besides, comparison data on different rotor setting from the tank is also shown.

Table 1: The Measurement Results when Overlap Ratio = 0

Water volume in tank (L)	Height of rotor from tank pipe, p (m)	Voltage, V (Volt)	Current, I (mA)	Power, P (W)	Rotational speed, ω (rpm)	Rotational speed, ω (rad/s)
30	1.0	4.2	78.9	0.3314	982	102.835
	1.5	4.8	64.2	0.3082	1052	110.165
60	1.0	4.9	76.9	0.3768	1127	118.019
	1.5	6.1	56.1	0.3422	1203	125.978

From Table 1, it can be observed that generated voltage is increasing when the height between the bottom tank and the mounted rotor is set higher. When this height is set at 1.5 metres, voltage can reach up to 4.8 V and 6.1 V when water volume is 30 and 60 litres, respectively. However, current shows inversely proportional relationship to the voltage, where larger currents are generated when height is decreased. In terms of blade rotation, it can be seen that when height is increased, the blades rotate faster. However, from the table, it can be summarised that higher power can be generated when the height between the bottom tank and the mounted rotor is shorten. This is due to higher torque created by the water pressure and also due to the shorter time taken for the released water from the tank to reach or hit the blades to spin. Besides, when water volume is increased, power can be increased as well.

3.2 Overlap ratio at 0.3

Table 2 shows the collected data when the overlap ratio of the blade rotor is set at 0.3. As in the previous subsection, the measured data when water volume in the tank is set at 30 and 60 litres is compared. Besides, comparison data on different rotor setting from the tank is also shown.

Table 2: The Measurement Results when Overlap Ratio = 0.3

Water Volume in Tank (L)	Height of Rotor from Tank Pipe, p (m)	Voltage, V (Volt)	Current, I (mA)	Power, P (W)	Rotational Speed, ω (rpm)	Rotational Speed, ω (rad/s)
30	1.0	4.1	77.1	0.3161	1212	126.920
	1.5	4.7	66.3	0.3116	1280	134.041
60	1.0	6.1	80.2	0.4892	1428	149.540
	1.5	4.7	90.1	0.4235	1278	133.832

From Table 2, it can be seen that similar trend as obtained in Table 1 is shown in this experiment, in which power is increases when the pipeline is designed and fabricated shorter. The generated current and power also increased better. When higher water level is considered, the power can be increased more than 50% when 1 metre pipeline is used. But, when the pipeline is designed longer, power only slightly increased though the water level has been doubled.

However, from the comparison between the measure data from Figure 2 and Figure 3, it can be seen that better power output can be generated (up to 0.49 watt) when the water level in the tank is increased double when 1.0 metre long pipeline is used. This is due the increment of generated current. With increment of water level, the volume of the water is increased. Thus, increasing the water pressure in the pipeline, consequently, causing the designed Savonius rotor blade work more efficient from the first experiment. Also, from tables' comparisons, it is found that higher overlap ratio will attribute to higher generation of electricity.

4. CONCLUSION

From the executed study, the proposed RWH system using a micro-sized two-bladed Savonius rotor with double-stage rotors, considering the changes in terms of the overlap ratio has been successfully designed and built. From the results, it can be concluded that better power output can be generated when higher overlap ratio is chosen. Also, from the findings, it was found that the electrical generation using the proposed RWH system depends highly on the efficiency of the ability of blade rotor's rotation. When the speed of rotor rotation is increased, the output power can be increased as well, as has been proven from the executed experimental. The height between the bottom storage tank from the mounted rotor also influence the rotor performance. When the height is shorter, water will strike the rotor shortly and thus, the rotor can automatically spin faster compared to the condition when longer height is set. The two-bladed double-stage Savonius rotor can rotate up to 1428 rpm when higher water volume and shorter distance between the bottom storage tank and the mounted blade rotor are considered. Also, it can be concluded that the Savonius rotor is applicable to be used as the RWH's turbine since this rotor manage to rotate quite fast, simple and easy to be designed and employed. Some recommendation that can be proposed to upgrade the designed system is by designing a more appropriate turbine design such as considering different number of stages, aspect ratios and number of blades. A lot of improvement should be done to increase the entire system performance and reliability.

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