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Development of Prototype Pico Hydropower Generation

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Abstract: In Malaysia, various types of renewable energy are used to produce clean and green energy. One renewable energy is hydroelectric energy uses water resources to produce electricity. Various types of hydropower according to the amount of energy produced range from large energy which is more than 100MW to pico energy which is less than 50kW. In this paper, the project has been tested on a small agricultural area where the place is rarely used and the small area is suitable for producing small and portable energy. For this project, the Pico hydropower is generated by using a Pelton turbine as mechanical energy and a generator as electrical energy which have been combined into one generator. It is connected to a water flow sensor which will read the speed of water flowing through the pipe and also the volume of water. By the Arduino Uno, the system can measure the water flow rate, the volume of water and the voltage output. This system is tested by generating the speed of water flow according to time which is proportional to 2 minutes per reading. Starting with the first 2 minutes, the water velocity rate is 12.04L/min with a water volume of 22.0L and 20 minutes later, the total water flow rate is 115.32L/min with a nearly equal water volume of 22.53L. The voltage output at the full opening of the water level is 11.67V and the partial opening is 6.98V. The energy generated is used on an LED lamp that uses 5V, 5W. Finally, it is found that a pico hydropower prototype can be built and generate electricity using the generator and turbine with pressurized water to use at DC loads.

Keywords: Pico Hydropower, Renewable Energy Sources, Turbines, Battery Chargers, Pipelines.

1. Introduction

Renewable energy is energy that is clean and produced through a process of constantly being replenished. There are various types of renewable energy, including solar energy, wind energy, hydroelectric energy and geothermal energy. Renewable energy is also said to be green energy and clean energy. Among other renewable energy that can be applied in Malaysia is Pico hydropower.

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Micro and pico-hydropower are small in comparison to mini- and large-scale hydropower. Pico-hydro is classified according to its ability to produce electricity up to 5 kW. Water is first will go through in pico-hydropower systems to generate the energy, which is then converted to kinetic head (through a nozzle). Hydro turbines use this kinetic head to generate mechanical energy. Hydro turbines are connected to alternators or generators to convert mechanical energy to about 5 kW of electrical energy. The penstock, nozzle, water turbine, main inlet valve, runner, and deflector are all parts of a Pico hydropower system [1].

An article describes the development of low-head small hydropower in Thailand. The researchers introduce a novel turbine form as a maritime propeller form with a reversed mean camber line. For this study, the developed hydro turbine indicated that the project is suited for water heads ranging from 10 to 20 m. The geometry distribution with the reversed mean camber line of the airfoil is used to determine the form of the runner blade. The runner blade, which is based on the design of a marine propeller and has a reversed mean camber line, is the most important component of a hydro turbine [2]. Another research article by Acharya et al. [3] used numerical modeling to improve the performance of a cross-flow hydro turbine. The results revealed that the efficiency gained was 63.7 percent, which was geometrically changed to improve efficiency by 13%.

Khan et al. [4] investigated a micro-hydro turbine to determine optimal flow parameters for power generation. Computational fluid dynamics was used to model turbine shapes. Computational fluid dynamics analysis of the turbine shape with various debris protector setups was performed to determine the optimal recovery of flow characteristics for maximum electricity generation. Several studies have been conducted, and the system's efficiency has also been demonstrated by many writers in the previously mentioned papers [5]. The Crossflow turbine was invented by Australian Anthony Michell, Hungarian Donát Bánk, and German Fritz Oss Berger. In 1903, Michelle received patents for his turbine design [6]. A crossflow turbine is a drum-shaped device that employs an elongated, rectangular-section nozzle directed against curved vanes on a cylindrically shaped runner. It looks like a "squirrel cage" blower. The crossflow turbine allows water to flow twice through the blades. The first pass occurs when water flows from the outside of the blades to the inside, and the second pass occurs when water flows from the inside back out. A guide vane at the turbine's entrance directs the flow to a specific section of the runner.

In this paper, the project was built and tested in small agriculture as this sector are used more water. With the use of water, this project can harvest hydroelectric energy without the nuisance of the piping system. This energy uses a generator suitable for a small amount of electricity that can control some small loads such as LED light. This Pico hydropower produces power in the form of DC and if it needs to be used in the form of AC, it requires an inverter to convert the form of energy. These Pico hydropower setups typically use a run-of-river type, meaning no reservoir will be used for the presence of water and in-pipe lines concept. It is simply a water channel that flows water slowly or quickly through a turbine before returning to the water drainage.

2. Materials and Methods

This section will discuss how to produce this project by stating the concept of the project and the main component of the project.

2.1 The Concept of Project System

This phase describes how the system generates electricity, beginning with the velocity of the water as the primary source and progressing to the incoming load as shown in Figure 1. The mechanism starts with a quick flow of water that rotates the turbine. The pico-generator is a part combined with a turbine; it works after the water rotates the turbine to generate electricity in one part. The rotating turbine's speed is affected by the speed of the water. The turbine, which is the initial process to generate power, can then be rotated by the presence of this fast flow of water. It is the mechanical component that permits this generator to move.

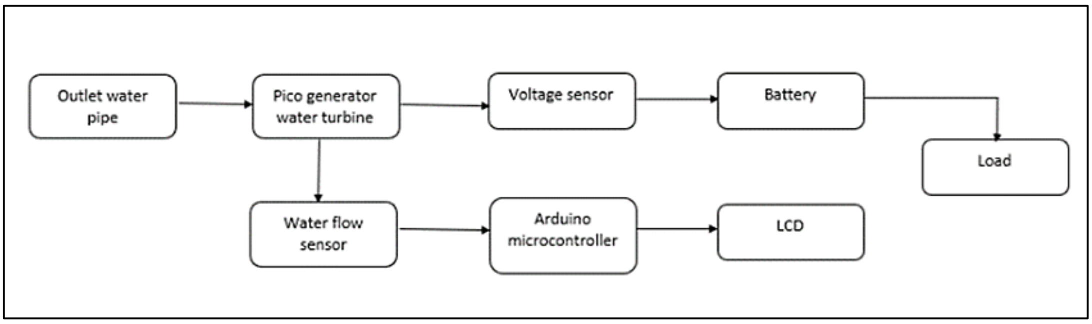

Figure 1: Block diagram of project system

The movement of this generator, which is the result of turbine rotation, serves as an interchange of energy from mechanical to electrical. This will result in voltage and current being delivered to the load. The fact that voltages must be kept within the prescribed range that electrical equipment can tolerate. So, this will be carried out by Buck's DC-DC step-down module which converts a higher voltage to the fixed voltage of 5V to load. The resulting load is confined to a DC load that can only be used with 5V produced. Aside from lights, it can also be used as a phone charger, radio, fan, and so on. But for this project is focused on the LED light as a load.

Furthermore, this system has its energy storage in the form of a battery, which is employed as a backup energy supply to the load. In the event that the system is damaged or something undesirable occurs, this device will act as a substitute for the generation of electrical current to the load. These batteries can also be used as an alternative option to save a small amount of load utilization at times. For example, because just a few loads, such as a fan, are utilized during the day, the battery will be utilized during the day and recharged at night, or vice versa. This battery is rechargeable at any time. This battery also has a battery charger, which controls the voltage to be charged to the battery and acts as a cut-off when the battery is fully charged. This is to protect the battery's life when using this device.

2.2. Main Components of Project

i. Water Turbine Generator

This water turbine generator produces a DC voltage that has a limit of 12V. It has a combination of turbine and generator in one tool and has two main pins namely positive and negative [7]. The maximum pressure at the outlet opening is 1.2Mpa and it will start working if the water pressure is 0.05Mpa. For this device, it is suitable to be used for required loads below 10W. It uses a Cross Flow water turbine where the shape is not elongated, and the blades are small and slightly vertical.

ii. Water Flow Sensor YF S201

This sensor serves to measure and calculate the flow rate and check the volume of liquid that has passed through a pipe, and control it as required. The sensor has 3 wires RED, YELLOW, and BLACK. The red wire is used for supply voltage which ranges from 5V to 18V and the black wire is connected to GND. The yellow wire is used for output (pulses), which can be read by an MCU. The water flow sensor consists of a pinwheel sensor that measures the quantity of liquid that has passed through it [8]. The pressure that forces the through pipelines determines the velocity. Because the cross-sectional area of the pipe is known and constant, the average velocity is a good indicator of the flow rate. For formula used to calculate it is shown Eq. (1) until Eq (6):

$$\text{Pulse frequency (Hz)} = 7.5Q, \qquad \textit{Eq. 1}$$

where

Q is flow rate in Liters/minute

Flow Rate (Liters/hour) = (Pulse frequency x 60 min) / 7.5Q *Eq. 2*

In other words:

Sensor Frequency (Hz) = 7.5 * Q (Liters/min) *Eq. 3*

Liters = Q * time elapsed (seconds) / 60 (seconds/minute) *Eq. 4*

Liters = (Frequency (Pulses/second) / 7.5) * time elapsed (seconds) / 60 *Eq. 5*

Liters = Pulses / (7.5 * 60) *Eq. 6*

iii. Battery Charger for Lithium-Ion

This type is called as TP4056 battery charger with protection for Lithium-Ion battery. It comes with a protection function where it will cut-off battery charging and protects against overvoltage and overcurrent charging [9]. There are 6 pins on the module, namely 2 input voltage pins, 2 output voltage pins and 2 battery charging pins. It makes it easier for users to charge the battery while using it. The input voltage for this device is around 4.5-5.5V and it will be fully charged at 4.2V.

iv. Voltage sensor

The voltage sensor as shown in Figure 5 reads the voltage received by the generator and displays it on the LCD. A low-power analogue conditioning circuit measures the current in one of the probe's capacitances to determine the power line voltage [10]. It just only uses the voltage divider concept to detect the value entered at the input as measurement. The following is the formula in Eq. (7):

$$Vout \quad (V) = (\frac{R2}{R1+R2}) \times Vin \qquad \text{Eq. 7}$$

where,

Input voltage (Vin): 5V

R1: 30000, R2: 7500

v. DC-DC Step-Down Buck Module

This device is named as XL4005 DC-DC step-down buck module. It works like a transformer to lower the voltage value from the input from 5-32V with a current rating of 5A and the output is around 1V-30V where it can be adjusted as appropriate. It can only handle half of the maximum current. The greatest current drawn by a buck converter is 4.29 A, which is within the buck converter's capability [11]. The output power produced is a maximum of 75W and also has a cut-off output function when overheated.

3. Results and Discussion

This project has been tested on 2 January 2022 (Sunday), 9.00 a.m. at a small agriculture area in UTHM near Stadium UTHM. It is also divided into two tests, namely the value of the resulting voltage to determine the value of power that can be produced and the value of current flowing in the project circuit, battery charger reading and the value of water velocity rate and volume of water flowing through the pipe. Figure 2 shows a complete prototype project to be tested.

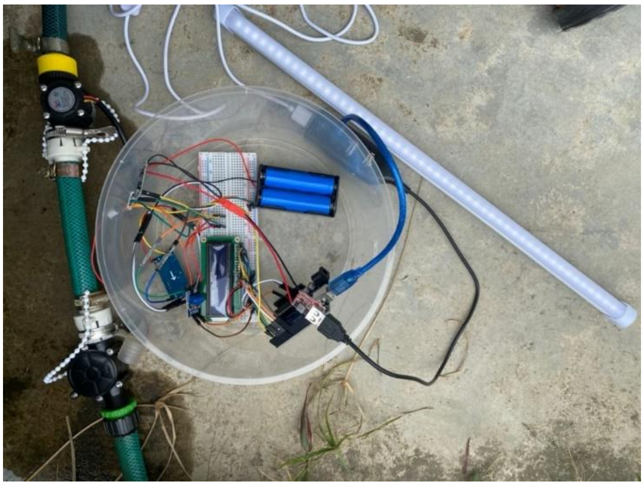

Figure 2: The complete of Prototype project

Table 1 tabulates the result of Pico generator water turbine. Based on Table 1, when the system works with the presence of voltage supply by Pico generator, it will go through the step-down voltage process using DC-DC step-down buck module which has been adjusted to 5V voltage output as it will pass through a component which is a battery charger module which receives a voltage of 4.5V-5.5V only. Based on the full water opening level, the voltage was read at the input supply from the pico-generator which is 11.67V which has gone through the maximum water level speed and the production of voltage by the maximum level pico-generator. Then, the voltage was lowered to 4.98V readings at that point. So, in the presence of an LCD lamp that receives a voltage of 5V DC equal to the power used which is 5W, then the calculation of current by using the power formula is 1.00A. It is also the same if the water opening is in a half state which produces a voltage of 6.98V then lowered to 4.91V. By calculating the basic formula of power, by which the load used is 5W, then it can determine the value of the flowing current which is 1.02A. It takes such a calculation because the value of the current cannot be read using a multimeter. So, a calculation is generated to find out the value of the current that flows at the load.

Table 1: Result of Pico generator water turbine

Opening water level	Voltage (V)	Voltage Step Down (V)	Current (A)	Power Output Load (W)
Fully opened	11.67	4.98	1.00	5
Semi opened	6.98	4.91	1.02	5

Table 2 shows the reading of the total water flow rate and volume of water produced on the water flow sensor. Based on Table 2 on water flow rate measurements, the water flow volume and circuit voltage show that the values increase over time. This measurement is taken to determine the increasing rate of water velocity as it is measured over time. The concept used by this sensor is to use a pulse every one minute. Due to that, its value increases. So, the measured time is according to every two minutes of reading of the recorded value, this is because every two minutes measured is easier to determine the increase and change in the measured value and also gives some time to measure and analyze each value.

This measurement is taken after the opening rate of the tap water valve is in the full opening. Therefore, the voltage generated by this pico-generator is 11.67V and gives a reading to the water speed measured using a water flow sensor. According to the value taken after testing, it was found that the value is approximately the same with the range between 22.00-22.67 (L/m). The change in value shown is to prove that the speed of water flowing every two minutes is the same value i.e. 22.00-23.00 (L/m) generally depending on the speed of water from the source obtained.

Table 2: Result of water flow rate and volume of water

Time taken (minute)	Fully Opened Test		
	Total Water flow rate (L/m)	**Volume of water (L)**	**Voltage of system (V)**
2	12.04	22.00	6.45
4	25.36	22.40	6.57
6	36.98	22.13	6.47
8	48.48	22.53	6.52
10	60.12	22.40	6.49
12	71.40	22.53	6.47
14	82.46	22.40	6.49
16	92.62	22.67	6.52
18	104.04	22.53	6.45
20	115.32	22.53	6.52

Then, the measurement is continued by determining the value of the volume of water produced from the same water velocity using a water flow sensor. The results have proved that the value of the resulting volume of water gives a great increase every two minutes is calculated. For example, in the second minute, the reading is 12.04L which is the reading of the first two minutes and the next two minutes show the value of the volume of water is increased to 25.36L. So the value difference between the both is 13.32L. If formulated, the difference in value between every two minutes taken is 10-15L of running water. However, the value of the volume taken will not decrease even if it is closed or no reading is taken. This is because it looks like a car driven from a distance is taken into account using a meter. It needs to be reset if it wants to return to its original value. Figure 3 (a) and (b) shows a graph of time taken for experimental in minute versus total water flow rate in liter/minute and a graph of time taken versus volume of water, respectively.

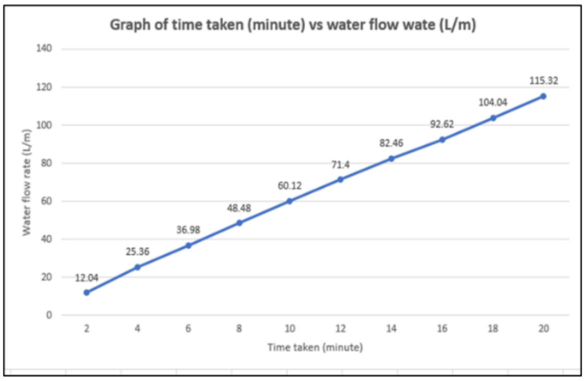

Figure 3 (a): Graph of time taken versus total water flow rate

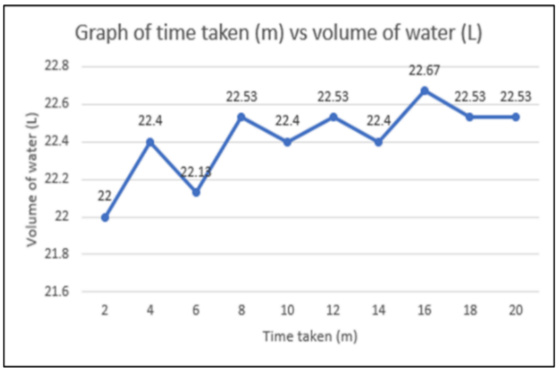

Figure 3 (b): Graph of time taken versus volume of water

The voltage value has been lowered from 11.67V to 5V to be assigned to the battery charger as the acceptable value is in the range of 4.5V-5.5V. However, the reading value shown is in the range of 6.52-6.57V. This is because the circuit also has two sources of energy channeled which is voltage supply from the pico-generator and the battery causes the voltage value to increase.

Table 3 shows an analysis of battery charger function for charge and discharge testing.

Table 3: Battery charger testing

Condition of Battery	Voltage (V)	Watt-hours
Charging	7.80	59.28
Discharging	6.05	45.98

When the condition of the battery is in a charging state, the circuit will provide current to the battery and voltage to recharge the battery. The battery uses two 3800mAh-capacity batteries each with a voltage of 3.7V. The voltage starts at 4.2V maximum and quickly drops down to about 3.7V for the majority of the battery life. Once hit 3.4V the battery is dead and at 3.0V, the cutoff circuitry disconnects the battery. When charging the battery for a certain period, the charged battery will meet the total voltage for the two batteries, which is 7.80V. The total battery capacity indicates it is in full condition for each battery. So the amount of energy that can be consumed in an hour is 59.28 watt-hours. When compared to the state when the battery was discharging, the battery was used within almost an hour and showed a battery voltage decrease of 6.05V. If used again, the amount of energy that can accommodate within an hour is 45.98 watt-hours. In conclusion, these batteries can be used over a certain period, depending on the capacity and voltage received by the battery.

4. Conclusion

The project focuses on a product called Pico hydropower system that produces a small amount of energy that is as much as 10W according to the voltage production level of a pico-generator water turbine. It is suitable for DC loads where this pico-generator produces power in the form of DC. This project has been successfully produced, bypassing the main objective of the study, which is to generate electricity in the form of pico hydropower sources that can be used for 5V DC load. This is because the output from the system has used a DC-DC step-down USB charger module which only produces 5V. It is suitable for use because almost all types of DC loads use USB-5V. For this project, energy production can be used for a 5V DC lamp with the required amount of energy is 5W. According to small energy produced, it is suitable for use in small areas or any emergency case. In addition, the project aims to study the level of battery use that can be re-charged which is Lithium-Ion batteries. If the supply is cut off, the battery can hold the energy to the required load for a particular time. This is called backup or secondary sources. Next, this project is also tested to determine the speed level of water and the volume flowing through the pipe by determining the water flow rate, volume of water and voltage generated using sensors and Arduino microcontroller. So, the performance shown proves that this system can be used anywhere in the presence of pressurized water.

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