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Modelling of Micro Hydropower System for Small Load Application

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Abstract: The implementation of Movement Control Order (MCO) to curb the spread of covid-19 in Malaysia has resulted in an increased financial burden on the people especially those from the low-income group. Therefore, taking advantage of the promising renewable energy as the free source of electricity could subsequently reduce the financial burden borne by this group. Hence, this paper conducts an analysis using MATLAB/Simulink software, to assess the viability of small-scale hydro turbines in converting potential energy of water heads into electricity for powering small load appliances. The analysis consists of several parts such as the DC generator, converter and charge controller. The data regarding volume of water usage in this study is based on water usage by the author. The result from simulation through the MATLAB software demonstrate a convincing reading in recorded voltage, current and power which indicate this system is feasible for electrification of small load appliances and indicate the potential for future improvement and research.

Keywords: Mini hydro, turbine, Li-ion battery, MATLAB

1. Introduction

Most Malaysian are struggling with financial hardship and about 2.8 million of bottom tier earners (B40) are reported to have lost their jobs since Covid-19 pandemic hit Malaysia in 2020 [1]. In response to this pandemic, the Malaysian government have implemented movement control orders (MCO) to all Malaysians whereby only essential services allowed to operate [2]. As a result, the electric bill of those who stay at home has risen above normal level further increased on electricity bill can cause financial burden of people, especially those from the B40 group [3].

The financial burden of the B40 group can be alleviated by practising an efficient usage of electrical energy or using the energy in an efficient manner. One of the approaches that can be applied is efficiently use the energy is by taking advantage of renewable energy as a promising source of electricity. If compared to conventional energy supplies, renewal energy is more difficult to store and extremely variable in time and space [4, 15]. However, it has relatively low maintenance costs. Hence, if a small-scale renewable power plant is installed in each household, it might give benefits in providing free electricity to consumers subsequently reducing the financial burden borne by this group.

This paper will analyse the viability of small-scale hydro turbines in converting the potential energy of water heads into electricity for powering the small load appliances through modelling and simulation on MATLAB/Simulink

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software. The basic principle of this small-scale hydropower is whenever consumers use water, the water will flow from a higher level to a lower level, then the resulting potential energy of water will be used to drive a generator. This hydropower is a very clean source of energy and only uses the water head. After generating the electrical power, the water is available for other purposes.

2. Materials and Methods

This section emphasized the principal, formula, hardware and software used in this paper. The small-scale Hydropower system in this paper is designed using MATLAB/Simulink software. Figure 1 below show block diagram of the system if the model implemented on water tank. The model of the system can be implemented on real scenario such as on water tank, incoming house water supply or even on the house drainage system, this is because the model of the system is suitable due to low head and high flow rates. The model of system if implemented in real scenario consists of a DC generator, buck converter, battery and load. Micro hydro turbine placed in the pipeline below the household water tank and is connected to the battery and load via the boost converter and charge controller.

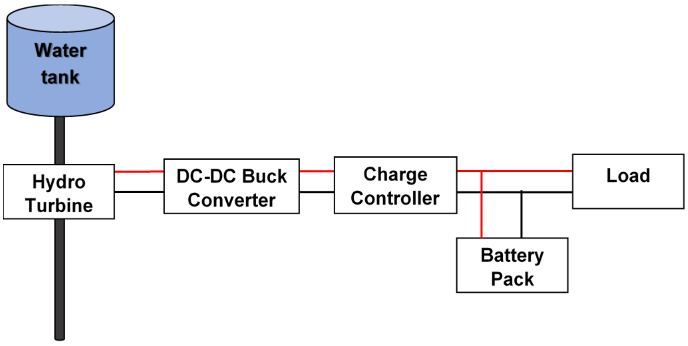

Fig. 1 - The block diagram of the small-scale hydro turbine

A water storage tank collects water and store it for later use and timely access [14]. This storage tank is usually placed at the rooftop or at elevated height. The overhead of water tank causing the water to flow towards gravitational force without using any external forces whenever the pipe faucet is open. Micro hydro turbine placed in the pipeline, the resultant potential energy from the flowing of water causing the turbine to rotate further producing electrical energy. The resultant potential energy of the water is proportional to the water pressure in the pipeline [13]. Next, the generated voltage will undergo voltage modification process instead projecting directly to the load. The generated power will be wasted if no load connected to the system. Therefore, the battery pack is use in parallel for storing the excessive generate power under this condition.

Figure 2 below shows the overall project model that have been developed by using the MATLAB/Simulink software. This hydro project system can be divided into 6 blocks as follows:

- Block 1: Known as DC generator part which is it presents the sub circuit of the hydro turbine generator. The field terminals voltage value is based on the hardware testing during 2 different scenarios, such as during non-peak hours and during peak hours.
- Block 2: Known as DC converter and it presents the buck-converter. The buck converter will step down the incoming voltage generated by the DC generator previously.
- Block 3: It presents charge controller to control the voltage and current charging for load part. It used to control the reverse power flow and keep electric cells from overcharging [5].
- Block 4: It presents battery pack and the types of battery is Li-ion battery. This process can be reversible and known as electro-chemical principles [6].
- Block 5: It presents the battery pack that connected to the load. The reason on why the li-ion battery has been chose in this project is because it has a high specific density thus it is useful for small appliances such as mobile applications [7].
- Block 6: It presents the scope to display the simulation results. It will show the graph analysis for this project simulation.

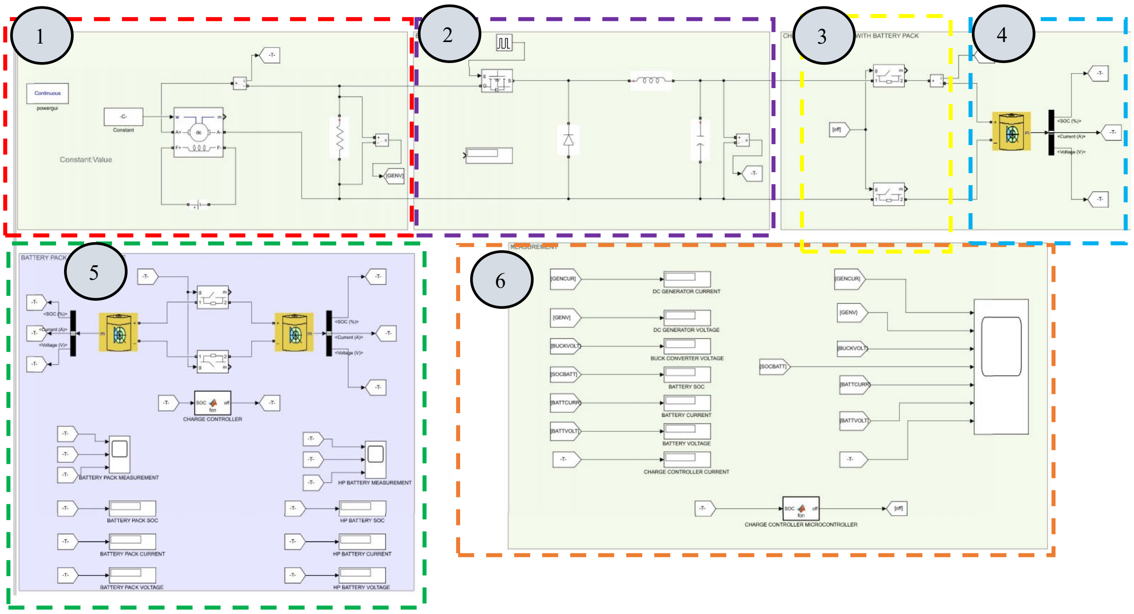

Fig. 2 - The overall small-scale hydropower system design by using the MATLAB/Simulink software

2.1 DC Generator

Small hydro power plants are hydraulic works which use water to generate electricity. They are further classified into the following categories according to the size of electrical power it produces as shown in Table 1 [8]. The output power produce by hydro power are depends on the rate of water discharge and heads.

Table 1 - Classification of hydropower plant

Power	Class
> 10 MW	Large
< 10 MW	Small
< 1 MW	Mini
< 100kW	Micro
< 5 kW	Pico

The electricity in the hydro turbine is produced by a DC generator which is mostly modelled based on its velocity speed or torque constants. In this project study, the basic circuit diagram for the DC generator that presents from MATLAB/Simulink software as shown in Figure 3.

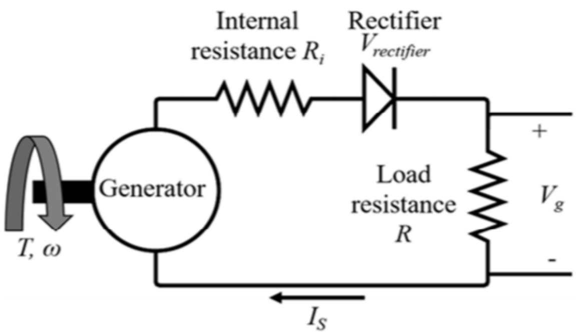

Fig. 3 - The circuit diagram of DC generator [9]

Based on the circuit diagram, the generated current, I_s in DC generator can be obtain by using the generator shaft, T and frictional torque T_f itself as shown in Equation 1.

$$I_s = \frac{(T - T_f)}{Kt} \quad (1)$$

Then, the voltage that developed by the generator can be represents as V_g, the speed of turbine in $\boldsymbol{\Omega}$, the voltage drops across the internal resistance or rectifier, $V_{rectifier}$ can be discussed as Equation 2.

$$V_g = \frac{\Omega}{K_v} - I_s R_i - V_{rectifier} \quad (2)$$

The modelling for the DC generator on MATLAB software as shown in Figure 4 below. The input of the DC generator is the speed. Thus, in this generator design the speed resemble the speed rotation of the hydro turbine. The higher the rotation speed, the higher the power produced by the DC generator.

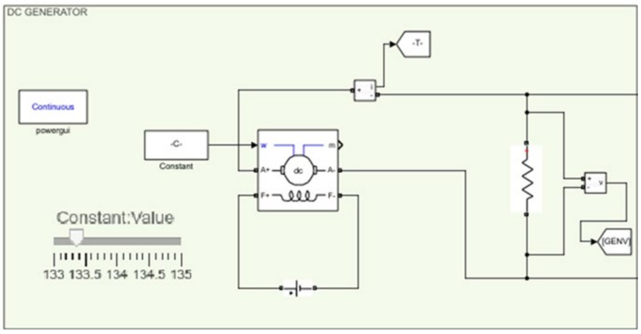

Fig. 4 - Model of DC generator micro-hydro generator

2.2 DC-DC Buck Converter

Buck converter is a type of DC to DC converter that an output voltage magnitude is lower than input voltage depending on duty cycle [11]. The power stage converter composed of DC input voltage, controlled switch, diode, filter capacitor, inductor and load resistance as shown in Figure 5.

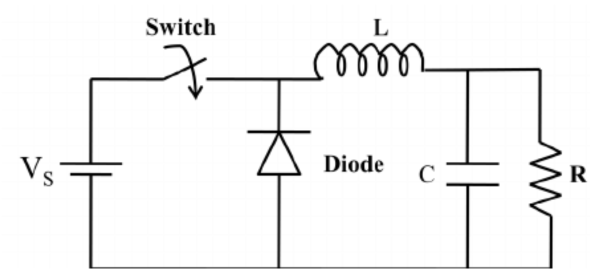

Fig. 5 - The DC-DC Buck Converter circuit diagram [12]

From figure 5, the relationship between voltage input and output can be measure by the following equations. Equation 3 shows the duty cycle, D can be acquired using the input voltage, V_{in} obtain and the required voltage output, V_{out}. While, for the Equation 4 the inductor value can be obtained using the minimum inductor value, L_{min}. Next, the capacitor value, C for the buck converter used is shown in Equation 5.

$$D = \frac{V_{out}}{V_{in}} \quad (3)$$

$$L_{min} = \frac{(1-D)R}{2f} \quad (4)$$

$$C = \frac{(1-D)}{8 \times L \times r \times f^2} \quad (5)$$

Figure 6 and table 2 shows the modelling and parameters of the DC-DC buck converter on MATLAB software. The DC-DC buck converter in this project will step down the incoming voltage generated by the DC generator into suitable voltage to store into the battery pack. The output voltage for the DC-DC buck converter is 5V.

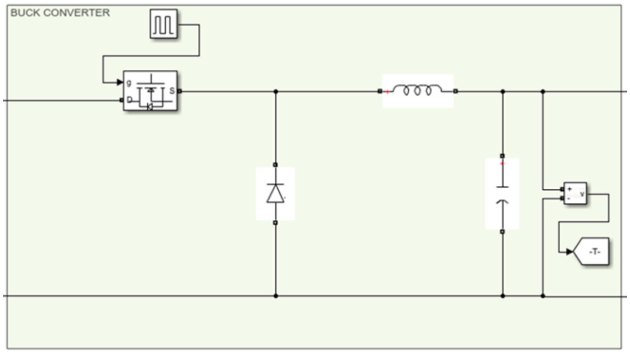

Fig. 6 - Model of DC-DC buck converter

Table 2 - The values used for each parameter of buck converter in MATLAB simulation

Parameters	Value
Switching frequency, f_s	50 kHz
Inductor, L_{min}	58.3 µH
Capacitor, C	40 µF
Resistor, R	10 Ω

2.3 Charge Controller

The charge controller in this project is responsible to smartly charge the battery pack in order to keep the battery pack from overcharging and control the reverse of power flow. The modelling design of the charge controller in this project is shown on Figure 7.

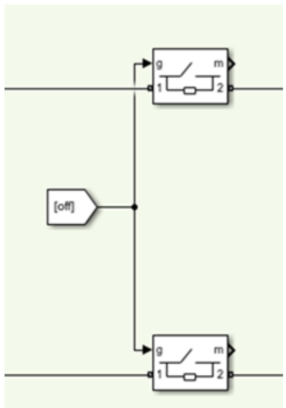

Fig. 7 - Model of charge controller

2.4 Battery Pack

Battery is an appliance that converts chemical energy into electrical energy. These principles known as electro-chemical principles and in a rechargeable battery this process can be reversible. The types of rechargeable battery use to construct the model of battery pack is Li-ion battery and rating for the battery pack is 5V with 2000 AH capacity. The modelling of battery pack in this project is shown on Figure 8.

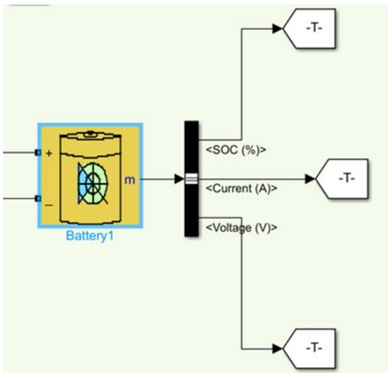

Fig. 8 - Model of battery pack

3. Results and Discussion

In order to study the viability of this small-scale hydropower system, an open circuit test has been conducted and the output of DC generator obtain from the test are as shown in Table 4. Then, the output result is used on DC generator's input value drawn in MATLAB simulation as shown in Figure 9. Thus, the overall circuit test simulation result is acquired in terms of battery pack with load output values. The generated voltage in DC generator is 10V average and the load's output voltage is 5V for both battery pack and load respectively. The performance of power generation in this system is approximately 0.45W.

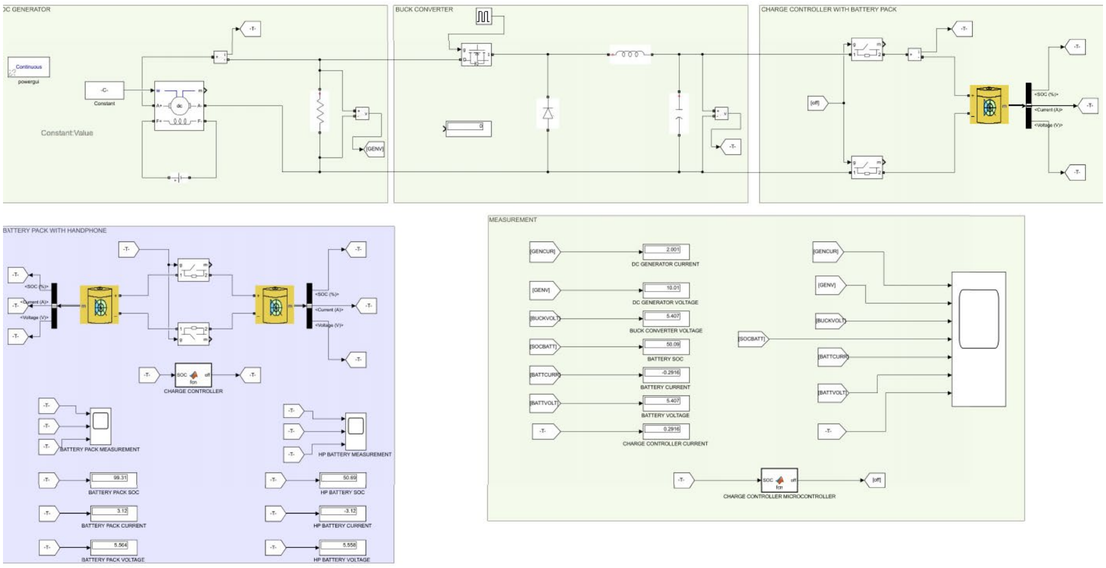

Fig. 9 - Overall circuit test simulation

Table 4 - Output of DC generator

Parameters	Value
speed constant	133.4
Average generated voltage (V)	10
Average generated current (A)	0.045
Generated power (W)	0.45

By the daily water usage for a household data taken, the generated power in a week can be measured roughly as shown in both Figure 10 and Table 5. Table 5 shows the period of water usage also took place in power generation as well. The velocity of water measured, $0.266m^3/h$ is applied to determine the period of water used in hour. Then, the generated power per day can be measured by product of generated power, 0.45W and the period of water used subsequently. Therefore, the amount of power generation in undertaking is 9.64Wh weekly and 38.56Wh monthly.

Hence, the voltage generated, and water pressure relationship is plotted in a graph as shown in figure 11. The relationship for both voltage and pressure are linearly proportional.

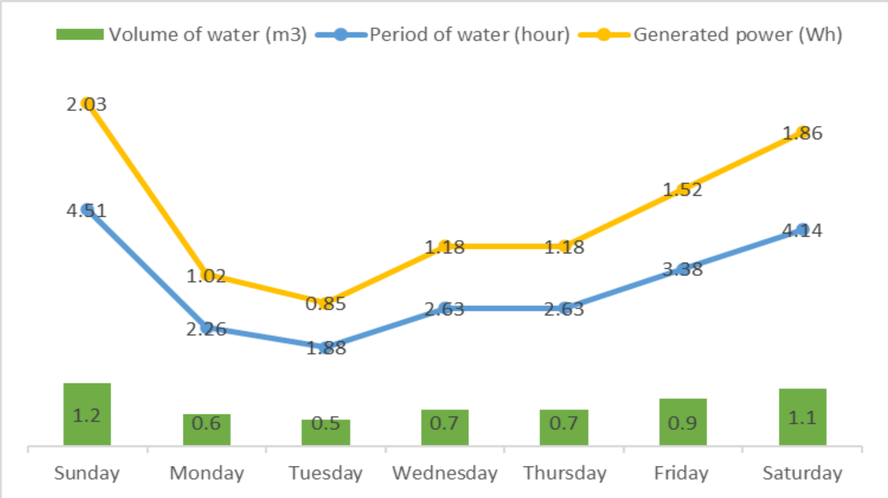

Fig. 10 - Daily water usage and generated power

Table 5 - Data of daily water usage and generated power

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Volume of water (m3)	1.2	0.6	0.5	0.7	0.7	0.9	1.1
Generated power (Wh)	2.03	1.02	0.85	1.18	1.18	1.52	1.86
Period of water (hour)	4.51	2.26	1.88	2.63	2.63	3.38	4.14

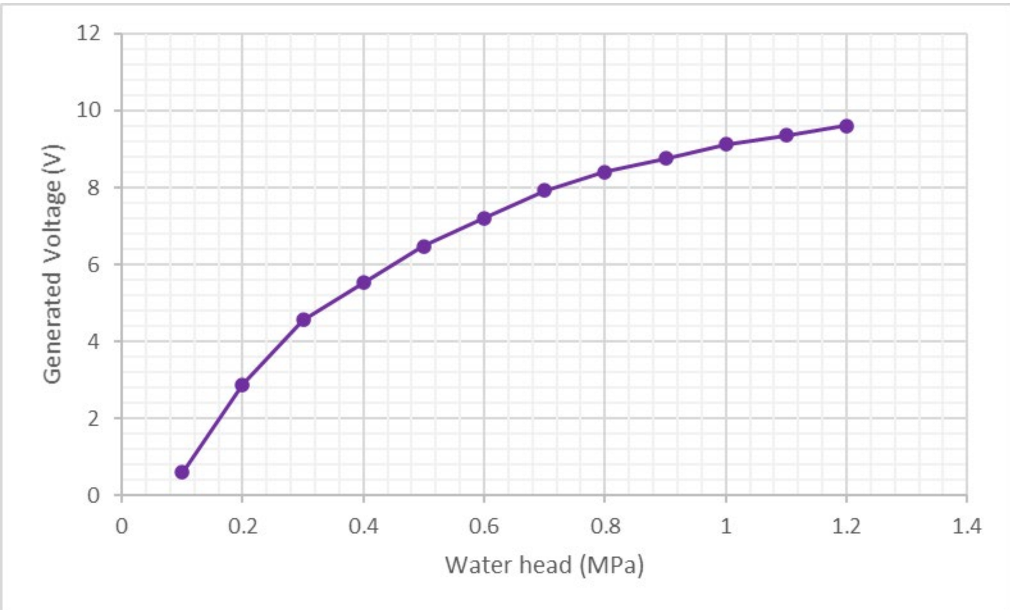

Fig. 11 - Graph of voltage generated vs pressure

4. Conclusion

In this paper, a simple small-scale hydropower system for small load application is developed under MATLAB software is proposed. This system shows it can be used to analyse the performance of real hydropower system in a simulation software. The main parts that need to be determined in this project simulation which are the DC generator. The power generated from this system is quite small, thus in real scenario it is likely to be able to charge handphone or to supply power for small lawn light. After the development of the project through MATLAB is complete several tests have been conducted in order to obtain the output voltage and power of the system.

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