Evolution in Electrical and Electronic Engineering Vol. 3 No. 2 (2022) 968-978
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Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Wind and Wave Hybrid Renewable Energy System

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DOI: https://doi.org/10.30880/eeee.2022.03.02.114
Received 28 June 2022; Accepted 02 October 2022; Available online 30 October 2022

Abstract: The aim of this study is to generate electricity using hybrid renewable energy, which is wind energy and wave energy, to design and build a smaller-scale hybrid wind turbine and wave energy converter to generate electricity using sea breeze and wave and to measure the efficiency of the proposed tool in harvesting renewable energy. The data that has been obtained from this project is the measured output voltage from the wing turbine and wave paddle, as well as the measurement of total output voltage after combining both voltages in series. The data were obtained over the period of 3 days at Air Papan Beach, Mersing. The highest recorded wind turbine output voltage is 9.3V at a forecasted wind speed of 13 km/h. The range of output voltage from wave energy is 0–4.4V. The range of total output voltage is 0 – 6V because of the voltage regulator LM7806 in the power circuit that regulates 6V DC voltage for the convenience of a rechargeable battery. In conclusion, we can produce power using renewable energy sources like wind and waves from the ocean. Gathering both renewable sources of energy under one platform, would not only be more cost-effective but would also reduce the strain on the building's infrastructure and workload. The constructed system's efficiency can be seen in the project's output because, by connecting the voltages in series, the system creates a load voltage equal to the total of both output voltages. This demonstrates an improvement in the efficiency of the produced output voltage. The loss of voltage or fluctuation caused by neither of the prime movers when there is no wind or wave can also be counterbalanced or smoothed by the capacitor.

Keywords: Renewable Energy, Wind Energy, Wave Energy, Output Voltage

1. Introduction

Electricity powers an essential part of our daily lives, such as communication, industry, home appliances, etc. Global power use increased steadily in past decades proportional to the increase in world population, to meet the demand of our industry and economic growth as well as social and welfare requires abundant energy in the future. There are two types of energy: renewable and non-renewable. Non-renewable energy includes coal, natural gas, and petroleum. They are made by burning fossil fuels

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to create energy. Renewable energy includes solar, hydro, wind, and wave energy [1]. Utilizing a renewable energy source to help tackle climate change is an excellent approach that needs to be sustainable and meet future generations' energy demands.

This project aims to harvest and combine two different types of renewable energy, which are wind energy and wave energy. The device functions by using wind turbines with DC generators to generate electricity from wind power velocity and a wave paddle with a DC generator fixed at the end to convert the kinetic energy from the forward and backward movement of the waves to electrical energy. Power from the wind and waves can balance one another, and wave energy can help smooth power fluctuations during periods of less wind and vice versa [2]. The ideal location for this project is clearly the seashore or beach. This is because the seashore has higher and more consistent wind speeds thanks to the sea and land breeze, as well as the waves pace and the rate at the highest peak [3].

This project is expected to have high efficiency in renewable energy harvesting thanks to its hybrid renewable energy technology, as well as lower the building cost and structural loading since wind and wave energy are generated on a single platform [3]-[4].

2. Materials and Methods

A wind and wave hybrid renewable energy system consists of a wind turbine and a wave paddle as the prime mover, connected to a DC generator as its power generator. Other components in the power circuit include a bridge rectifier, capacitor, diode 1N4007, and 7806 voltage regulators, which serve as the main voltage control unit for input and output voltage. The secondary control unit is a solar charge controller, which is used to charge and discharge the output voltage from the circuit to a rechargeable battery and load. The rechargeable battery is used to store the electric current from the generators by charge and discharge for future use. An analog voltmeter is connected to the power circuit to measure the rectified and smoothed output voltage from the generators. Figure 1 shows the power circuit for this project.

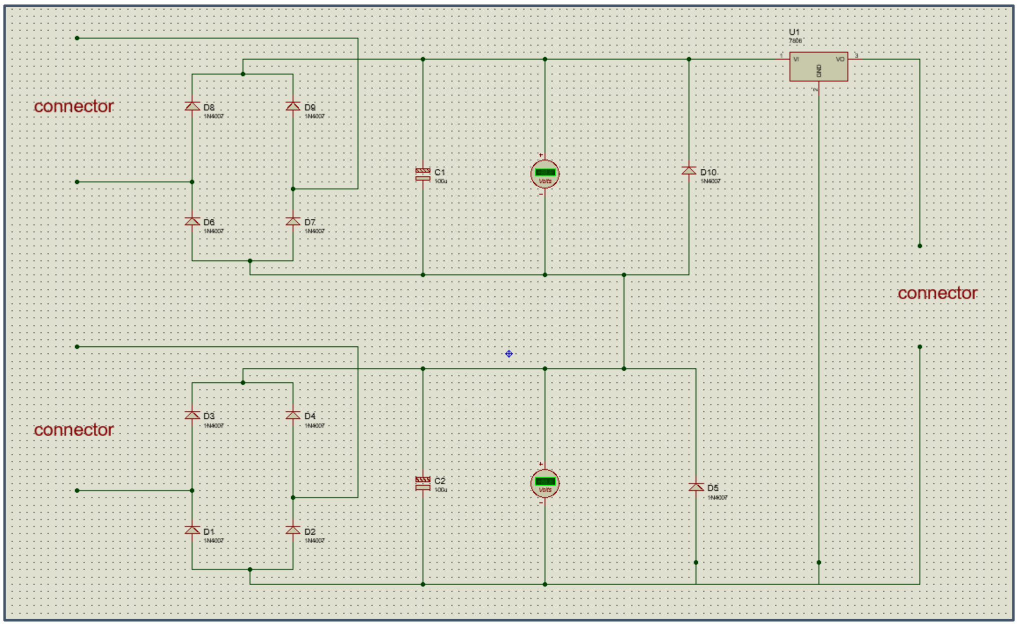

Figure 1: Power circuit schematic diagram

2.1 Mechanical design

The overall design is inspired by hybrid wind-wave energy systems that are already on the market, referring to Figure 2, with simple modifications, such as being smaller in size, having more turbine blades, curved and thinner wave paddle because it is more suitable for harvesting low wind speeds and wave heights in Malaysia compared to European countries, which is ideal for wind-wave energy harvesting. The project is also designed as a seashore harvesting system rather than the traditional deep-offshore floating platform that is currently being developed by corporate energy companies. The material used for the prototype wind turbine and wave paddle in this project is low cost and affordable compared to the in-market wind-wave hybrid mechanism, which is a very high cost on account of revolutionary wave energy harvesting, deep-offshore platform building and maintenance. Despite the differences between both systems, there are also similarities in more ways than one, which is being able to produce green energy and innovate new possibilities for hybrid renewable energy, which can be considered the main aim of this project.

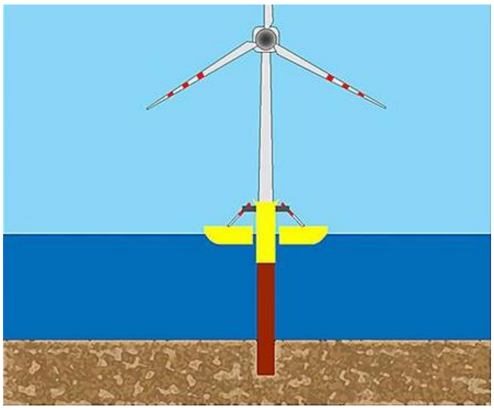

Figure 2: Inspiration for the design

2.1.1 Wind turbine design

A wind turbine is a mechanism that captures wind flow to move a propeller-like blade. By doing so, the turbine converts kinetic energy into electrical energy with the help of a generator. The wind turbine in this project as shown in Figure 3, is designed to be suitable for the average wing speed in Malaysia, which is 7 km/h. Five blades have been used in order to capture more wind velocity despite being smaller in size. The tip of the turbine blade is curved on one side to become pointed, and the edges of the blade have been sharpened to allow the turbine to rotate more aerodynamically. The root of the blade also curves outward to capture more wind velocity. The blades are attached to a hub with five arms, one for each blade. The hub is then directly connected to the DC generator. The DC generator will be placed at the back of the hub, which is also known as the nallece. The turbine blades are made with PVC material because of their lightweight, durability, and strong properties, which are suitable for the prototype of the device built in this project rather than the traditional fiberglass-reinforced polyester. The tail vane function that is used to angle the turbine to rotate in the direction of the wind is unused in this project since the tower height is relatively low and could harm the operator if the function is still applied.

Figure 3: Wind turbine design and assembly

2.1.2 Wave energy converter design

Wave energy converters are a common term for a mechanism that is used to harvest kinetic energy from the movement of waves into electrical energy. There is a plethora of innovative methods for wave power conversion that have been invented in the last three decades, and more are being created each year in the hope of perfecting their creation into an efficient and leading-edge wave energy converter to harvest the unlimited amount of wave energy from the motion of waves. The type of WEC that is used in this project as shown in Figure 4, is an oscillating wave surge converter, which extracts wave energy through the force of the horizontal movement of nearshore waves rather than the common vertical movement of waves. Contrary to the traditional massive wave surge converter's wave paddles that are fixed to the seafloor, the smaller wave paddle used in this project is suspended from the upper part of the body. The nearshore waves push the wave paddle of the wave surge converter backward, causing the wave paddle to make half a rotation along with the connected DC generator. Then the retractable spring will pull the wave paddle forward, causing the DC generator to make half of the rotation once more and generate negative voltage. Although the reverse direction rotation of the generator will generate a negative voltage, the bridge rectifier in the power circuit will rectify the negative voltage to a positive voltage in order to not waste the converted energy.

Figure 4: Wave surge converter design and assembly

2.2 Efficiency

Every device loses some energy, sometimes in the form of heat or friction from moving parts. Efficiency measures the amount of energy that is converted into useful energy and how much energy has been wasted. The efficiency of the developed system is calculated using Eq 1.

$$Efficiency = total\ energy\ out \div total\ energy\ in \qquad \text{(Eq1)}$$

Following the formula above, the efficiency of the developed system is calculated by considering the average of the combined output voltage from wind and wave as total energy in and the average of the total output voltage as total energy out. Over a three-day period, the average combined output voltage from wind and wave is 8.17V. Over a three-day period, the average total output voltage as total energy out is 4.83V. Using the formula above, the efficiency of the developed system is 0.59, or 59%.

3. Results and Discussion

The results of project development are divided into two parts as follows: (i) the hardware, and (ii) the electronic circuit of the device.

3.1 Hardware

In the first part, as shown in Figure 5, the frame for the device is custom-made to fit the wind turbine, wave paddle, and DC generator, along with the power circuit, solar charge controller, voltmeter, and battery that are merged inside a junction box.

Figure 5: The complete project

The frame of the device is made of iron, including the wave paddle, the turbine hub, and the tower. The wind turbine blades are made with PVC because of their lightweight and durable properties. The wind turbine blade and tower are detachable from the whole-body frame for transport convenience. Most of the device's iron parts have been coated with metallic paint to prevent rusting or oxidation caused by sea breeze and saltwater. The design specification can be referred to in Table 1.

Table 1: Hardware and design specification

Design	Specification
Weight	30 kg
Body dimension (LxWxH)	45 cm x 45cm x 80cm
Tower dimension (LxWxH)	20cm x 136cm x 170cm
Overall dimension (Body + Tower)	65cm x 45cm x 230cm
Blade radius	70cm
Material	Iron and PVC

3.2 Electronic circuit

In the second part, the power circuit of the device is developed as shown in Figure 6. The device has a power circuit that converts negative voltage from the reverse rotation to a positive voltage, then smoothens the voltage ripple, combining two different voltages, and finally regulating the output voltage to 6V in order to be able to charge the rechargeable battery.

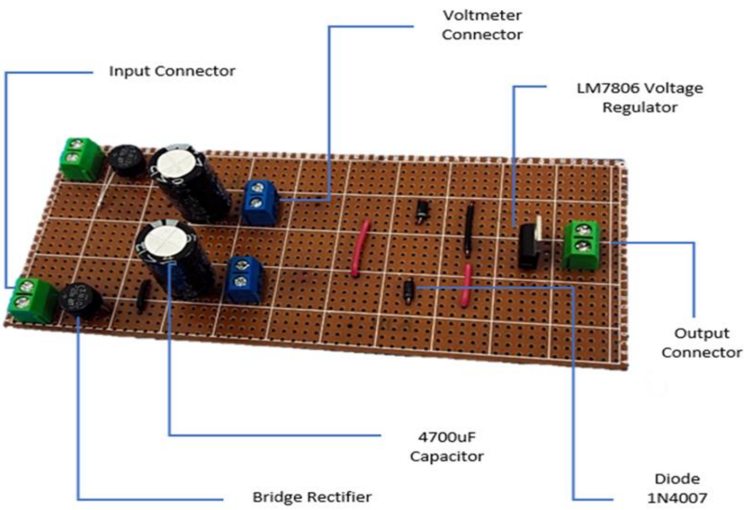

Figure 6: The power circuit

The power circuit is used to control, direct, and alternate the current and voltage from the generator to the load. The power circuit that is used in this project consists of two bridge rectifiers, two 4700uF capacitors, two diodes 1N4007, and a voltage regulator LM7806. The voltage from each generator first passes through the bridge rectifier to eliminate negative voltage that is produced due to the opposite rotation of the generators, and then converts that negative voltage to positive voltage as well. Then the positive voltage is passed through a 4700uF capacitor to ensure a stable and smooth voltage output, which otherwise could have voltage ripple or unstable voltage input. The regulated and smooth power supply from both generators is combined in series with diode 1N4007, also known as a reverse biased diode, across each power supply to avoid either power supply being exposed to the reverse voltage of another when that power supply is not active while another does and vice versa. Finally, the combined voltage will flow through the voltage regulator LM7806 to limit the output voltage to the battery and load to 6V. The circuit is built on a breadboard along with connectors to insert wires of input voltage, output voltage, and voltmeters.

3.3 Output voltage of wind turbine

From Figures 8, 10, and 12, we can see the data for the output voltage of the wind turbine. We are able to know that the fluctuation of wind speed directly affects the output voltage of the wind turbine. Based on the wind velocity of days 1-3 fluctuating, referring to Figures 7, 9, and 11, the voltage output from wind turbines for respective days fluctuates accordingly as well. As per research, the minimum wind speed at Air Papan Beach, Mersing, is 5 km/h, while the maximum is 14 km/h. The wind speed gradually rises in the afternoon and reaches its peak of the highest wind speed of the day. The wind velocity then starts to drop in the evening. The measurement for output voltage is taken around that period of time.

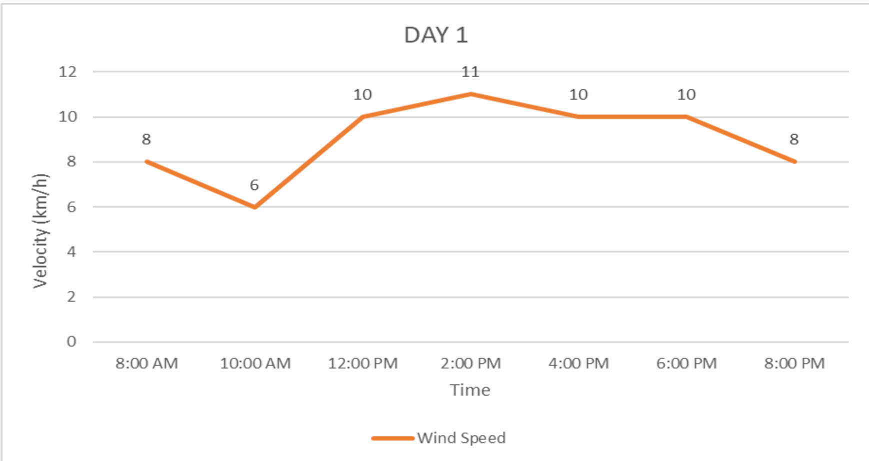

Figure 7: Day 1 wind speed forecast

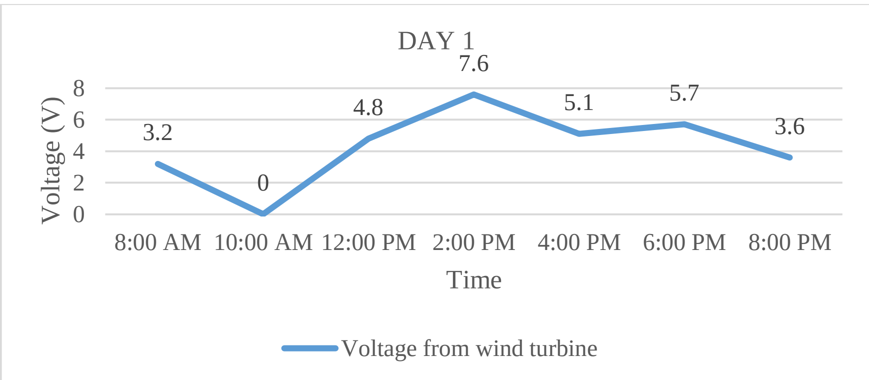

Figure 8: Day 1 output voltage from wind turbine

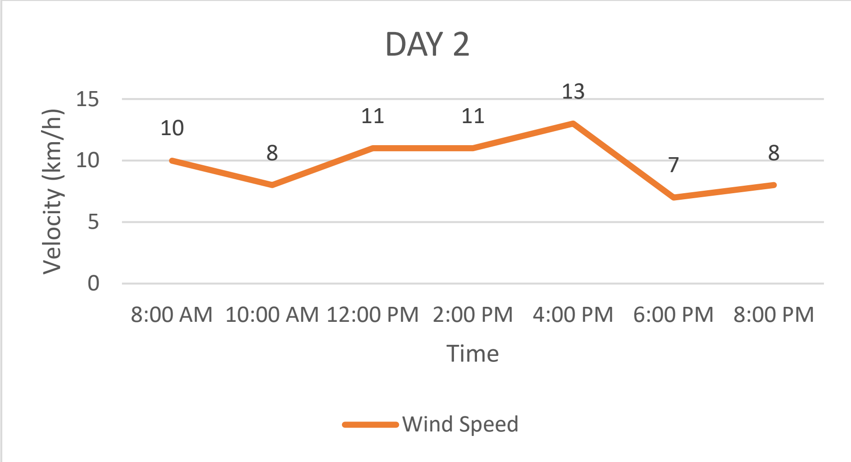

Figure 9: Day 2 wind speed forecast

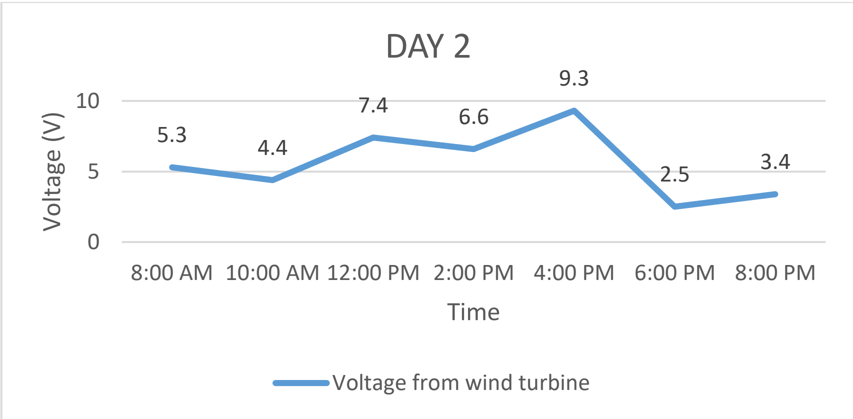

Figure 10: Day 2 output voltage from wind turbine

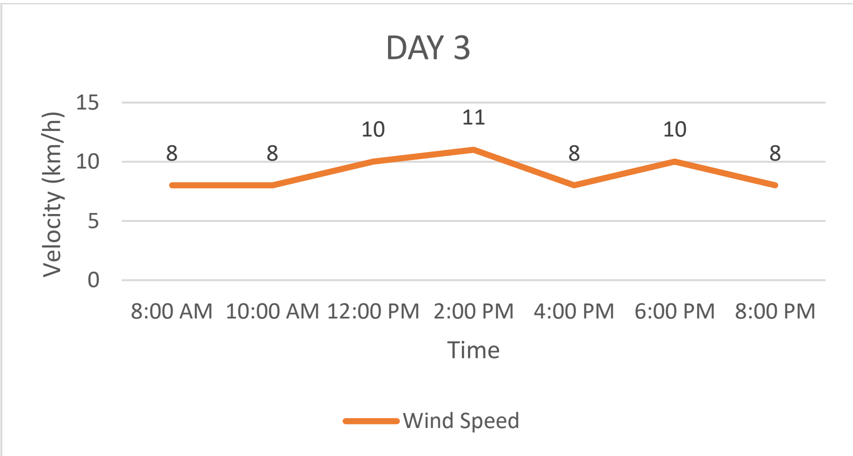

Figure 11: Day 3 wind speed forecast

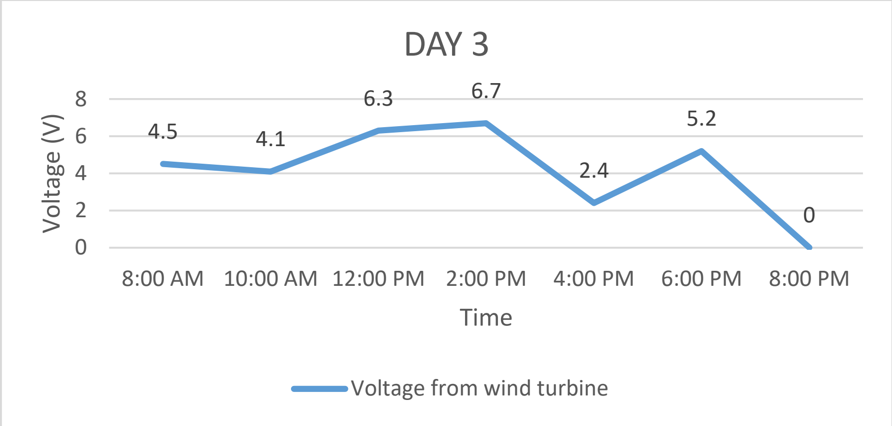

Figure 12: Day 3 output voltage from wind turbine

3.4 Output voltage of wave surge converter

From this data of the output voltage of the wind turbine, we are able to know that the wind velocity indirectly affects the wave velocity, even slightly. Higher wind speeds create more frequent and higher velocity waves, which in response generate more voltage. Referring to Figures 13 to 15, it is determined that wave energy is able to produce a constant and stable voltage throughout the day, although it varies according to the surrounding conditions such as wind velocity and atmospheric humidity.

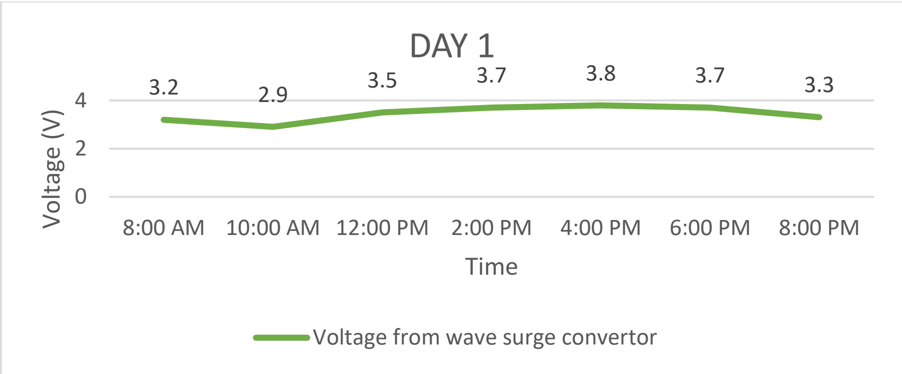

Figure 13: Day 1 output voltage from wave surge converter

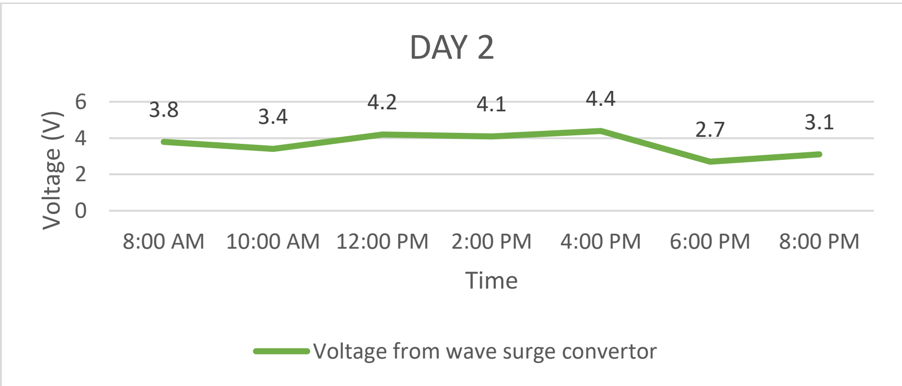

Figure 14: Day 2 output voltage from wave surge converter

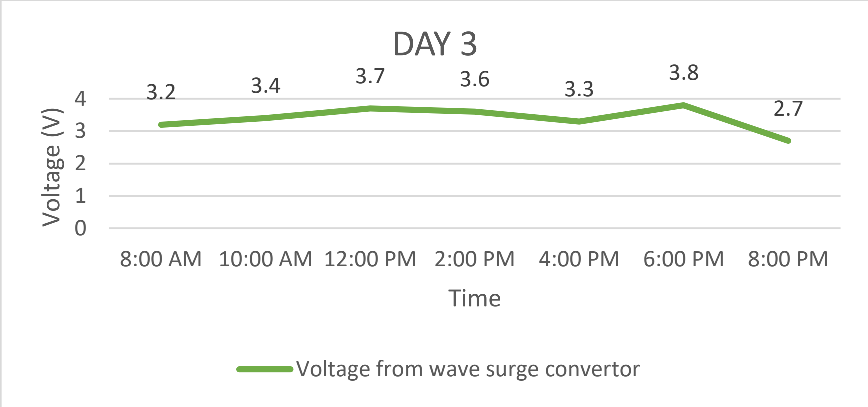

Figure 15: Day 3 output voltage from wave surge converter

3.5 Total output voltage of wind and wave hybrid

From this data of the total output voltage from both the wind turbine and wave surge converter, we are able to compare the output of both prime movers side by side along with the final total output. The loss of voltage or fluctuation from either one of the prime movers during a lack of wind or wave can also be counterbalanced by another or smoothened by the capacitor. Referring to Figures 16 to 18, the total output voltage from the prototype is limited to 6V in order to avoid overcharging the 6V rechargeable battery since the combined voltage of both generators in series, depends on natural wind and waves could rise rapidly and be highly unpredictable.

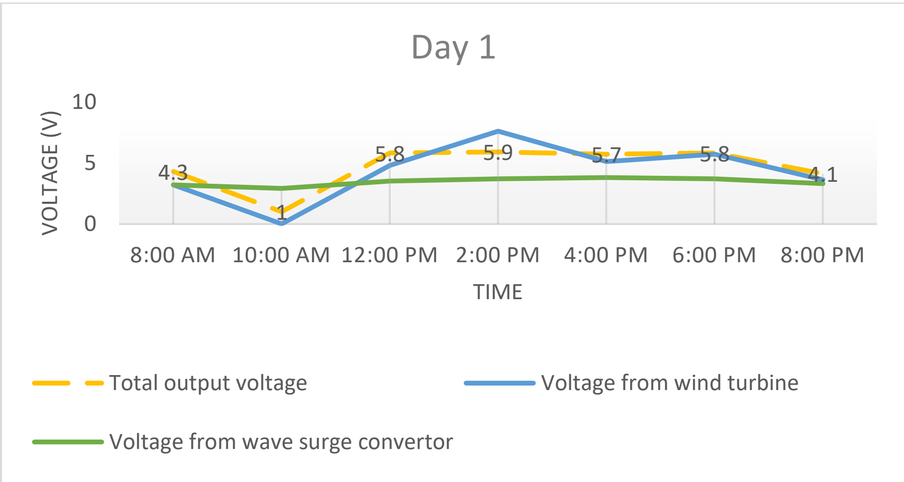

Figure 16: Day 1 total output voltage comparison

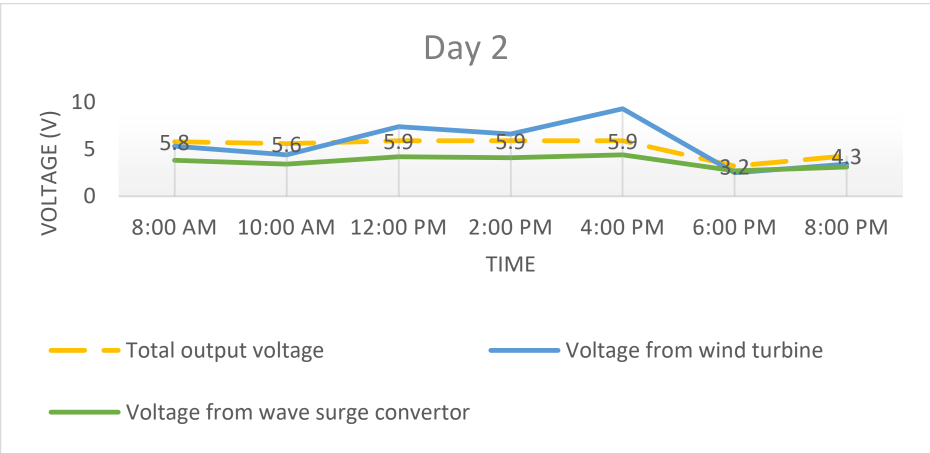

Figure 17: Day 2 total output voltage comparison

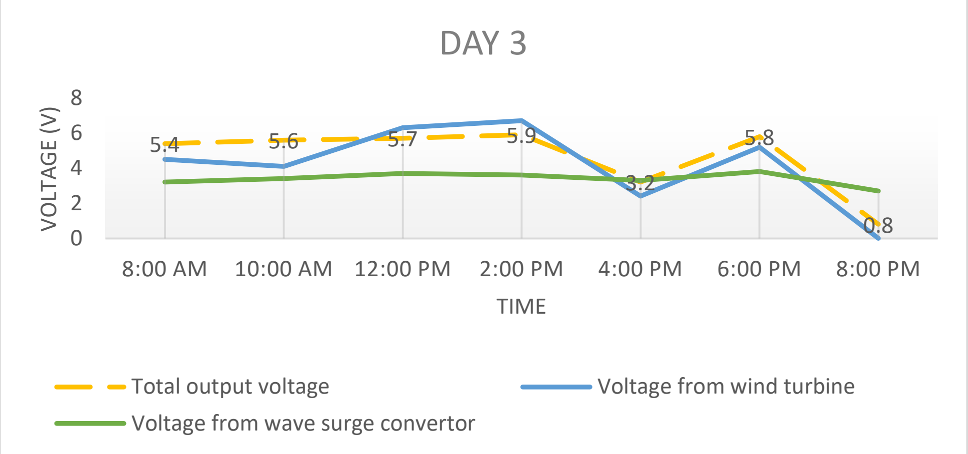

Figure 18: Day 3 total output voltage comparison

3.6 Discussion Summary

The efficiency of the proposed tool in harvesting renewable energy is achieved by measuring the output voltage of each prime mover using an independent voltmeter. The efficiency of the developed system can be noted in the output of the project since combining the voltages in series, the system generates a load voltage that is equal to the sum of both output voltages. This shows the increase in efficiency of the produced output voltage. The obtained data and measurements from the prototype of the device are used to compare the forecast wind speed with the output voltage from the wind turbine and wave paddle as well as the total output voltage. The data that has been obtained from this project is the daily measured output voltage from the wing turbine and wave paddle, as well as the measurement of total output voltage after combining both voltages in series. From these measurements, we are able to know the efficiency of the harvested energy by the device. The data were obtained over the period of 3 days at Air Papan Beach, Mersing. The measurement is taken once every two hours for 12 hours from 8 am to 8 pm as shown in Figure 19.

Figure 19: Testing the project

4. Conclusion

In conclusion, we can generate electricity using renewable energy sources such as sea waves and breezes. If two different renewable energies are available in the same location, why don't we harvest both green energies under one platform, which not only provides an efficient way but also lowers the cost, structure load, and workload. Wave energy is captured directly from surface waves, whereas wind energy is captured from the sea breeze, which would be optimal. Smaller scale devices also have their advantages, such as lower cost and ease of replacement if damaged. A DC generator is used as a power-generating device since it produces a steadier DC voltage. A DC generator uses a rotating motion to generate electrical current, which is ideal for wind turbines and wave surge converters. The excessive generated electricity can be stored in a rechargeable battery for later usage. This device's application is undoubtfully efficient in the seashore. Apart from that, the objective and aim of this project have been achieved. The main objective of this project is to generate electricity using hybrid renewable energy using wave energy and wind energy is achieved by harvesting and combining the mentioned natural energies under a single platform. The next objective is to design and build a smaller-scale hybrid wind turbine and wave energy converter is achieved by building the prototype device with slightly modified features such as a smaller five-blade wind turbine and a suspended wave paddle. The last objective is to measure the efficiency of the proposed tool in harvesting renewable energy is achieved by adding voltmeters into the power circuit to measure the output voltage of each DC generator. This project enhanced my knowledge of electronic construction, circuit designing, and also component connection. During hardware development, the information on circuit designing, components selections and measurement reading have been improved. Theory related to the subject studied can be applied in this project. Plenty of new skills were learned in developing this project.

Acknowledgement

The authors would also like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

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