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Development of HRES with Monitoring System

Muhammad Fitri Najmi Mohd Farid[1], Azuwien Aida Bohari[1]*

[1] *Faculty of Engineering Technology,*
Universiti Tun Hussein Onn Malaysia, 86400 Pagoh, Johor, Malaysia.

*Corresponding Author: azuwien@uthm.edu.my
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Abstract

Development of Hybrid Renewable Energy System (HRES) with integrated system monitoring capabilities to address the growing need for sustainable and efficient energy solutions. This innovative system harnesses solar, hydro, and wind energy by developing a small-scale prototype that leverages the strengths of each energy source. The methodology involves the design and implementation of a compact, multi-source energy generation unit, utilizing photovoltaic panels to capture solar energy, a micro-hydro generator to harness hydro energy, and wind turbines to exploit wind energy. Detailed design considerations were made to ensure optimal energy conversion and storage. The developed prototype is equipped with IoT features for real-time data monitoring, allowing for continuous performance tracking and system diagnostics. This real-time monitoring capability not only ensures the system's operational efficiency but also provides valuable data for future improvements and scalability. The prototype shows a practical solution for small-scale power generation, emphasizing the importance of integrating multiple renewable energy sources with advanced monitoring technologies to achieve sustainable and efficient energy systems.

1. Introduction

Renewable energy sources are now necessary to address the issues of environmental sustainability, energy security, and climate change. These energy sources produce clean and sustainable energy by utilizing replenishing natural resources like sunlight, wind, water, geothermal heat, and biomass. However, the unpredictable and inconsistent nature of renewable energy poses certain inherent difficulties that may compromise the stability and dependability of the grid [1]. The idea of hybrid renewable energy systems has gained popularity as a solution to this problem.

Hybrid renewable energy systems (HRES) merge several renewable energy sources into a single integrated system, providing an innovative solution to the erratic and unpredictable nature of individual renewable energy sources. Utilizing the complementing qualities of various renewable energy sources, HRES improves power generating efficiency, stability, and dependability. For instance, wind energy may be more prevalent at night or during times of low solar irradiation, whereas solar energy production peaks during the day. Similarly, hydroelectric power may supplement the variable output of solar and wind energy by offering a dependable baseload component [2].

A HRES can create electricity using a variety of combinations, such as photovoltaic-wind-diesel, hydro-wind-photovoltaic, biomass-wind-photovoltaic, wind-photovoltaic, and photovoltaic-wind-hydrogen/fuel cell systems. HRES has various advantages over single-source solutions, including enhanced reliability, less demand for energy storage, and more efficiency. However, a HRES may be large or insufficient constructed, resulting in increased installation costs [3]. As a result, completing detailed technical and financial assessments is critical when building and implementing a HRES to successfully use renewable energy sources. Because HRES are complicated, they need to be carefully considered.

The need for sustainable and renewable energy solutions is greater than ever due to the world's growing energy consumption. Nevertheless, there is still a long way to go until renewable energy is widely adopted. Installing renewable energy systems comes with difficulties in both rural and urban regions, mostly because there aren't enough reasonably priced, flexible, and well-monitored hardware options. This has left an empty space that has to be filled to encourage the use of renewable energy sources in a variety of conditions.

The lack of hardware alternatives that are now available for small-scale hybrid renewable energy systems that are economical, simple, adaptable, and efficiently monitored is the primary reason why renewable energy solutions are not widely implemented in both rural and urban areas [4]. Lack of monitoring infrastructure and a lack of compact, integrated hardware solutions for small-scale hybrid renewable energy systems and difficult to deploy sustainable energy solutions in remote or off-grid areas. This leads to inefficiencies, higher upfront costs, maintenance issues, and a lack of insight into system performance [5].

The objective of this project is to design a hybrid power generator with real-time system monitoring, to develop an integrated hybrid system that optimally combines wind, hydro and solar energy sources to ensure a reliable and efficient power supply and to verify the performance of the proposed system via experimental setup. This project is to design a hybrid renewable energy system with integrated monitoring capabilities. The system will harness the power of hybrid energy such as solar, hydro and wind to generate electricity and provide real-time monitoring using Internet of Things. Designing compact low-cost hardware (pvc pipe and plywood) and integrated components (solar panels, wind and hydro using DC motor generator and battery pack) in isolated and dark areas, with a steady and dependable power source. The system defines the experiment setup with hardware and software requirements, specifying data collection methods from voltage and current sensor and solar charger controller, also, presenting results in real-time in Thingspeak channel.

2. Literature Review

This section attempts to give a general overview of the process for developing a hybrid renewable energy prototype system integrated with IoT features.

2.1 Review on Renewable Energy

Renewable energy is becoming essential for sustainable development and climate change prevention. This reviews recent research on renewable energy sources, technology, and energy system integration. The shift from fossil fuels to renewable energy sources, including solar, wind, hydro, and geothermal, is crucial not only for reducing greenhouse gas emissions but also for offering sustainable energy security and economic stability. Even though there are efforts to support renewable energy, 73.5% of the world's electricity came from fossil fuels in 2017, while only 26.5% came from renewables. Lack of public acceptability and knowledge is a major obstacle to the use of renewable energy [6].

Renewable energy technologies, including wind, solar, and geothermal, are currently undergoing various phases of investigation, advancement, and commercial implementation. These technologies differ in terms of the cost, industrial foundation, availability of resources, and possible influence on greenhouse gas emissions. Wind and solar energy sources, which are renewable, have the characteristic of being intermittent. To maintain a consistent energy supply, substantial energy storage systems are necessary. Problems with renewable energy integration into power systems can be solved with technological advancements and a solution structure that evaluates energy sources according to their cost-effectiveness [7].

2.2 Review on Solar Energy

Solar energy, harnessed from the Sun's radiation, is an environmentally friendly, plentiful, and sustainable energy resource. This can be utilized for several uses, such as energy generation, heating, and fuel manufacturing. Although solar energy technologies have great potential, there are obstacles and possibilities for enhancing their efficiency, cost-effectiveness, and scalability.

Solar energy has a lot of advantages and solar energy is a clean energy source that doesn't release any greenhouse gases when operated, which helps slow down climate change [8]. Additionally, Solar power has many benefits, including a decrease in reliance on fossil fuels, an increase in energy security, and the ability to bring power to rural places without grid access [9]. The solar business has created a lot of jobs in many areas, from research and development to manufacturing and installation [10]. Solar PV power systems provide several benefits over time, but also confront obstacles such as intermittency, initial expenses, and storage. Balancing these strengths and weaknesses is critical for maximizing the benefits of solar energy while efficiently resolving their limits as solar panels do not produce energy at night, necessitating energy storage or alternative power sources during dark hours [17]. A hybrid system allows to generate electricity using solar panels while being connected to the grid. This means the system utilizes solar electricity during the day and switch to grid power at night or during periods of insufficient sunlight.

2.3 Review on Hydro turbine

Hydro turbines are equipment that turn water's kinetic and potential energy into mechanical energy, which is ultimately converted into electrical energy. Various hydro turbine concepts and designs have been created to maximize efficiency, affordability, and flexibility to changing climatic circumstances.

In field experiments, a new hydrokinetic turbine idea based on oscillating hydrofoils showed potential hydrodynamic efficiencies of up to 40% [11]. Crossflow turbines, which are well-known for their affordability and simplicity of manufacture, can attain 88–90% efficiency by maximizing head-to-kinetic energy conversion and coordinating runner and nozzle designs [12]. A low-cost, highly reliable wind turbine design based on hydro-viscous gearbox has been put out to reduce power fluctuations [13]. By taking conservation principles into account and reducing frictional losses, simple reaction hydro turbines intended for low head applications in remote places can operate at peak efficiency [14].

In Malaysia, several hydropower projects have been undertaken to harness the country's renewable energy potential. One notable project is the Batang Ai hydropower development in Sarawak, which was the first major hydropower project in the region, constructed between 1981 and 1985. Subsequently, the Murum hydropower project, with a capacity of 944MW, was also initiated in Sarawak, contributing to the region's energy infrastructure. Furthermore, the Malaysian government has set ambitious targets to increase the hydropower capacity, particularly in Sarawak, under the Sarawak Corridor of Renewable Energy (SCORE) initiative, with a goal of reaching 7723 MW by 2020. Additionally, the country is focusing on the development of its small hydropower potential, aiming to add 490 MW by 2020 to enhance its renewable energy portfolio [15]. These projects and initiatives demonstrate Malaysia's commitment to leveraging hydropower as a significant component of its renewable energy strategy.

2.4 Review on Wind turbine

In the 1980s, the power electronics utilized in wind turbines consisted of a soft starter. This device was employed to connect a squirrel-cage induction generator (SCIG) with the power grid at the beginning of power production by the wind turbine. Thyristors, which are basic power semiconductor devices, were used in power electronics because they did not require continuous power transmission. In this system, the generator's rotational speed remains constant, causing any changes in wind speed to directly affect fluctuations in mechanical torque and subsequently current fluctuations in the generator. Hence, this approach necessitates a robust electrical grid that can withstand the substantial mechanical strain induced by wind gusts. Furthermore, the wind turbine is unable to achieve its highest level of efficiency throughout a wide range of wind speeds, resulting in a decrease in energy production [16].

To decide whether to incorporate wind energy into the FiT plan, the government is now evaluating Malaysia's onshore wind energy potential. Development of wind energy in this low-energy area is more complicated than what first appears. Numerous earlier wind studies conducted in Malaysia relied on subpar data and very basic or insufficient methodology, which led to wildly incorrect estimations of prospective wind speed. Furthermore, the government's two wind turbine generating demonstration projects have been unsuccessful. Above all, though, the main thing preventing Malaysia's RE development from moving further is the shaky political backing for these initiatives [17]. As this project is a development on HRES, this project focuses on 3 hybrid power input, as the wind turbine is not capable to support the power on supply power, solar has potential to fully support the system.

3. Methodology

The first part is on the introduction to the title project findings while brainstorming the idea before submitted. This includes background of study, problem statement, project aim, objectives and scope of project. Through the title which has been selected, the research and literature review: review literature related previous study for hybrid renewable energy system and monitoring system and their integration to determine the state of technology now and any prospective issues that require consideration.

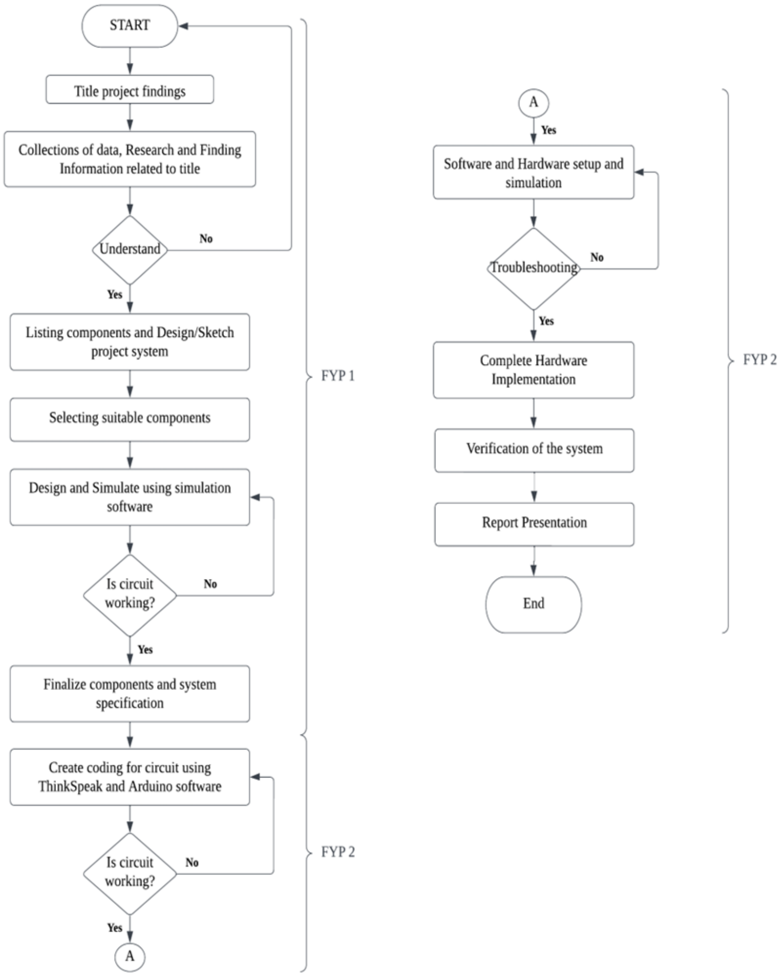

Fig 1 *Project Workflow Diagram*

Following the idea of the research listing components and design or sketch project system from chapter 3 allows more idea of the carrying out studies. For part 2, producing coding for circuits and connecting the hardware and software are the main tasks for the project making. In the end of the overall flow, report presentation is the finalize to end these studies and result for the system.

Figure 2 shows the operating principle of the system. This includes the item for this project involve and the problem possible happen to the system. The system begins by checking the operational status of the solar PV array. If sufficient sunlight is available and the PV system is functional, the Solar Charge Controller (SCC) ensures optimal power extraction. The regulated direct current (DC) output from the SCC charges the battery bank. Simultaneously, relevant system parameters are transmitted to the Internet of Things (IoT) monitoring system for real-time data acquisition. If the PV system is unavailable due to factors such as nighttime or system malfunction, the system checks the hydro generator's availability. If the hydro generator is operational, the hydro generated electricity directly charges the battery bank.

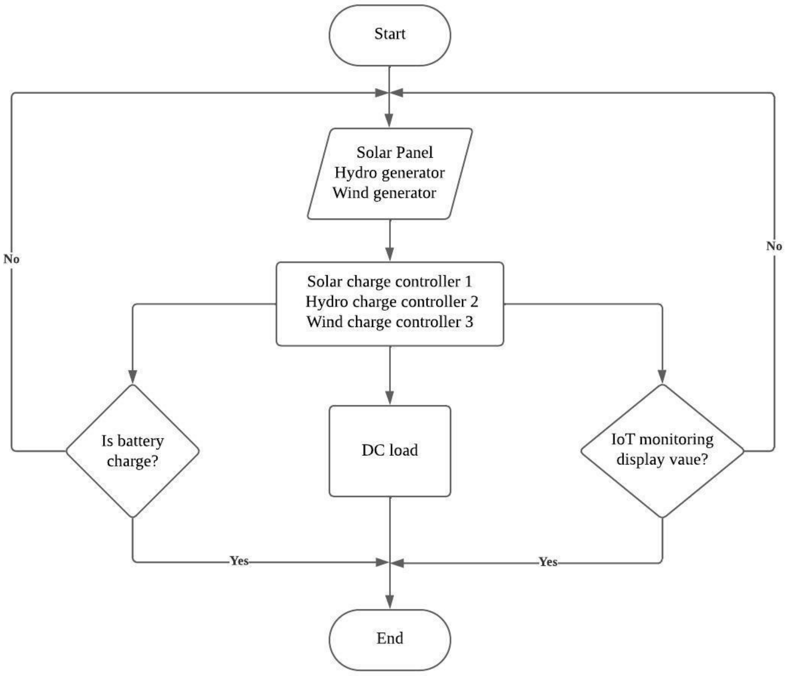

Fig 2 *Flowchart of the whole system*

The IoT monitoring system also receives system data for comprehensive monitoring. If the hydro generator is also unavailable, the system assesses the wind generator's status. If wind speed is sufficient for power generation, the wind turbine's output is converted to DC through the internal control system and used to charge the battery bank. Data is again transmitted to the IoT monitoring system. This standby state could involve battery discharge to meet critical load requirements or system shutdown during extended periods of insufficient renewable energy generation.

Figure 3 shows a detailed wiring diagram of how different parts work together to monitor and control power inputs from solar, wind, and hydro sources. The system uses an ESP32 microcontroller to do this and is connected to an LCD_I2c for data display and multiple voltage and current sensors to measure and manage the power flow to each charge controller. Figure 4 shows the overall design of prototype that concept the combines different types of renewable sources of energy into a single system that collects and uses energy well. A wind generator with blades meets the wind at the very top of the tall pole and turns the generator into power. Following this, the power is sent to the parts of the system that store and control.

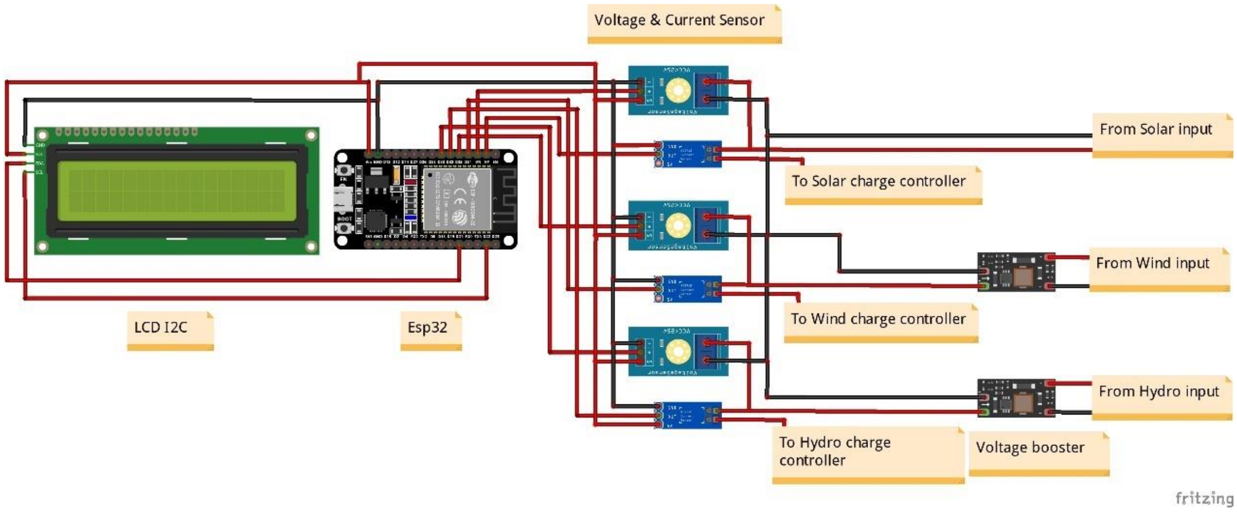

Fig 3 *Structural design of prototype circuit diagram*

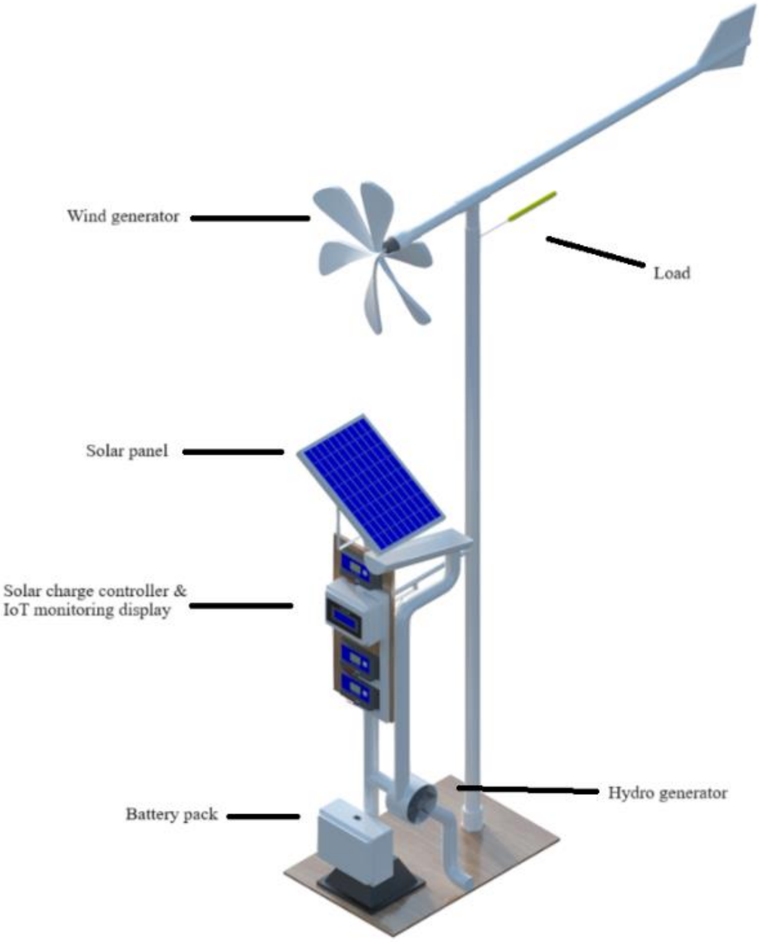

Fig 4 *Structural design of prototype overall structure of HRES*

4. Result and Discussion

This chapter provides a clear explanation of the overall results obtained from prototype testing. Furthermore, this explores a thorough examination of the data and a perceptive examination of the findings, completely demonstrated through visual representations such as figures and tables.

4.1 Performance on solar panel

Table 1 shows the results taken using a multimeter and voltage display on a solar charger controller. The solar panel's specifications highlight the significance of rated voltage, current, and power, which are crucial for understanding its performance under different conditions. The table provides data on irradiance, temperature, open-circuit voltage (Voc), short-circuit current (Isc), calculated power (Voc * Isc), and charge controller voltage at different times of the day.

Table 1 *Result of collected data on solar panel*

Time	Irradiance (G)	Temperature (°C)	Voc(V)	Isc(I)	Calculated Power = Voc*Isc
9:00	555	34.6	6.7	0.45	3.015

9:15	447	40.3	6.7	0.4	2.68
9:30	370	31.5	6.74	0.23	1.55
9:45	580	43.2	6.8	0.4	2.72
10:00	681	43.8	7.01	0.7	4.907
10:15	562	45.3	6.75	0.6	4.05
10:30	296	45.3	6.7	0.36	2.412
11:00	622	42.5	6.7	0.48	3.216
11:15	620	48.1	6.72	0.7	4.704
11:30	806	50.5	6.92	0.65	4.498
11:45	777	49.6	7.02	0.92	6.458
12:00	905	57.5	7	1.32	9.24

Figure 4 shows the graph analysis on irradiance over time. The graph illustrates the relationship between irradiance and time from 9:00 AM to 12:00 PM, crucial for solar energy studies. Initially starting around 600, irradiance dips to 500 by 9:15 AM, peaks at 700 by 10:00 AM, then sharply drops to 400 at 10:30 AM, likely due to passing clouds or shading. Subsequently, irradiance gradually rises, reaching 800 by 11:45 AM and nearly 900 by noon, indicating optimal conditions for solar panel efficiency. These fluctuations highlight the importance of accounting for external factors impacting solar panel performance, such as cloud cover or obstructions. Understanding these patterns is vital for optimizing solar energy systems to harness maximum energy from the sun for sustainable power generation.

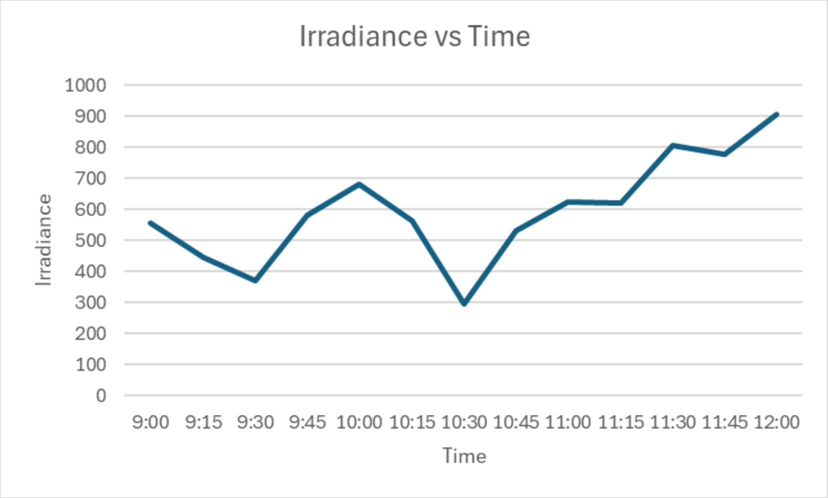

Fig 4 *Irradiance vs Time*

Figure 5 shows the graph analysis on irradiance over time. The graph illustrates temperature variation over time, relevant to solar panel efficiency. Initially, from 9:00 to 9:15, a sharp rise in temperature reflects the morning sun beginning to heat the environment, starting solar energy production. Between 9:15 and 10:00, temperature fluctuations suggest transient cloud cover or varying sunlight angles, affecting solar panel output. From 10:00 to 10:45, a steady temperature indicates consistent solar radiation and stable energy production. After 11:00, temperatures rise noticeably until 12:00, aligning with the sun's peak position, leading to maximum solar radiation but potentially reduced panel efficiency due to higher temperatures. Solar panel performance is influenced by these temperature changes, as higher temperatures generally decrease efficiency.

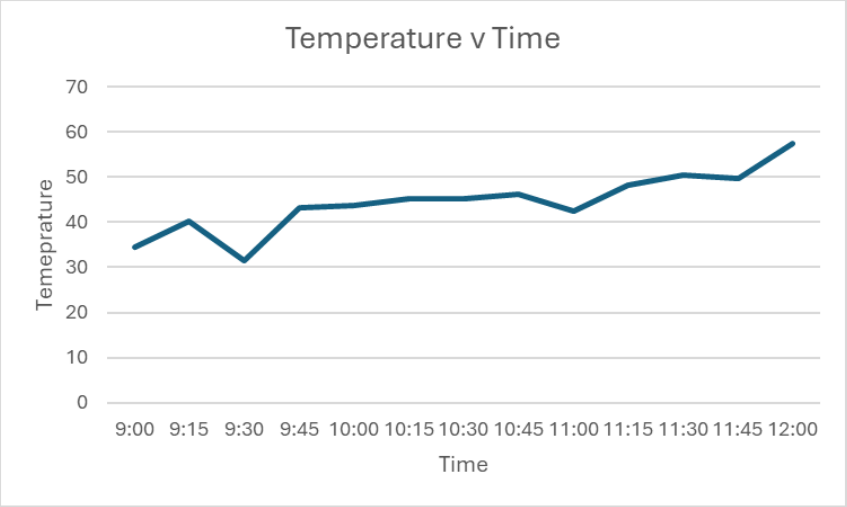

Fig 5 *Temperature of solar panel vs Time*

4.2 Performance on wind turbine

Table 2 shows the results taken for the wind turbine. The wind turbine specification highlights the significance of rated voltage and current, which are crucial for understanding its performance at various wind speeds. The table provides data on wind speed, RPM, voltage before and after the booster, and current. The results demonstrate the wind turbine's ability to convert wind energy into electrical energy. At the lowest wind speed of 1 km/h, the turbine produces no RPM, resulting in zero voltage and current, both before and after the booster. This indicates that the wind speed is insufficient to generate any significant rotational or electrical output.

Table 2 *Result of collected data on wind turbine*

Wind speed(km/h)	rpm	Voltage before booster(V)	Voltage after booster(V)	Current(A)
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	40	0.9	0.9	0.06
5	80	0.93	0.93	0.1
6	277	0.97	0.97	0.15
7	386	1.05	1.05	0.23
8	410	1.26	1.26	0.25
9	455	1.29	1.29	0.27
10	470	1.54	1.54	0.3
11	2232	2.05	6.07	0.36
12	3383	3.7	12.08	0.4

Figure 6 illustrates the relationship between RPM and wind speed for a DC motor, showing an initial low RPM at lower wind speeds due to insufficient torque to overcome the motor's starting friction and inertia. As wind speed increases moderately (between 5 and 10 km/h), RPM rises gradually, reflecting the motor's increasing efficiency in converting wind energy into rotational motion. At higher wind speeds (above 10 km/h), there is a sharp increase in RPM, indicating that the wind provides sufficient torque to drive the motor more efficiently, resulting in a rapid rise in rotational speed. This pattern aligns with DC motor theory, where increased torque leads to higher speeds, demonstrating the motor's improved performance at higher wind inputs.

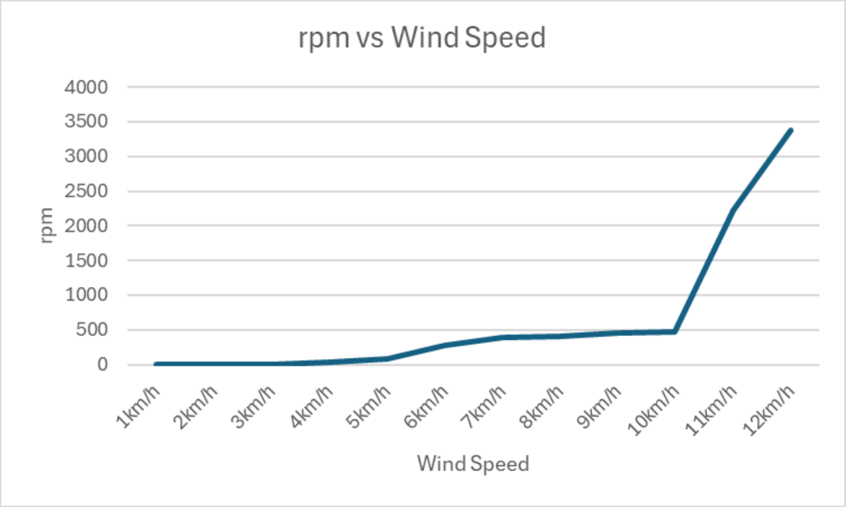

Fig 6 *rpm of generator vs wind speed*

Figure 7 compares the voltage output of a DC motor before and after the application of a voltage booster across different wind speeds. At lower wind speeds (1-3 km/h), both the pre- and post-boosted voltages remain low, indicating minimal energy conversion. As wind speed increases from 4 to 10 km/h, the voltage before the booster shows a gradual rise, reflecting the motor's increasing efficiency in generating electrical energy. The voltage after the booster, however, shows a more significant increase, demonstrating the booster's effectiveness in amplifying the voltage output. At higher wind speeds (above 10 km/h), there is a sharp increase in both pre- and post-boosted voltages, but the post-boosted voltage rises much more dramatically, reaching a peak of around 16V at 12 km/h. This indicates that the booster significantly enhances the voltage output, especially at higher wind speeds, allowing the motor to produce more electrical energy than it would without the booster. This pattern aligns with the expected behavior of voltage boosters, which are designed to amplify the voltage output from the motor, improving its performance under higher energy inputs.

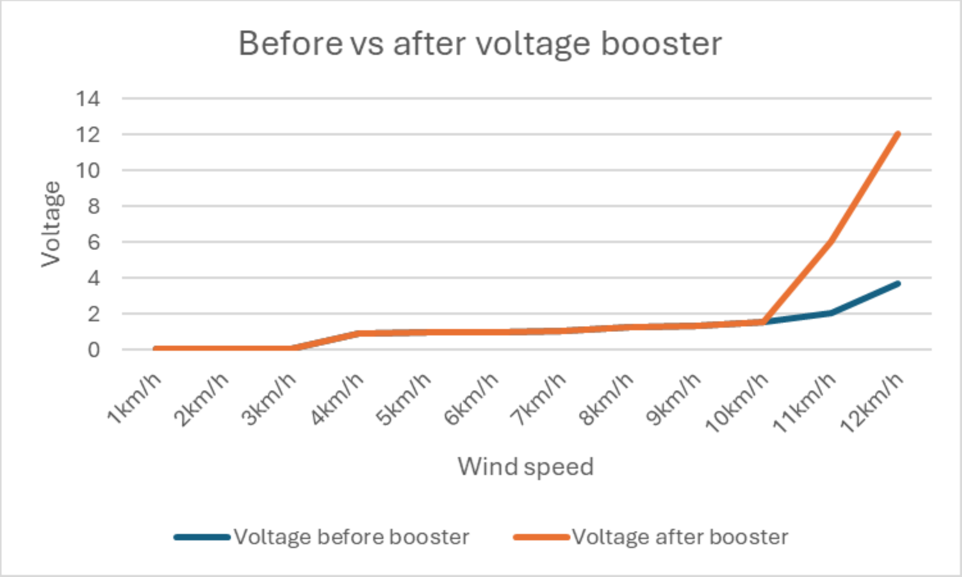

Fig 7 *Before vs after voltage booster*

4.3 Performance on hydro turbine

Table 3 shows the voltage and current outputs for a hydro turbine, with a maximum of 0.42V and 0.01A, indicating very low electrical output.

Table 3 *Result of collected data on hydro turbine*

Output	Voltage	Current
Maximum	0.42	0.01

This limited performance could be due to several factors: insufficient water flow rate, which is essential for driving the turbine; inefficiencies in the turbine's design, such as poorly optimized blades or angles; significant mechanical losses within the system; an electrical load that is too high, causing a drop in output; potential inaccuracies in the measurement equipment; or environmental factors like debris or turbulence affecting the water flow. Each of these factors can contribute to the suboptimal performance of the hydro turbine, suggesting the need for further investigation and potential improvements.

4.4 Performance on hybrid system

Table 4 shows a complete time-series study of electrical characteristics obtained at ten-minute intervals between 1200 and 1500 hours. The parameters are Solar Voltage, Solar Current, Wind Voltage, Wind Current, Hydro Voltage, and Hydro Current.

Table 4 *Result of collected data on hydro turbine*

Time	Solar Voltage	Solar Current	Wind Voltage	Wind Current	Hydro Voltage	Hydro Current
1200	6.78	0.26	0	0	0	0
1210	6.8	0.3	2.6	0.47	0	0
1220	6.9	0.3	0	0	0	0
1230	7.02	0.39	2.4	0.42	0	0
1240	6.8	0.5	1.5	0.12	0	0
1250	6.9	0.52	0	0	0	0
1300	6.88	0.4	2.8	0.49	0	0
1310	7.02	0.3	0	0	0	0
1320	7	0.6	0	0	0	0
1330	6.8	0.4	0.4	0.06	0	0
1340	6.82	1.12	0	0	0	0
1350	6.83	0.8	0	0	0	0
1400	7.02	0.73	0	0	0	0
1410	6.8	0.45	0.5	0.08	0	0
1420	6.9	0.5	0	0	0	0
1430	6.95	0.4	1.6	0.23	0	0
1440	6.97	0.9	0.3	0.01	0	0
1450	6.57	0.33	1.1	0.22	0	0
1600	6.74	0.4	0	0	0	0

Significantly, hydro turbines provide electrical power by transforming the kinetic energy of moving water into mechanical energy. This technique relies on enough rainfall to ensure the required water flow. The hydro turbine is inactive during periods of insufficient or no rainfall, as indicated in the table, which leads to a zero voltage and current output. On the other hand, both solar and wind energy systems demonstrate fluctuating performance throughout time. At 1200 hours, the solar system generated 6.78 volts and 0.26 amps, and at 1310 hours, the solar system produced 7.02 volts and 0.33 amps. The wind energy system exhibited notable operation at 1310 hours, generating an output of 2.4 volts and 0.42 amps. These fluctuations emphasize the irregular characteristics of renewable energy sources and emphasize the significance of ongoing surveillance to maximize energy generation and integration into the power grid.

5. Conclusion

In conclusion, the project for the development of Hybrid Renewable Energy with System Monitoring (HRES) aims to monitor the effectiveness of power generators generated by hybrid renewable energy. The system is integrated between solar, hydro and wind as a power source. In the initial stage of the project, different hardware and software components are carefully selected and optimized for the system's efficient performance and power output. This system utilizes battery management as a store to the input power. In the middle of the system, solar charger controller is used to keep safely charges and maintain batteries at a high state of charge without overcharging. The system also includes a smart monitoring system, which utilizes ESP32 microcontroller connected with Thingspeak channel to present real-time data and 2 different types of sensors which is current and voltage sensor to monitor the output from the solar panel and 2 DC generator. Overall, the prototype for the development of Hybrid Renewable Energy with System Monitoring (HRES) with IoT features achieves the solution for small scale power generation and real-time data monitoring.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Muhammad Fitri Najmi Bin Mohd Farid*[1]*, Azuwien Aida Binti Bohari*[2]**;* ***data collection:*** *Muhammad Fitri Najmi Bin Mohd Farid*[1]*;* ***analysis and interpretation of results:*** *Muhammad Fitri Najmi Bin Mohd Farid*[1]*, Azuwien Aida Binti Bohari*[2]**;* ***draft manuscript preparation:*** *Muhammad Fitri Najmi Bin Mohd Farid*[1]*, Azuwien Aida Binti Bohari*[2]**. All authors reviewed the results and approved the final version of the manuscript.*

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