Experimental Investigation of a Small-scale Hybrid Wind-Solar Renewable Energy Systems

Baizura Bohari
Department of Aeronautic Engineering and Aviation, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia

Raja Ejjy Raja Akhmar
Department of Mechanical Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia

MR Saad
Department of Aeronautic Engineering and Aviation, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia

https://doi.org/10.5109/7323415

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 10, pp.1239-1245, 2024-10-17. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

Experimental Investigation of a Small-scale Hybrid Wind-Solar Renewable Energy Systems

Baizura Bohari[1], Raja Ejjy Raja Akhmar[2], MR Saad[1]
[1]Department of Aeronautic Engineering and Aviation, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, 57000 Sungai Besi, Kuala Lumpur, Malaysia. [2]Department of Mechanical Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, 57000 Sungai Besi, Kuala Lumpur, Malaysia.,
Corresponding author email: baizura@upnm.edu.my

Abstract: *The study aims to identify the right combination of wind and solar conditions for a hybrid wind-solar energy generation system within a selected zone on campus. It analyzes the power generation performance of a small-scale off-grid wind-solar hybrid renewable energy system (HRES) prototype to meet localized energy demands. The HRES consists of a Savonius Vertical Axis Wind Turbine and a solar panel connected to a charge controller that distributes power to a 12V DC battery. The study tests the feasibility of wind and solar power generation at selected locations, with the football field being the best site. The assembled HRES could generate up to 50W of rated power in optimal conditions and a minimum of 5.08W, sufficient to charge multiple mobile devices simultaneously, while overcoming the drawbacks of standalone renewable energy systems.*

Keywords: renewable energy; vertical axis wind turbine; solar power; hybrid energy sources.

1. INTRODUCTION

The global renewable energy sector is experiencing a surge in growth and momentum. In 2023, new renewable energy installations reached record high levels, driven primarily by China's massive investments. China alone installed as much renewable capacity in 2023 as the entire world did in 2022. Across the G20 countries, wind and solar power generation have risen rapidly, with wind power increasing by 10% and solar power increasing by 25% [1]. Looking ahead, fossil fuels and other finite energy alternatives are poised to become outdated, not primarily due to resource depletion but because renewable energy sources are becoming increasingly affordable and accessible [2]. Research by Shafiee & Topal [3] projects that the estimated years until coal exhaustion, based on growth rates in India, China, Russia, and the USA, are approximately 315, 83, 1034, and 305 years, respectively. Energy poverty is strongly associated with economic growth and urbanization. A recent study has examined the dynamic linkages between renewable energy use, economic growth, urbanization, employment, consumer price index, and energy poverty in the region from 2000 to 2020 [2]. Additionally, the study found that increased renewable energy use can help alleviate energy poverty in South Asian countries.

As technology progresses, it is evident that renewable energy sources represent the future of power generation, with ongoing optimization in power generation from these sources. However, certain factors delay the widespread adoption of renewable energy, like solar and wind power, as the primary global energy sources [4]. One critical variable is the geographical positioning of the sun concerning the photovoltaic module and the current wind speed, both heavily influenced by real-time weather conditions. An off-grid solar power system, for example, generates power solely during daylight hours, with fluctuating output due to weather conditions, cloud cover, and variations in peak solar hours [5]. Similarly, a wind power system's output is directly linked to the prevailing wind speed, which fluctuates throughout the day based on factors such as weather conditions and the turbine's altitude.

Due to Malaysia's geographical location, the country generally encounters low wind speeds year-round [6,7]. The average daily wind speed is approximately 2 m/s during the day and 1 m/s at night, as indicated by the same study. However, with two monsoon seasons (Northeast and Southwest) annually, wind speeds in the east coast of Peninsular Malaysia can vary from 7 m/s to 15 m/s [6,7]. Conversely, urban areas in Malaysia experience notably lower average wind speeds compared to mainland regions.

The study by Shivarama Krishna & Sathish Kumar [8] defines a hybrid system as the integration of two or more renewable or non-renewable energy sources. In this context, a hybrid wind-solar power generation system is proposed to leverage the strengths of each source while mitigating their individual limitations [9]. During peak sun hours, when solar radiance is at its highest due to direct sunlight, photovoltaic modules generate significant energy. However, in the early morning, evening, and night, solar energy production decreases substantially, with no energy generation at night due to the absence of sunlight. This limitation results in only about 10 hours of power generation per day. The use of a hybrid renewable energy system aims to address these challenges by combining wind and solar power to ensure a more consistent and reliable energy supply throughout the day [10].

Wind energy generation is primarily facilitated by wind turbines, which harness the kinetic energy of the wind to generate electricity. These turbines consist of blades that rotate either on a horizontal or vertical axis, driven by the drag or lift force exerted by the wind. As the blades rotate, they are connected to a shaft and generator, converting the kinetic energy into electrical energy. This process allows wind turbines to efficiently capture the power of the wind and contribute to the generation of renewable electricity. The primary advantage of a Vertical Axis

Wind Turbine (VAWT) [11] is its smaller scale, facilitating ease of transport for off-grid power generation systems. VAWTs are considered advantageous for urban installations due to their simple installation process and low noise levels, making them environmentally friendly options [12]. This advantage is not present in Horizontal Axis Wind Turbines (HAWTs) [13,14]. However, VAWTs have drawbacks, such as inefficiency during high wind speeds due to their low starting torque. Unlike HAWTs, VAWTs require additional external force, beyond the wind force, to initiate blade rotation. To address this issue, a DC motor can be connected to the turbine shaft to provide the required torque for system activation [14]. The efficiency of a VAWT can be improved by carefully considering the installation location, size, and shape of the turbine blades. Placing the VAWT near areas with rapidly accelerating traffic, such as flyovers, slip roads, and tunnels, can also enhance its performance by taking advantage of the increased wind speeds in these locations [15].

Hence, despite the inherent limitations of individual renewable energy systems, combining them into a hybrid power generation setup could offer advantages by offsetting their respective weaknesses [16]. Both the photovoltaic module and the vertical axis wind turbine would operate simultaneously, feeding power into a shared battery. To prevent issues like overcharging and over-discharging, a battery charge controller (BCC) would be interposed between the wind turbine, photovoltaic module, and the battery. Additionally, to prevent overcharging, a diversion load (dump load) was linked to the BCC. This load, typically a heating element, dissipates excess voltage from the wind-solar hybrid modules when the battery reaches full capacity, safeguarding the battery's longevity [4]. The BCC would also channel direct current to a DC motor connected to the wind turbine shaft, providing the necessary torque for the VAWT. Power electronics circuits, particularly DC-DC converters, are widely used in renewable energy systems due to the low voltage produced by renewable energy sources like photovoltaic (PV) modules. This paper presents a comparative analysis of two commonly used power electronics DC-DC converters - the Boost Converter and the SEPIC Converter [17]. The paper shows that both the Boost and SEPIC converters have been highly enhanced to support various renewable energy sources [17].

The research aims to identify the optimal combination and location for a compact hybrid wind-solar renewable energy system, serving as a foundational step towards establishing sustainable energy production on campus. It will involve a detailed evaluation of the prototype's power output to meet the modest energy requirements for residential, commercial, and emergency purposes. Additionally, the study will advance the development of hybrid renewable energy systems integrating VAWTs and solar panels. Moreover, the system is suitable for generating small-scale energy and can serve as a reliable option for emergency scenarios like power disruptions, thanks to its off-grid power generation setup. It can deliver an output ranging between 40 W and 60 W, sufficient to operate household devices with low power requirements, including battery chargers, small appliances, and mobile phones. The project will enhance the understanding and application of Hybrid Renewable Energy System (HRES) [4,9] in Malaysia, a domain less explored compared to conventional non-renewable energy systems, contributing to the existing knowledge base and theoretical frameworks in this field.

2. DEVELOPMENT OF HYBRID RENEWABLE ENERGY SYSTEM (HRES)

Upon collecting and analyzing the essential data for all four proposed placements of hybrid wind-solar renewable energy generation systems on campus, the next step would be to begin the design and development phase of the hybrid system. All the specified elements were assembled following the schematic diagram illustrated in Fig. 1. Building on the foundational findings of the VAWT system, enhancements were implemented to boost efficiency, voltage output, and the overall integration of both the VAWT and solar energy systems. The wind turbine system (WTS) segment of the hybrid setup utilizes a Savonius VAWT system connected to a DC motor, serving as a generator linked via a shaft to produce DC voltage.

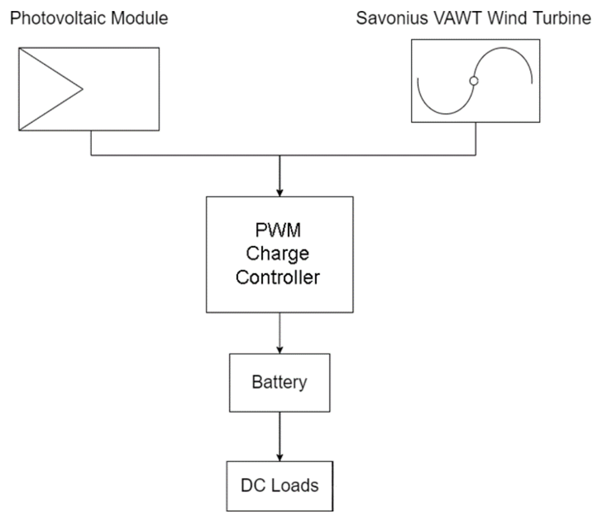

Fig. 1. Components used within hybrid renewable energy generation system.

The WTS frame is constructed using mild steel, following the specified dimensions with some adjustments. These modifications included lowering the height of the pillars and ensuring the VAWT blades extended above the frame. This was done to prevent the pillars and plating from obstructing the wind flow. Additionally, downsizing the frame enhances overall portability and maneuverability of the system. Fig. 2 showcases the finalized assembly of the HRES, prepared for testing.

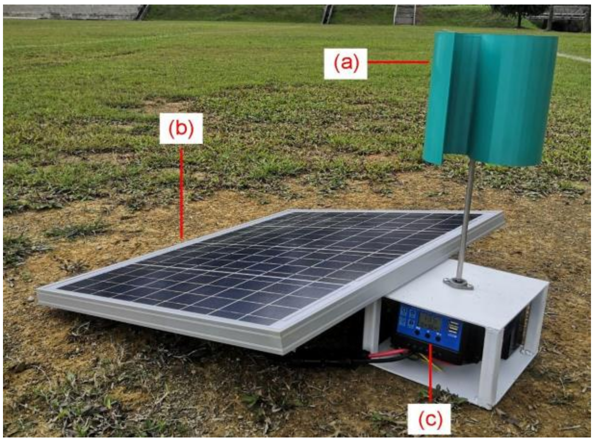

Fig. 2. Completed assembly of HRES. (a) VAWT Blade; (b) Solar Panel; (c) PWM Battery Charge Controller.

2.1 VAWT Blade Composition

The three-bladed VAWT aims to enhance the omnidirectional capabilities of the WTS. The performance of the two-bladed VAWT revealed limitations where, at specific wind speeds, it could become fixed at an angle, hindering blade efficiency, and resulting in minimal torque generation. Introducing a three-bladed design addresses this issue by ensuring a consistent torque application to the WTS shaft, enabling the DC generator to produce voltage effectively. Fig. 3 illustrates the configuration of the three-bladed VAWT designed for the WTS component of the HRES.

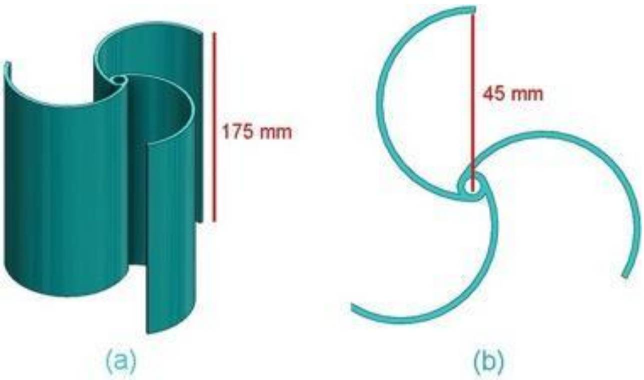

Fig. 3. Three-bladed VAWT composition. (a) Isometric view; (b) Top view

2.2 Gear Component

To address the challenge posed by the high rotation per minute (RPM) of the DC motor and the low, unpredictable wind speeds near the campus, a gearbox is integrated into the WTS of the HRES. The gearbox is designed to increase the revolutions per minute (RPM) received by the DC motor. This compensates for the low RPM generated by the VAWT due to the local wind conditions, although it requires higher torque to spin the VAWT blades. By employing a gear configuration consisting of a 13-tooth gear (as shown in Fig. 4(a)) and a 49-tooth gear (as depicted in Fig. 4(b)), the revolutions per minute (RPM) transmitted to the DC motor generator is amplified. This amplification leads to an overall enhancement in the voltage output. The gear ratio, approximately 1:3.8, achieved through the difference in teeth, results in the DC motor rotating 3.8 times for every revolution of the VAWT shaft. Fig. 4 illustrates the positioning of the gears within the WTS framework.

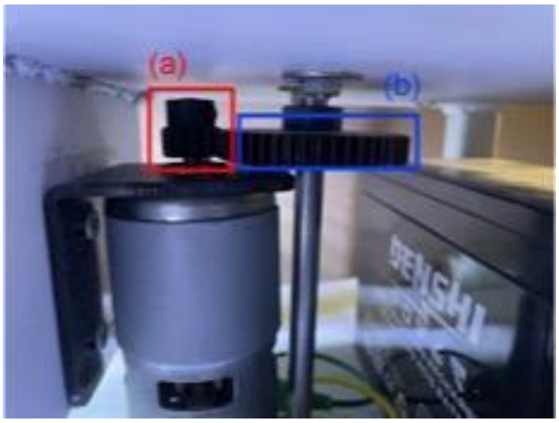

Fig. 4. Gear placement of 13T gear connected to DC motor (a), and 39T gear connected to VAWT shaft (b) of WTS.

2.3 DC-DC Boost Converter

In addition to mechanically boosting voltage through higher RPM, voltage elevation is achieved by employing a DC-DC boost converter linking the DC motor to the charge controller. The chosen DC-DC boost power module (XL6019 5A LM2577) as tabulated in Table 1 is an electronic device designed to amplify the DC voltage sourced from the DC motor for the charge controller. Leveraging inductance and switching principles, this module efficiently steps up the input voltage to a more optimal output voltage level, with the added benefit of adjustable output voltage settings. Positioned between the DC motor's input and the charge controller's input, the module enhances voltage conversion. Fig. 5 illustrates the power module utilized in the system, detailing the input and output connections.

Table 1. XL6019 5A LM2577 data sheet

Model	XL6019 5A LM2577
Maximum Input Voltage	35 V DC
Output Voltage	5-40 V DC
Maximum Current	5 A
Output Current	max. 1.5 A
Power	max. 20 W

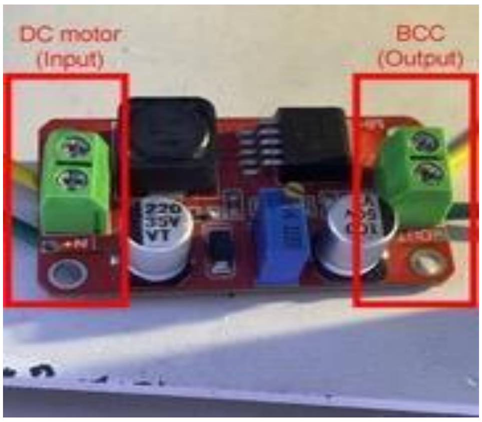

Fig. 5. DC-DC Boost Power Module and orientation

2.4 Solar Energy System

In the solar energy segment of the hybrid system, a 50

Wp PV module is selected as the solar panel of preference. The solar provider supplies the solar panel's datasheet and physical attributes, detailed in Table 2.

Table 2. SPM050-P data sheet

Model	SOM050-P
Maximum Power Pm	50 W
Maximum Power Voltage	18.8 V
Maximum Power Current Im	2.65 A
Open-Circuit Voltage Voc	21.30 V
Short-Circuit Current Isc	2.84 A
Cell Efficiency	13.2 %
Module Efficiency	10.0 %
Maximum System Voltage	DC715V %
Power Tolerance	±3 %
Series Fuse Rating	10 A %

2.5 Charge Controller

A Battery Charge Controller (BCC) will link the wind and solar energy inputs, managing the flow of DC voltage to the battery. This control mechanism safeguards the battery's longevity by preventing overcharging, thereby enhancing the HRES dependability. The selected BCC for the HRES is the KLD1210, a Pulse Width Modulation (PWM) BCC, depicted in Fig. 6. Detailed specifications of the BCC are outlined in Table 3.

Table 3. KLD1210 data sheet

Model	KLD1210
Regulation Type	Pulse Width Modulation (PWM)
Rated Voltage	12/24 V auto
Charge Current	10 A
Discharge Current	10 A
Maximum Voltage Input	50 V
Equalization	14.4 V
USB Output	5V/3A
Weight	150g

Fig. 6. Physical characteristics of KLD1210

Fig. 7 displays a clear visual representation of how the different components of the system, such as the PWM BCC, DC-DC Boost Power Module, and solar panel, are integrated and connected within the overall design.

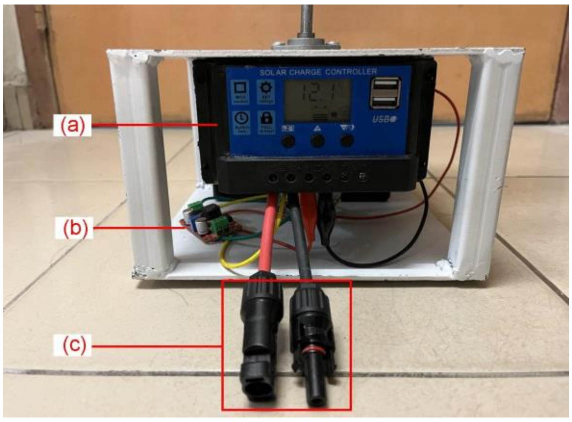

Fig. 7. Front view of frame and components. (a) PWM Battery Charge Controller; (b) DC-DC Boost Power Module; (c) MC4 connectors for solar panel.

2.6 Battery Cell

The hybrid system incorporates a 12 V 7 Ah lithium battery to store the energy produced by the wind and solar energy setups. Details regarding the battery specifications can be found in Table 4.

Table 4. Denshi DP1270

Model	Denshi DP1270
Cycle Use	14.4 - 15.0 V
Initial Current	<2.1 A
Standby Use	13.5 - 13.8 V
Dimension	150 x 65 x 100 mm

Fig. 8 illustrates the key components and their interconnections in the hybrid wind-solar renewable energy generation system. By illustrating these key components and their interconnections, it shows how the various elements are integrated to harness, condition, and store the electrical power produced.

Fig. 8. Side view of frame and components. (1) Shaft connected to VAWT and gears; (2) DC motor; (3) DC-DC Boost Power Module; (4) PWM BCC; (5) 12 V Battery.

3. RESULTS & DISCUSSIONS

3.1 Solar and wind feasibility study

Wind speed is a crucial factor in determining the efficiency of a hybrid wind-solar energy generation system. To further investigate the potential for such a system within UPNM, four locations have been identified for data collection and analysis. Table 5 provides the specific descriptions of the location where the wind velocity measurements were taken. The most suitable location will be selected based on the collected data, which will ensure that both wind and solar energy requirements are met.

Table 5. Selected location for wind feasibility testing

Location Name	Elevation
Puncak Gemilang	50 m above sea level
Football Field	1 m above sea level
11th Floor of Bestari Building	80 m above sea level
Sports Court	1 m above sea level

Assessments were carried out to evaluate the viability of wind and solar energy resources at specific location on campus. The purpose of these assessments was to determine the potential for implementing a HRES in those identified locations. The wind feasibility study, as illustrated in Fig. 9, illustrates the variability of wind speeds on campus, influenced by factors such as elevation, surrounding obstacles like trees and buildings, and the time of day. The data reveals that the 11th Floor of Bestari Building experiences the highest average wind speed at 5.8 m/s followed by the football field at 4.4 m/s, Puncak Gemilang at 2.5 m/s, and the lowest wind speed recorded at the Sports Court at 1.8 m/s.

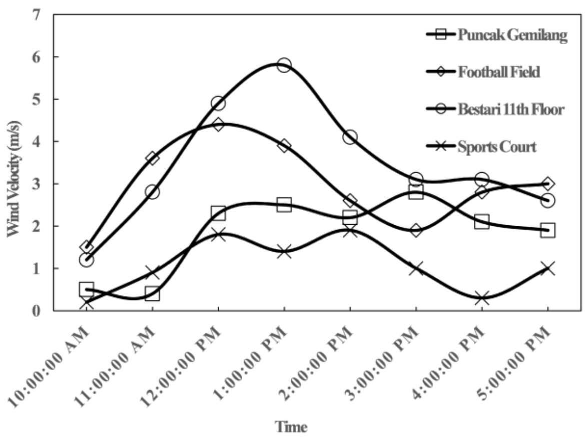

Fig. 9. Average hourly wind velocity against time for selected location.

It is crucial to note that the 11th Floor Balcony of the Bestari Building, where wind speed measurements were taken, is subject to significant shading. While the VAWT system of the HRES shows promise due to favorable wind speeds in this area, the solar energy system would not generate substantial power output compared to other suggested sites.

Furthermore, due to the balcony's design, wind access is restricted to a single point, specifically the open section of the balcony. This limitation reduces the effectiveness of a Savonius VAWT, which is intended to respond to wind from all directions. Therefore, after assessing all four locations, the best possible site that maximizes both wind and solar energy potential is the football field. This site benefits from consistent wind speeds from various directions and avoids any shading that could impact the performance of the PV panel.

To carry out the feasibility assessment on campus, measurements were specifically carried out on the football field because of its open surroundings, guaranteeing minimal shading from natural or artificial structures that might influence the measurements. The data collected from the solar energy feasibility study corresponds with the anticipated daily solar radiation trend. Generally, solar radiation levels are lower in the morning and evening, peaking around midday, as shown in Fig. 10.

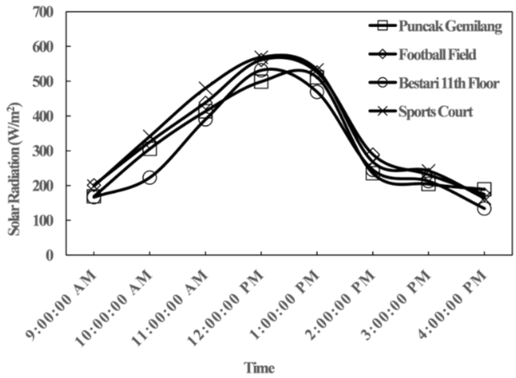

Fig. 10. Average solar radiation against time for selected location.

3.2 Power analysis of HRES

Once the HRES had been built and completed, its power production would be assessed. The hybrid renewable energy generation system is positioned in the selected location that meets both the wind and solar criteria. Utilizing a multimeter, the uncontrolled and controlled voltage (Fig. 11) produced by the system were measured hourly from 7.00 am to 7.00 pm.

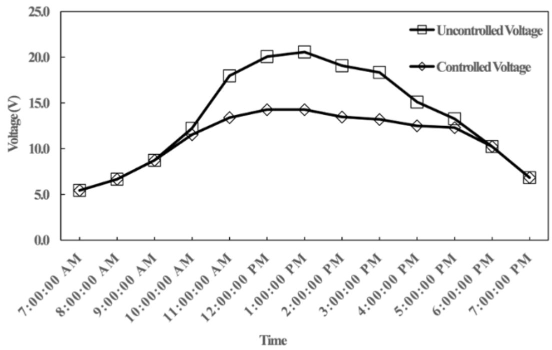

Fig. 11. Average uncontrolled and controlled voltage generated against time.

To further validate the viability of employing a HRES over an independent renewable energy system, the WTS will undergo individual testing as a standalone unit to assess the power output in comparison to the assembled HRES (Fig.12). Subsequently, the fully assembled HRES will undergo comprehensive testing as a unified system at the selected site, chosen for its best blend of wind and solar energy generation capabilities within the campus boundaries.

During the HRES testing, both solar and wind power generation were individually measured to distinguish the power output of the solar energy system and the WTS. This comparison aimed to differentiate the power generated by each source. From Fig. 12, it is evident that the primary source of power generation in the HRES is solar energy. In contrast to previous research depicted as Baseline, a recent study conducted an experiment involving the construction of a wind-solar HRES and examined the produced voltage and current [18]. This is attributed to several factors, including the inconsistent and relatively low output of wind power compared to the consistent energy flow from the sun. Consequently, during the hourly data collection intervals, the energy production from wind may not always be captured. Nonetheless, it is important to note that the wind power contribution to the HRES complements solar energy generation, especially during periods of reduced solar irradiation. For example, during low solar radiation hours like 7.00 to 10.00 am and 6.00 to 7.00 pm, when solar energy production is minimal, the wind power generation increases significantly, reaching up to 2.2 W at 6.00 pm. During nighttime when solar energy is unavailable, the WTS continues to generate electricity, providing a reliable source of power.

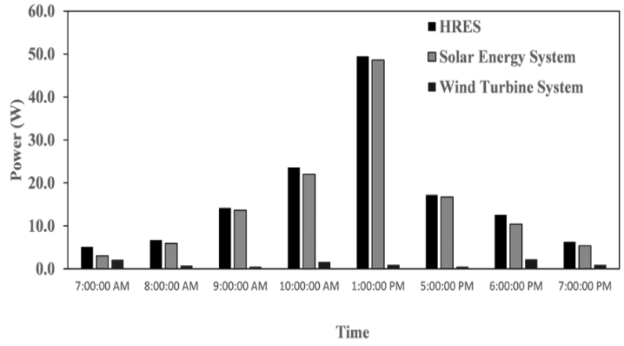

Fig. 12. Power generation from wind turbine system, solar energy system, and HRES.

A detailed examination of the distribution of power generated from both wind and solar sources, as well as the total power output of the HRES, can be observed by reviewing instances during testing where power is generated from both components of the hybrid system as depicted in Fig. 13.

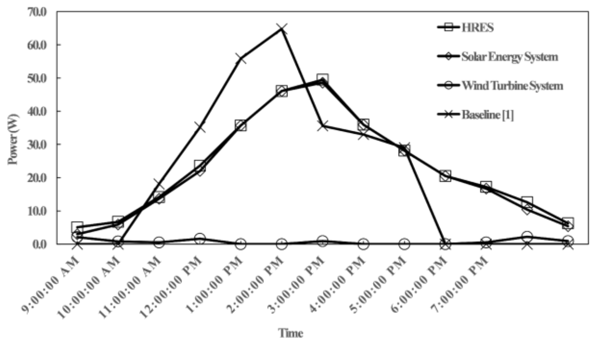

Fig. 13. Power generation from HRES, solar energy system, WTS, and previous study Baseline [18] against time

4. CONCLUSIONS

An artificial test of the voltage and power generation of the VAWT system within the HRES was conducted through artificial means with the artificial wind being supplied from a wind tunnel. Thus, the designing and testing of the fundamentals of the VAWT system within the HRES is completed, with the requirement of further adjustments and additions towards the WTS for increased voltage and power generation, that being a gear system, similar to large-scaled HAWT, as well as electrical components such as a DC-DC boost converter to increase the voltage supplied towards the BCC. prototype resulted in a success, generated a maximum wattage of 50 W from both sources, capable of charging the 12 V DC battery. Furthermore, the HRES prototype was able to charge multiple mobile devices such as smartphones, and power banks. It is worth noting that the WTS is the weakest link of the HRES, as the low and inconsistent wind resulted in the WTS being unable to produce the 12 V output needed to charge the battery consistently. However, the study concluded that the combination of both solar and wind energy generation would increase the voltage output overall, allowing a far more efficient and faster charging time thus satisfying the project's goal when compared to standalone wind or solar renewable energy systems.

For future work, it is strongly recommended to optimize the VAWT systems by fabricating the blades with greater diameter and height to capture more wind energy. Additionally, implementing an adjustable base for the WTS enables the system to access faster winds at higher altitudes. In summary, these factors contribute to significant improvements in wind speeds and, consequently, the overall power generation of the HRES.

5. REFERENCES

[1] "Global energy trend 2023," https://www.enerdata.net/publications/reports-presentations/world-energy-trends.html (accessed 25.6.2024).

[2] M. M. Rahman, S. Hosan, S. C. Karmaker, A. Z. M. Shafiullah, and B. B. Saha, "The Link Between Renewable Energy Use and Energy Poverty: Panel Estimation for South Asian Region," International Exchange and Innovation Conference on Engineering and Sciences, (2021) 198–203.

[3] S. Shafiee and E. Topal, "When will fossil fuel reserves be diminished?" Energy Policy, vol. 37, (2009) 181–189.

[4] Q. Hassan, S. Algburi, A. Z. Sameen, H. M. Salman, and M. Jaszczur, "A review of hybrid renewable energy systems: Solar and wind-powered solutions: Challenges, opportunities, and policy implications," Results in Engineering, vol. 20, (2023) 101621.

[5] E. I. Come Zebra, H. J. van der Windt, G. Nhumaio, and A. P. Faaij, "A review of hybrid renewable energy systems in mini-grids for off-grid electrification in developing countries," Renewable and Sustainable Energy Reviews, vol. 144, (2021).

[6] A. Albani, M. Z. Ibrahim, and K. H. Yong, "The feasibility study of offshore wind energy potential in Kijal, Malaysia: the new alternative energy source exploration in Malaysia," 2014.

[7] S. Mekhilef, A. Safari, and D. Chandrasegaran, "Feasibility study of off-shore wind farms in Malaysia," Energy Education Science and Technology Part A: Energy Science and Research, vol. 29, no. 1, (2012) 519–530.

[8] K. S. Krishna and K. S. Kumar, "A review on hybrid renewable energy systems," Renewable and Sustainable Energy Reviews, vol. 52, (2015) 907–916.

[9] P. K. Roy, J. He, T. Zhao, and Y. Singh, "Recent advances of wind-solar hybrid renewable energy systems for power generation: A review," IEEE Open Journal of the Industrial Electronics Society, vol. 3, (2022) 1–1
[10] Y. Sawle, S. C. Gupta, and A. K. Bohre, "Review of hybrid renewable energy systems with comparative analysis of off-grid hybrid system," Renewable and Sustainable Energy Reviews, vol. 81, no. March 2016, (2018) 2217–2235.
[11] R. I. Ahmed Khalid, "A Comprehensive Review of Vertical Axis Wind Turbines for Urban Usage," International journal of novel research and development, vol. 7, no. 4, (2022) 336–343.
[12] M. H. Ali, S. N. Mehdi, and M. T. Naik, "A Review on Vertical Axis Wind Turbine Used for Household Applications," Journal of Emerging Technologies and Innovative Research, vol. 6, no. 2, (2019).
[13] C. J. Bai and W. C. Wang, "Review of computational and experimental approaches to analysis of aerodynamic performance in horizontal-axis wind turbines (HAWTS)," Renewable and Sustainable Energy Reviews, vol. 63, (2016) 506–519.
[14] M. K. Johari, M. A. A. Jalil, and M. F. M. Shariff, "Comparison of horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT)," International Journal of Engineering and Technology (UAE), vol. 7, (2018).74–80.
[15] S. Rana, B. Roy, B. B. Saha, and S. Ghosh, "Energy Harvesting from Highway Traffic Vehicles Movement via VAWT," International Exchange and Innovation Conference on Engineering and Sciences, (2022) 122–127.
[16] K. Babaremu, N. Olumba, I. Chris-Okoro, K. Chuckwuma, T.-C. Jen, O. Oladijo, and E. Akinlabi, "Overview of Solar–Wind Hybrid Products: Prominent Challenges and Possible Solutions," Energies, vol. 15, no. 16, (2022).
[17] N. Ahmed and A. U. Araf, "Comparative Performance Analysis Between Multi-Input Boost Converter and Multi-Input SEPIC Converter for Renewable Energy Sources," International Exchange and Innovation Conference on Engineering and Sciences, vol. 9, (2023) 453–459.
[18] M. Malson and R. Baharom, "Development of hybrid solar photovoltaic and wind energy powered ups system for small loads supply," Evolution in Electrical and Electronic Engineering, vol. 3, (2022) 292–299.