A Study of a Hybrid Renewable Energy System: Solar PV And Wind Energy with Battery Storage

M. Mustaffa[1]*, J. A. Besar[2] and B. Mustapha[3]

[1,2]Kolej Komuniti Beaufort,
89807 Beaufort, Sabah, Malaysia

[3]Politeknik Sultan Salahuddin Abdul Aziz Shah,
40150 Shah Alam, Selangor, Malaysia.

*Corresponding Author's Email: mazuwan.mustaffa@kkbeaufort.edu.my

Article History: Received 30 July 2023; Revised 12 September 2023; Accepted 15 October 2023

Abstract

Hybrid renewable energy systems generate power by combining two or more renewable energy sources. Traditionally grid energy method having an intermittent failure issues which can interrupt many industrial activities. The aims of this research to implement a combination of a PV-Wind-Battery hybrid renewable energy system (HRES) using MATLAB/Simulink software. As a result, the usage of renewable energy (RE) sources such as solar PV and wind energy is required as a backup. The combination of both as a non-conventional energy can overcome the power failure issue. Because solar energy is intermittent, a hybrid energy source that combines two or more renewable sources with battery storage may help to increase the scheme's effectiveness. Emphasis is given to the analysis of parameters and performance of the standalone solar PV system, which incorporates a DC-DC boost converter employing the Perturb and Observe (P&O) algorithm. The battery modelling also being addressed, where it will serve as a backup power source for the entire system. The MATLAB/Simulink simulation result shown that the input and output characteristics of the solar PV, wind turbine and battery energy storage were accurately captured and aligned with manual calculations. The implementation of the boost converter with Perturb and Observe (P&O) MPPT technique proved beneficial. The successful simulation

outcomes and analyses pave the way for further research and improvements in optimizing non-conventional energy systems and ensuring their seamless integration with the grid.

Keywords: Renewable energy, Hybrid non-conventional energy, PV-Wind-Battery

1.0 Introduction

The universe now responds for more sustainable and low carbon energy. One of the energy generation options with the greatest growth is non-conventional energy (RE). Non-conventional energy sources that are cleaner and ideal to replace traditional power sources contain wind power, PV energy, and battery power. Solar projects are the most prevalent non-conventional energy source in Malaysia due to the reduced production costs of photovoltaic (PV) equipment and the accessibility of finance for green projects. However, the efficiency still not at its best especially when operating at standalone mode. Since wind and solar energy are intermittent, a hybrid energy source that combines two or more renewable sources with battery storage may assist to upsurge the effectiveness of the scheme. Various power generators such as wind, solar, and battery are well-known as popular non-conventional energy (RE) sources can be combined as hybrid non-conventional energy system (HRES). The combination of the HRES will involve the power electronic equipment.

Unpredictability and uncontrollability are the fundamental HRES downsides especially for solar PV. Consequently, it is challenging to produce the necessary amount of power to satisfy the load demand, and voltage and frequency fluctuations are common in generated electricity. The minimum solar irradiance in Mantanani Island with only 61.3 Wh/m^2 [1] and the maximum irradiance level in Sabah is 300W/m^2 [2]. Another study conducted by K. Sukarno [3] found the highest monthly average of radiation at Kota Kinabalu is only 378.76 W/m^2. The data showed that solar PV energy can be supported from other sources to improve the efficiency of the renewal energy system [4].

The problems may be overcome by integrating storage technology with solar PV and wind non-conventional energy sources. Power electronic inverters and converters are necessary for such integration to improve the effectiveness of power transfer and to guarantee system reliability. To incorporate a range of energy sources, hybrid power production systems use several kinds of power electronic converters or inverters. In a Solar PV scheme, the output power is typically in DC form [5] and is linked to a boost converter to increase the voltage. On the other hand, a wind turbine provides an AC voltage, which is transformed to DC using a bridge rectifier [6]. This DC voltage is then increased using a DC-DC boost converter. The battery that provides voltage regulation serves as a backup for both the Solar PV and wind systems during unfavourable conditions [7]. The DC output from the PV-Wind -Battery Hybrid Non-conventional energy Scheme (HRES) is then linked to the DC link. The PV-Wind-Battery hybrid non-conventional energy scheme is considered one of the most effective results to address the intermittent power supply issue in hybrid non-conventional energy systems (HRES) [8], particularly in standalone solar PV systems or wind turbine systems. The primary challenge with solar and wind energy is their unpredictability, making it difficult to ensure a continuous and reliable power generation. Therefore, the integration of HRES is necessary to tackle this problem, and when linked to the grid at the PCC, it can meet the power demand. The aims of this project to simulate and analyze the system that consists of a 107.4 kW solar PV, 5.78 kW wind turbine, 200 Ah battery, and a 400V 50Hz grid using MATLAB/Simulink.

2.0 Literature Review

Study is becoming more interested in non-conventional sources of energy because of the improved demand for energy and the limited supply of traditional energy. Numerous studies are being conducted to increase the power efficiency of unconventional sources and make them

Politeknik & Kolej Komuniti Journal of Engineering and Technology, Vol.8, No. 1, 2023
eISSN 0128-2883

more dependable and useful. A hybrid non-conventional energy system (HRES) uses many sources so that we can simultaneously harvest energy from several sources, hence increasing efficiency. Understanding the process of a PV/Wind/Battery hybrid scheme as well as the benefits and drawbacks of hybrid systems is needed including the efficiency of the system. Many researchers have already discussed the combination of the non-conventional energy system (RES) in terms of power generation stability and output quality of power issues. Table 1 below summarize the HRES combination from previous researchers and its regulator approach to enhance the system quality of power.

Table 1: Comparison of recent study of HRES combination

Author & Year	**Configuration**	**Operating Mode**	**System Stability**
Balakishan, Chidambaram, & Manikandan (2021) [9]	PV - Wind	Grid Linked HRES	Stable and meet load demand
A. B. Bilal & J. Jin-Woo (2022) [10]	PV - Wind	Stand-alone HRES	Unstable and meet load demand
A. Shaqour, H. Farzaneh, Y. Yoshida and T. Hinokuma (2020) [11]	PV – Wind - Battery	Stand-alone HRES	Stable and meet load demand
M. Maaruf, K. Khan & M. Khalid (2022) [12]	PV – Wind - Battery	Grid Linked HRES	Stable and meet load demand

Grounded on previous research, the wind and PV hybrid energy scheme (HRES) are the most stable combination that has been discussed. The intermittent nature sources for solar and wind can be overcome by adding a battery energy system as a backup to the system.

3.0 Methodology

The model and parameters used for the hybrid non-conventional energy system (HRES) is presented as shown in Figure 1.

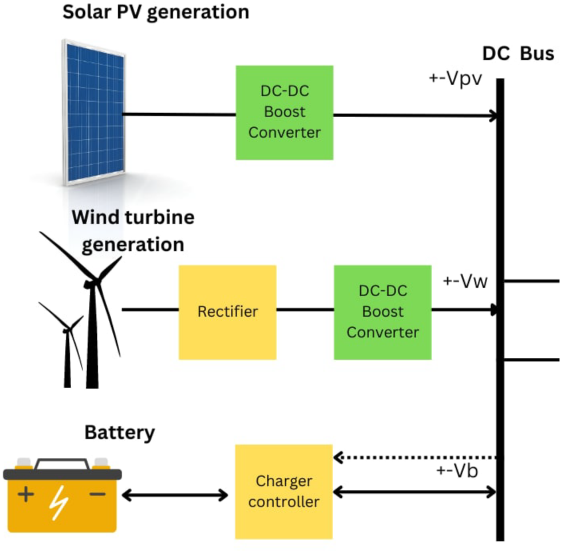

Figure 1: Proposed hybrid non-conventional energy system

The HRES configuration includes a 107.4 kW solar PV, a 5.78 kW wind turbine, a 200 Ah battery, and a SAPF. The DC voltage produced by the solar PV scheme is first boosted using a boost converter and then linked to the common DC bus. Similarly, the AC voltage produced by the wind turbine is rectified and converted to DC voltage using a rectifier. This DC voltage is further boosted using a boost converter and then linked to the same DC bus. To ensure system reliability, the battery serves as a backup and is also linked to the common DC bus through a bidirectional DC-DC converter. The DC sources, namely solar PV, wind, and the battery, will be linked to a common DC bus. This arrangement allows the battery to efficiently charge, and discharge as needed. For maximizing power extraction from both solar PV and wind turbines, MPPT methods are employed. The flow chart as shown in Figure 2 explain the operation of hybrid renewal energy system.

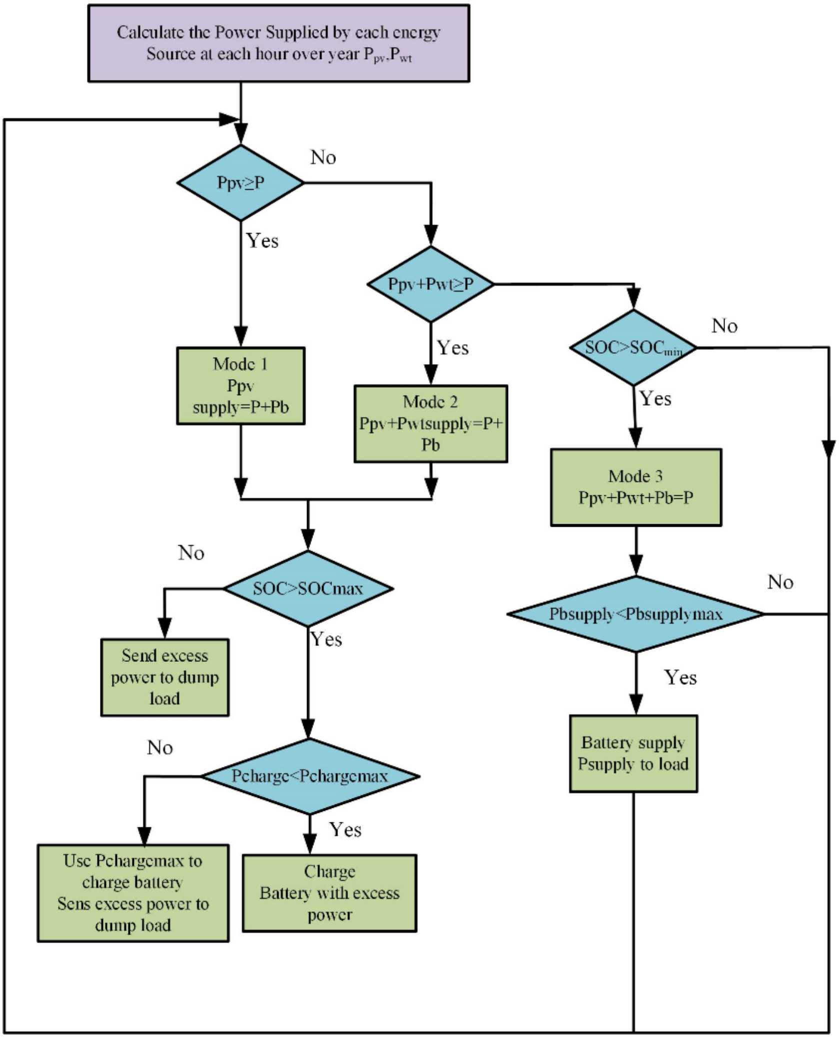

Figure 2: Flow chart of the operation of hybrid renewal energy system

The Perturb and Observe (P&O) process is one of the greatest widely used strategies in MPPT implementations due to its simplicity and minimal requirements. The flow chart of the P&O process used in this study is depicted in Figure 3. After sampling the operating voltage, the algorithm modifies it in the desired direction and samples of ΔV.

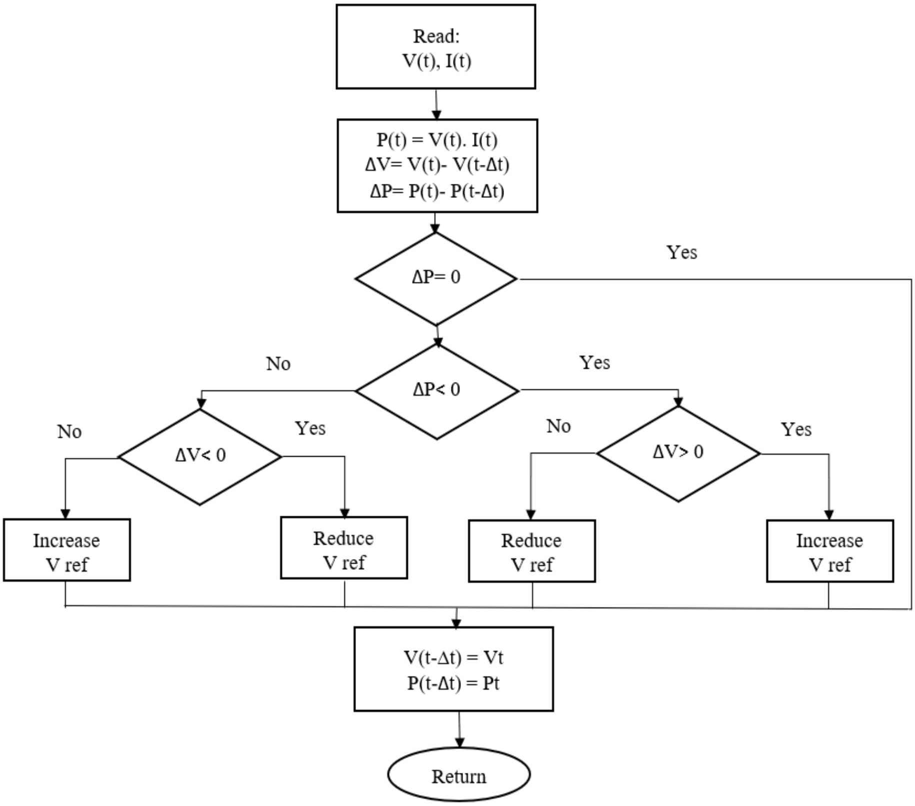

Figure 3: P&O algorithms flow chart

4.0 Results and Discussion

The simulation model presented in this study involves a comprehensive hybrid non-conventional energy system (HRES) comprising a photovoltaic (PV) array, a wind turbine, a battery, and various control elements aimed at optimizing power generation and enhancing system efficiency. The simulation model is designed to analyse the performance of the entire HRES under varying working circumstances. The PV panel has a rating of 522 volts and a capacity of 107.4 kW. The wind turbine is rated at 5.78 kW. The battery is characterized by a nominal voltage of 480 V and a capacity of 200 Ah. The simulation model, depicted in Figure 4, provides a comprehensive platform to analyse and optimize the HRES's performance. The final output power as indicated in Table 2.

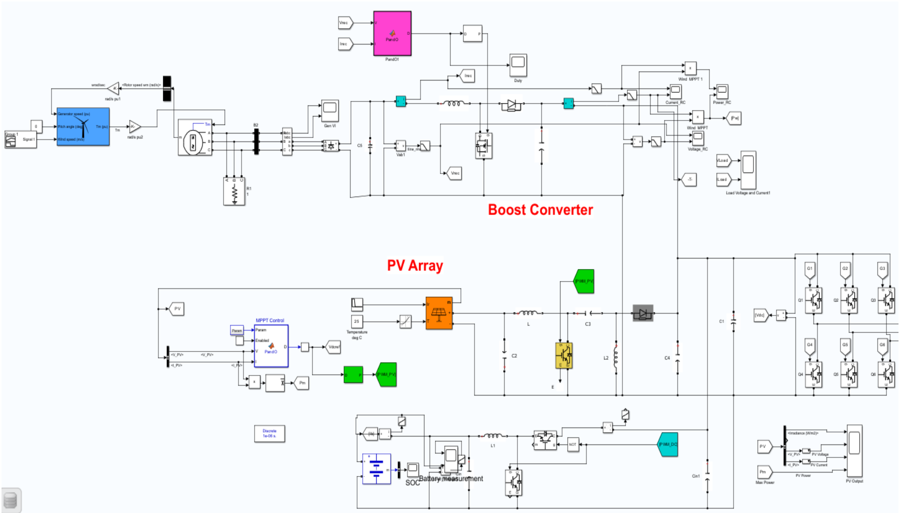

Figure 4: MATLAB/Simulink simulation model of PV-wind-battery

Table 2: Final Output Power

Measurement Point	Output Power
Hybrid System Output	7.5 kW
Battery Output	2.5 kW
Wind turbine output	5.78 kW
Solar Module Output	107.4 kW

4.1 Solar PV simulation results

In the simulation model, the PV panel voltage is reserved constant at 522 volts, while the PV current is maintained at 205.7 A, resulting in a steady PV power output of 107.4 kW under an irradiance level of 1000 W/m2. However, at the time of 0.8 seconds, a sudden change in irradiance occurs, dropping from 1000 W/m2 to 0 W/m2. Because of this abrupt change in solar irradiance, the PV power generation rapidly diminishes and eventually drops to zero. The output from PV array consists of power (P), voltage (V) and current (I) are calculated as simple equation:

$$P_{pv} = \text{Parallel string} \times \text{Series String} \times \text{Max. Power} \quad (1)$$

$$V_{pv} = \text{Series String} \times V_{mp}. \quad (2)$$

$$Ipv = \text{Parallel string} \times Imp. \quad (3)$$

This behavior is expected as the PV panel's output power is directly proportional to the incident solar irradiance. When the irradiance level decreases to zero, the PV panel's ability to convert sunlight into electrical energy is completely inhibited, resulting in a complete cessation of power generation. This simulation result emphasizes the importance of adapting the control strategies and management mechanisms in hybrid non-conventional energy systems (HRES) to respond to dynamic changes in weather conditions. Rapid changes in solar irradiance, as seen in this scenario, can have an important impact on the overall power generation capability of the PV system. In practical applications, this behavior necessitates the incorporation of energy storage systems and intelligent control algorithms to ensure a stable and reliable power supply during periods of low or no solar irradiance.

4.2 Wind energy conversion simulation results

The wind energy speed set up at maximum base speed which is 12m/s. The wind generator rectifier power remains constant at 4200 W from 0 to 0.8 seconds, but then rises to 5600 W from 0.8 to 1.5 seconds. Similarly, the wind generator boost converter power maintains a consistent output of 4000 W from 0 to 0.8 seconds and then increases to 5400 W from 0.8 to 1.5 seconds. This simulation depicts the dynamic conduct of the wind generator scheme under varying wind speeds or loading conditions. By controlling the voltage and current levels in both the rectifier and boost converter, the system can efficiently adjust its power output in response to changes in wind speed or load demand.

4.3 Battery energy storage system simulation results

During the specified time frame, the battery operates under carefully regulated conditions to ensure optimal performance. The battery voltage is consistently maintained at 520 volts, ensuring a stable and reliable power supply throughout the entire duration of the operation. In the initial phase, from 0 to 0.8 seconds, the battery current is upheld at a constant rate of 206 A. This controlled current flow allows for efficient energy delivery to the linked system or load. The battery power is closely monitored and held at a steady rate of 107.12 kW.

5.0 Conclusion

As a conclusion, the simulation result of solar PV emphasizes the importance of adapting the control strategies and management mechanisms in hybrid non-conventional energy systems (HRES) to respond to dynamic changes in weather conditions. Rapid changes in solar irradiance, as seen in this scenario, can have an important impact on the overall power generation capability of the PV system. In practical applications, this behaviour necessitates the incorporation of energy storage systems and intelligent control algorithms to ensure a stable and reliable power supply during periods of low or no solar irradiance. Future work in HRES development should further explore advanced control techniques and energy storage integration to enhance system resilience and improve overall efficiency, ensuring a consistent and uninterrupted energy supply under varying environmental conditions.

Acknowledgements

The journal committee would like to thank all the authors and JPPKK for their manuscript contributions.

Author Contributions

M. Mustaffa: Software, Design, Data collection; **J. A. Besar**: Supervision, Validation, Conceptualization, Methodology; editing; **B. Mustapha**; Result interpretation, Writing and final touch-up editing.

Conflicts of Interest

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission, and declare no conflict of interest in the manuscript.

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