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EFFICIENT ENERGY CONTROLLING STRATEGY FOR HYBRID POWER HARVESTING SYSTEM

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Abstract

In this manuscript, the isolated hybrid Wind-PV system's efficient energy controlling, and management method is implemented using fuzzy logic. The suggested system comprises 500 W PV systems and a wind energy system powered by a 600 W Permanent Magnet Synchronous Generator. A 48V Battery Energy Storage System (BESS) is charged through an appropriate down converter attached to the hybrid energy harvester system. The 1.1 kW systems are used to power a 1 kW system's load. Due to the irregular nature of renewable systems, a BESS system is utilised to support the demand when there is a shortfall of energy produced. The system's output voltage is optimised using the Fuzzy Logic-based Maximum Power Point Tracker (MPPT) being used for the energy management approach. To verify the system's efficacy, the proposed topology is modelled and analysed using the Simulink platform.

Keywords: Energy management, Fuzzy logic, Hybrid power generation, MPPT algorithm, PMSG, Power optimization.

1. Introduction

The usage of alternative energy has become more prevalent in place of coal-based manufacturing due to the ongoing depletion of fossil resources and population growth. With their improved efficiency, environmentally friendly, and economically advantageous power supply to the users, distributed energy resources based on renewable resources are the potential options for clean and green energy [1]. Photovoltaic (PV), and wind energy are more appealing and are used more frequently due to their widespread abundance of renewable energy resources. Rural electrification of homes and businesses necessitates a backup source of energy that can guarantee a steady supply of electricity. Current systems are extremely effective in terms of maximum power point tracking and the increase of system efficiency thanks to the revolutionary breakthrough in converters [2-4]. More efficient control methods are being researched for the system as a source of dependable, affordable, and high-quality power from the sun and wind. The Permanent Magnet Synchronous Generator (PMSG) is the most popular wind turbine due to its simplicity, dependability, and lack of a gearbox [5].

The system often incorporates MPPT control algorithms to harvest the maximum amount of power from changing wind and Photo Voltaic (PV) irradiations by varying the duty ratio [6]. To keep the voltage constant across the load, the MPPT control method is essential. Many of the ongoing studies for WECS and PV systems have used a variety of MPPT approaches [7]. Several Techniques are implemented in the works of literature. Due to its efficiency and simplicity, the Perturb and Observe approach is a well-known MPPT methodology [8]. P&O is simple to implement and affordable for standalone systems. However, due to the fast variations in wind velocity and sun irradiation, the P&O tracks the system's power point and the MPPT fails to achieve its primary goal [9]. Fuzzy logic controllers (FLC) are employed in this classification since they track the MPP for quick adjustments [10].

The P&O control technique efficiently generates an effective duty ratio for the converter operation by tracking the variation in wind velocity and solar irradiations [11]. As a result, based on the available wind velocity, the most power is generated [12-13]. Buck converters (BC) are also frequently used to connect the built-in solar and wind system to the DC bus [14]. The PMSG produces AC, which is then transformed into DC by a rectifier to remove the AC component's ripple. To reduce the ripple brought on by non-linearity, a smoothing capacitor is connected across the rectifier. Since the PV system naturally produces DC electricity, no rectifier equipment is needed [15].

When RE is insufficient, the suggested energy harvesting architecture is combined with the storage system to supply power to the load. This research proposes an effective FLC-based energy management approach to improve the stability of the HRE. The suggested topology examines the energy loss brought on by the DC/DC converter as well. The proposed control technique has an increased ability to harness the full potential of a hybrid renewable wind-PV system, as well as an effective energy management system.

This manuscript has the following format. The modeling of various WECS and PV system parameters is briefly detailed in the section after. The hybrid system's control strategies are described in section 3 of the article. The simulation of the suggested model and its noteworthy results are then addressed in section 4, and section 5 closes the paper.

2. Modelling of Hybrid Wind-PV System

This section explains the modeling for constructing the entire hybrid system, including the PMSG, PV system, and converters. Figure 1 depicts the suggested topology's overall design. A hybrid RE system is designed by fusing the PV and wind systems with the self-regulated buck converter as illustrated in Fig. 1. To convert the wind generator, which is AC by nature, to DC and feed it to a DC/DC BC to match the load requirements. To create a hybrid system, both sources are combined at the common DC link bus capacitor. The suggested FLC topology is utilised to efficiently manage energy depending on load demand while tracking the MPPT. The following subsections show the modeling of PV and wind systems as well as the construction of a fundamental basic circuit for an energy controller system.

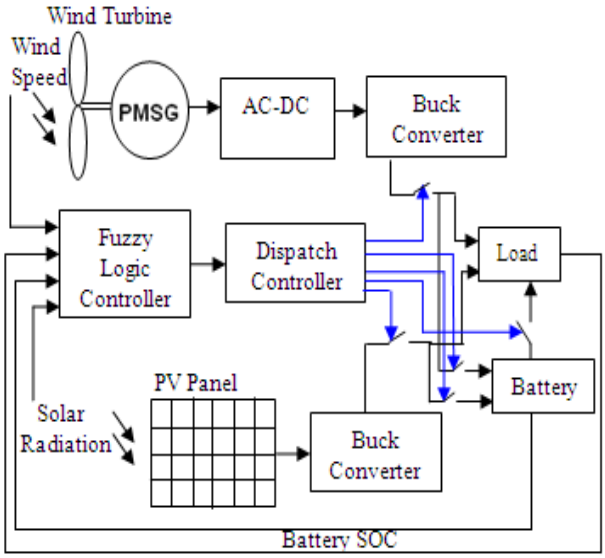

Fig. 1. Proposed hybrid system topology using wind and solar.

2.1. Design of photovoltaic

This subsection describes the modelling of PV systems in the design of RE systems. The created energy harvester design, which is represented in Fig. 2, takes into account and incorporates a single diode-type PV cell. The following are the fundamental I_{PV}-V_{PV} properties of PV panels that are used in the modelling of the PV system.

The specification of PV system PV voltage (V_{pv}) and current (I_{pv}) are as follows,

$$V_{pv} = \frac{\eta KT}{q} ln\left(\frac{I_{ph}}{I_{pv}} + 1\right) \tag{1}$$

$$I_{pv} = I_{ph} - I_{pvrsc}\left(e^{\frac{q\left(V_{pv}+I_{pv}R_s\right)}{\eta KT}} - 1\right) - \frac{V_{pv} + I_{pv}R_{se}}{R_{sh}} \tag{2}$$

The PV output power depends on the availability of solar irradiations and temperature in the environment, and it is determined easily through the traditional equation and as follows [3],

$$P_{PV} = A_{PVP} * G_n * \eta_{PVP} \tag{3}$$

The accurate I_{PV}-V_{PV} characteristics of PV panels.

$$R_{se} = 0.09\frac{V_{oc}}{I_{sc}} \tag{4}$$

$$R_{sh} = 11\frac{V_{oc}}{I_{sc}} * \frac{G}{G_n} \tag{5}$$

The solar PV system with a capacity of 500 Watts is considered to use for simulations and the design requirement is listed in the Table. 1.

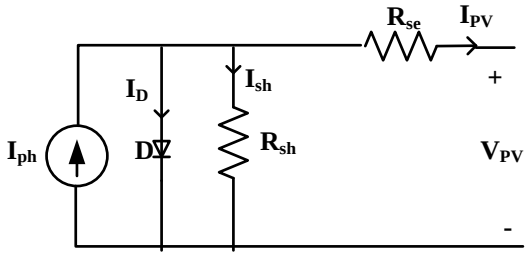

Fig. 2. Electrical equivalent two-port model for a solar system.

Table 1. PV parameter specification.

Parameter Description	Rating
P_{MP}	560 W
I_{MP}	7.83 A
V_{MP}	24.31 V
I_{SC}	8.50 A
T	25^0 C
V_{oc}	30.61V

2.2. Design of wind energy systems

Modeling of wind turbines and electric generators is most to the efficiency of WE systems. The wind turbine generates mechanical power by receiving as input the wind speed (V_w), the rotor speed, and the pitch angle. The wind turbine's total mechanical output power (P_m) is equal to the cube of the wind speed [2], which can be obtained from Eq. (6).

$$P_m = \frac{1}{2}\rho A C_p(\lambda,\beta)V_v^3 \tag{6}$$

A 600 Watts WECS system is analysed in this system and the parameters are depicted in Table 2.

The total power (Pw) produced by WECS is expressed from Eq. (7)

$$P_w(V_v) = \begin{cases} P_n \frac{V_v^2 - V_d^2}{V_n^2 - V_d^2} & ; \quad V_d < V_v < V_n \\ P_n & ; \quad V_n < V_v < V_c \\ 0 & ; \quad V_v \leq V_d and V_v \geq V_c \end{cases} \tag{7}$$

The parameters V_d and V_s refer to cut-in and cut-off wind velocity (*m/s*); P_n refers to standard power (*W*), and V_n is rated wind velocity (*m/s*).

Table 2. Parameter of 600 W wind system.

Description	Rating
P	600 W
R_a	0.775 Ω
L_q and L_d	7.31 mH
$Ø_m$	0.37387 wb
B	0
P_P	2
T/A	1.1216 Nm/A
V_d	4 m/s
J	0.00126811 kg/m^2
V_n	12 m/s (26.8 mph)

2.3. Design of DC/DC converter

Given that BCs are a common circuit type for usage as DC/DC converters, they are utilized in this work. The input DC voltage is often limited by using a BC. The BC's main advantage is its ability to regulate output voltage using duty ratio. The fundamental wind turbine characteristics and basic circuit are shown in Figs. 3 and 4. The continuous conduction mode and the discontinuous conduction mode are the two primary operating modes of BC. The high-frequency operation of the switch restricts the output of DC voltage. In the equation, the average output voltage is stated, in Eq. (8).

$$V_{out} = V_{in} * D \tag{8}$$

where *Vout = output voltage*, *Vin = input voltage*, and *D = duty ratio to switch*.

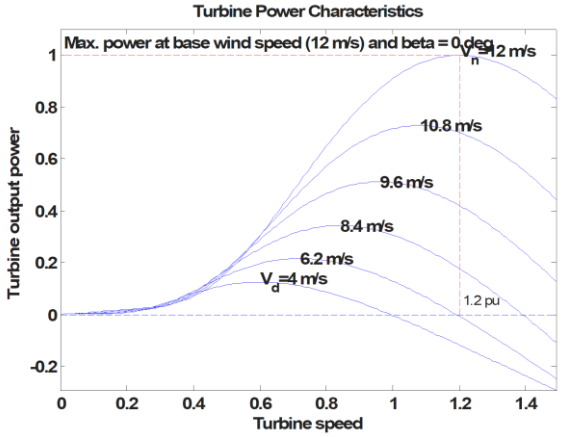

Fig. 3. Wind turbine characteristics.

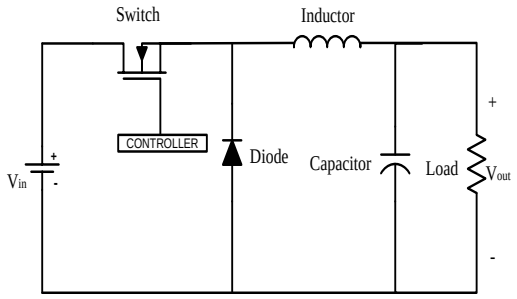

Fig. 4. Basic design of BC.

In Table 3, the L and C values incorporated in the study in completed.

Table 3. Parameter specifications of BC.

Description	Rating
L	3.65 mH
C	3 mF
R	150 Ω

3. Proposed Energy Management System

The production of electricity from the RE sector only depends on the state of the weather. In other words, the load's ability to receive electricity continuously is a significant worry that only depends on the battery's state. As a result, an energy management system is required to improve the performance of produced energy harvester. This harvester uses an FLC, and Table 3 lists the parameter considerations for it to be effective. Analysis of the 48 V rated battery voltage and provision of a DC bus voltage (DBV) of 5 V is used to model the control strategy for the battery system (53 V to 43 V).

Figure 5 depicts the hybrid system's battery regulating mechanism that was taken into consideration for the suggested system. Two hysteresis bands with high (V_{dc}, high) and low frequencies make up the regulation (V_{dc}, low). The reference power won't change if the voltage between the hysteresis bands is varied. The energy management will cease charging the battery if the bus voltage within area "H" is higher than Vdc high. Both the DBV and the reference power should be lowered. The BESS will stop providing power to the load inside of region "L" if the DBV is lower than V_{dc} low, the reference power flips to MPP, and the DBV is increased.

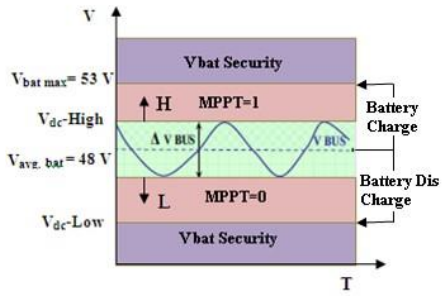

Fig. 5. Regulation of BESS.

3.1. Fuzzy logic control strategy

A traditional control approach is straightforward to implement, but it is less intelligent and accurate. The FLC algorithm is created and used in this study to address the shortcomings of the convention control strategy method. The advantages of an FLC system include quick convergence, handling nonlinearity, and imprecise input. FLC has three major blocks and training modules. Defuzzification, Fuzzification, and Rule base lookup tables are all shown in Fig. 6. To frame the fuzzy system rule, pertinent system knowledge is necessary. The artificially closed-loop decision-making controller is called FLC. Fuzzy controllers' inputs in real life are error signals and changes in error signals. After linguistic variables and signal calculations have been completed, FLC uses specified fuzzy rules to provide the duty ratio as the result. Following that, the BC receives this duty ratio for additional control and energy management. The effectiveness of FLC only depends on prior system knowledge, accurate error computation, and rule-based table framing.

The criteria used to model FLC are shown in Table 4, where *E* stands for error signal and CE for change in the error signal. The five levels of the rules are Negative High (NH), Negative Low (NL), Zero (Z), Positive Low (PL), and Positive High (PH).

The fundamental definition of the inference process comes from the FLC membership functions, which assess the applicability of the criteria in Table 4. Figures 7 to 11 show how the FLC controller's input and output functions are represented. The terms Minimum (min) and Maximum (max) specify the inference and aggregation methods. The centroid is used for processing in the defuzzification technique.

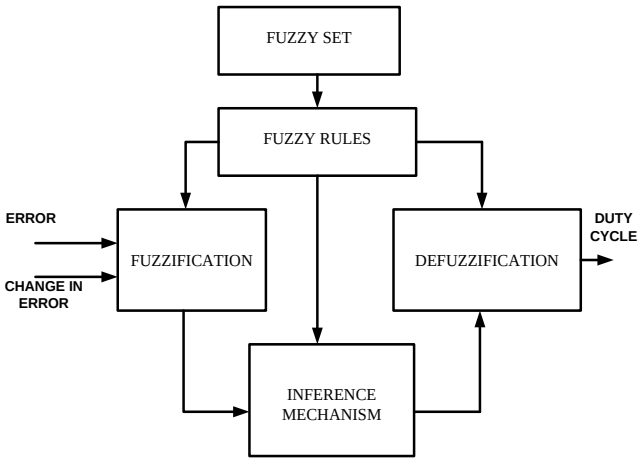

Fig. 6. Fuzzy logic circuit (FLC) structure.

Table 4. Parameter consideration of Fuzzy logic system.

E/CE	NB	NL	Z	PS	PH
NB	Z	PH	Z	NB	NL
NL	PS	Z	Z	NB	NL
Z	Z	Z	Z	Z	Z
PS	PS	PH	Z	Z	NL
PH	PS	PH	Z	NB	Z

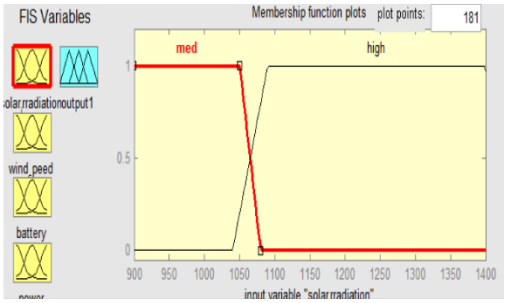

Fig. 7. Membership function of PV FIS variable.

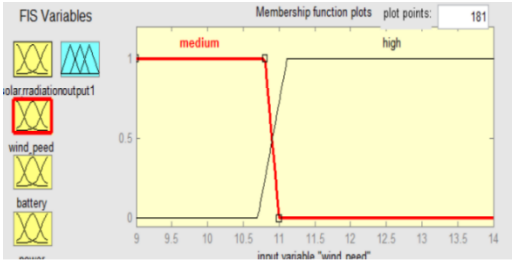

Fig. 8. Membership function of WECS.

The battery voltage level is shown in three fuzzy sets: Low, Medium, and High as shown in Fig. 9.

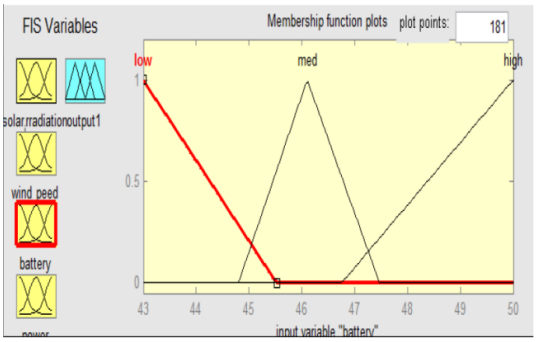

Fig. 9. Membership function of BESS level.

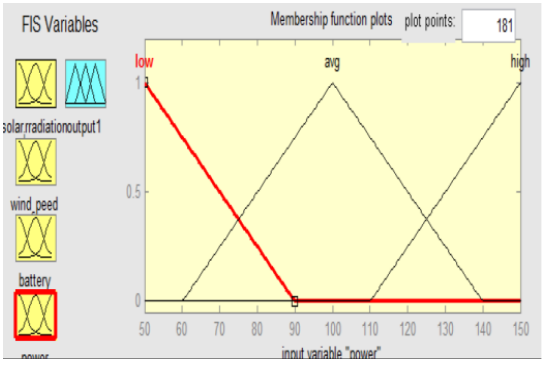

Fig. 10. Membership functions for Power demand for varying loads.

FLC is faster and more accurate at tracking rapid changes in wind velocity and solar irradiation. The controller monitors variations in output voltage and current while also producing an error signal that is used as input during the fuzzification process. The Mamdani approach is used in this instance to transform the input data into the appropriate fuzzy linguistic sets. A suitable fuzzy output is then produced using fuzzy rules once the fuzzy set has been analysed in the inference system. Next, as a form of duty ratio in defuzzification, the fuzzy output is transformed into the systematic crisp value. The converter switch's switching pattern is thus managed by the duty ratio.

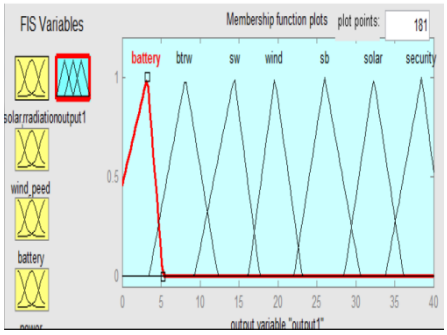

Fig. 11. Membership functions for the output threshold value.

4. Results And Discussion

The performance of PMSG-based WECS and PV system BC incorporated with an FLC in MATLAB/Simulink. The effectiveness of the suggested energy management system is evaluated under various climatic conditions, as was already mentioned, to confirm its efficacy. The system's major goal is to keep the DC voltage provided to the load constant throughout a variety of weather conditions and when renewable resources are available. The fuzzy controller's output DC voltage is depicted in three dimensions in Fig. 12. It is noted that the controller is capable to produce a constant output voltage of roughly 35 V for the different values of solar irradiation and wind velocity circumstances. To run the simulation, solar irradiation between 900 and 1400 and wind velocity between 9 and 14 are considered to produce the simulated output voltage. It suggests that a fuzzy-based energy management system can produce constant voltage under a variety of scenarios while also acting intelligently through a predefined set of rules.

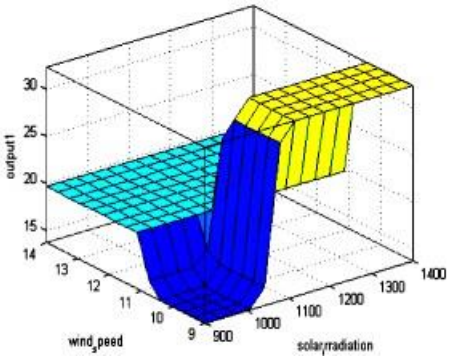

Fig. 12. Surface view of simulated output voltage produced by the Fuzzy controller.

As previously noted, one of the major sources of power generation in the established system is solar PV. The hybrid system's produced solar energy system's output waveforms are shown in Fig. 13. The dynamic variation in PV irradiance is considered for the modelling to validate the performance of the proposed system. The variation in PV irradiance represents the variation in power generated by the PV system. The suggested control method maintains the DC output voltage at 48V.

The output voltage waveforms produced by the wind energy system used in our hybrid system are shown in Fig. 14, and characteristics are very close to the characteristics observed in Fig. 13. The simulation platform is used to simulate a dynamic change in wind velocity to verify the performance of the proposed system. The PMSG output power changes according to the available wind velocity. As shown in Figs. 13 and 14, the regulation of a common DBV at 48V is derived to connect the PV and Wind systems. Fig. 13 and 14 depict the conditions considered for the climatic state of the solar and wind systems along with the measured voltage and current.

Figure 15 displays the results of the proposed control method when an FLC-based control system is used. When the power output from renewable systems is low, the suggested control approach uses the battery. It also indicates the voltage supplied to the battery by using a developed energy management system. To ensure a continuous supply to the load, the suggested control approach also keeps the DBV constant.

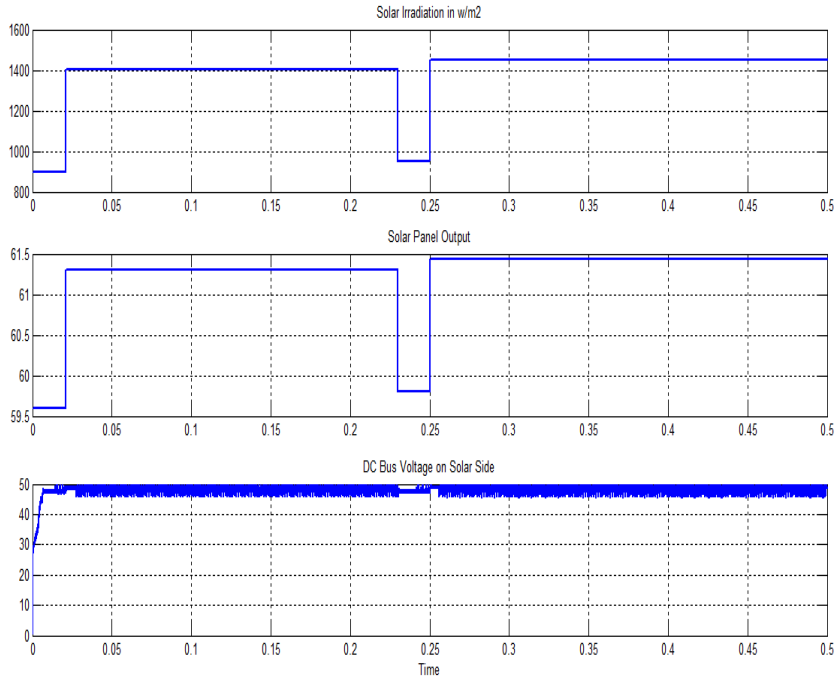

Fig. 13. Output waveform of solar energy system.

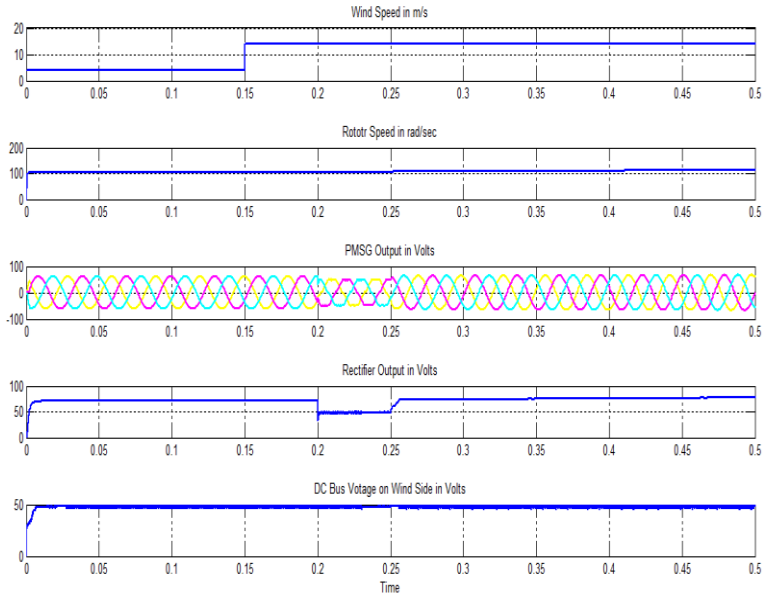

Fig. 14. Wind energy system output waveform.

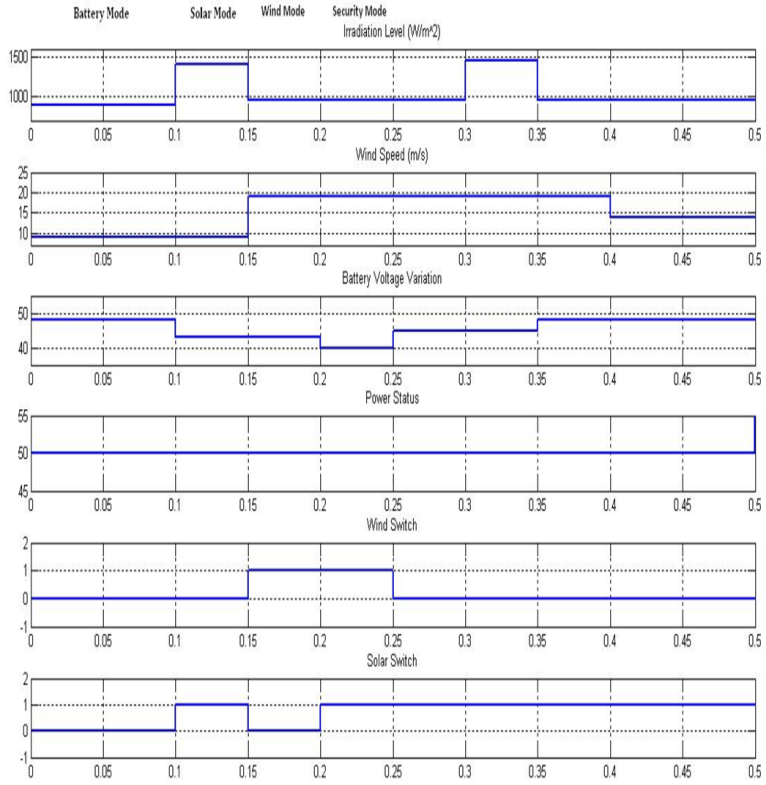

Fig. 15. Simulation results for fuzzy based energy system.

5. Conclusion

In this study, MATLAB/Simulink is used for modeling and analysing a Fuzzy based energy management system. Utilizing a combination of solar and wind energy, a hybrid energy collecting device has been created. For maximum power, a fuzzy-based energy management system is integrated with this hybrid harvester. Additionally, this system uses a battery management system to sustain the load when the generator is not producing enough power. Additionally, the BC is used to control the load voltage. The proposed technology might be considered for remote location applications where energy control is crucial. According to the load requirements, variables like wind, solar, and battery voltage are employed as crucial input circumstances, together with reference power, to simulate the produced system. The results collected demonstrate that a fuzzy-based energy management system outperforms a conventional technique in terms of stability, quicker monitoring capability, and volatility. It can be concluded that the fuzzy-based energy-controlling strategy is the optimized model for remotely located hybrid renewable systems.

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