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Energy Management System for Hybrid Microgrid Using Fuzzy Controller

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Abstract: An effective energy management system is introduced for a hybrid microgrid that integrates wind, solar, and battery-based power sources. The development encompasses the creation of wind and solar energy conversion systems, a battery storage system, power electronic converters, control algorithms, and controllers, all designed to assess the functionality of the hybrid microgrid. The solar power generation system is governed by a Fuzzy-based Maximum Power Point Tracking (MPPT) Controller to optimize performance. To accommodate variations in renewable energy generation and load demands, an energy management system is implemented to sustain power balance. This proposed system aims to ensure the reliable and stable operation of a microgrid with multiple Distributed Generators (DGs) and a battery energy storage system through coordinated energy management strategies. By utilizing a Fuzzy-based MPPT Controller, the system optimally extracts power from the solar system. The hybrid microgrid, as suggested, serves as a valuable testing ground for researching and validating algorithms in the realm of smart grid applications.

Keywords: EMS, Hybrid System, Microgrid, Solar Energy, Wind Energy, Fuzzy MPPT Controller.

1. Introduction

The ongoing global push for self-sufficient renewable energy systems has spurred the development of hybrid solutions that integrate diverse sources such as solar and wind power. Given the intermittent nature of these sources, the incorporation of Energy Storage Systems (ESS) becomes imperative. To optimize power transfer, a range of control techniques is employed, tailored to the specifics of the energy conversion system and converters in use. Simulations have been conducted to comprehensively analyze the performance of these hybrid systems under varying load conditions and different weather scenarios [1]. The study encompasses the design and implementation of a coordinated control system for microgrid energy management, addressing both standalone and grid-connected operational modes [2]. Additionally, a hybrid wind-solar-battery ESS system has been subjected to simulation to assess the effectiveness of state-of-charge control. To ensure sustained power balance within the microgrid, an innovative energy management system is proposed [3]. This system demonstrates adaptability to fluctuations in load demand and changes in renewable energy availability.

2. Related Work

The system proposed in Fig. 1 is structured into three main components: i) renewable energy sources supported by a battery storage system, along with their respective converters connected to the DC bus, ii) the load side inverter, and a single-phase load, and iii) a real-time controller implementing the energy management system [4]. The wind energy conversion system incorporates a wind turbine driven by a Permanent Magnet Synchronous Generator (PMSG). For the solar photovoltaic (PV) panel, Maximum Power Point Tracking (MPPT) is employed when the power generated by both PV and wind falls below the load demand [5]. In instances where power

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generation exceeds demand, the surplus power is directed to the battery [6]. Once it becomes unsafe to continue charging the battery, the MPPT function is deactivated.

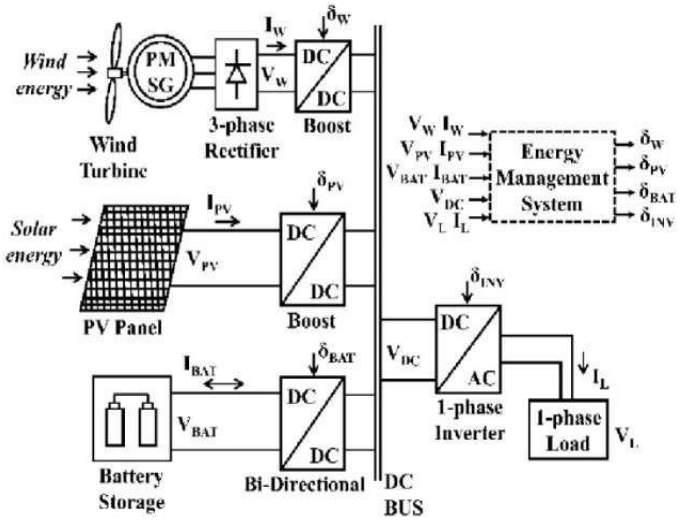

Figure.1 Components of hybrid microgrid with EMS.

The battery storage system plays a crucial role in maintaining energy balance within the system [7]. An energy management system is utilized to govern power flow under diverse conditions, ensuring a stable supply to the load through a single-phase inverter.

2.1. Solar Energy Conversion System (Secs)

The SECS consists of a solar PV panel, a DC-DC boost converter and a fuzzy MPPT controller [8]. The P-V characteristics of the solar panel with effect of irradiance is shown in Fig. 2. The characteristics are shown for different values of irradiance ranging from 400 W/m2 to 1200 W/m2 at a constant temperature of 250C.

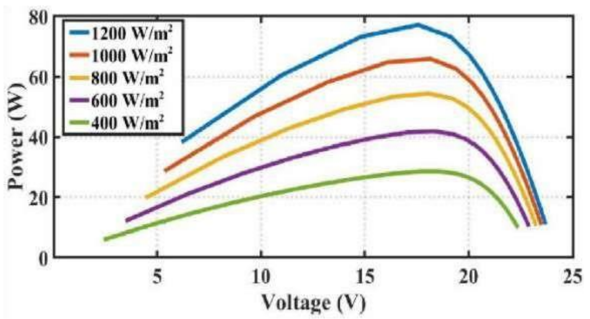

Figure.2. Effect of irradiance on PV array performance at T = 250C.

2.2. WIND ENERGY CONVERSION SYSTEM (WECS)

The WECS consists of a wind turbine, a PMSG, a three phase rectifier, a DC-DC boost converter and controller [9]. The power extracted from the wind is where is the air density in kg/m3, A is the area swept by the rotor blades in m2, and v is the wind velocity in m/s. Cp is the power coefficient and is a function of tip speed ratio (TSR,) and pitch angle ( ).

2.2.1. Wind Turbine

Wind turbines operate similarly to aircraft propeller blades by harnessing the kinetic energy in moving air to power an electric generator, producing an electric current [9]. In essence, a wind turbine functions in the reverse manner of a fan. Unlike a fan that utilizes electricity to generate wind, wind turbines utilize the force of the wind to generate electricity. As the wind causes the blades to rotate, they, in turn, spin a shaft connected to a generator, converting the

$$P_{pv} = VI \qquad (1)$$

mechanical energy into electrical energy.

2.2.2. PMSG

where, V is the voltage across the terminals of the PV panel and I is the current through it.

Fuzzy MPPT Controller: The fuzzy logic controller MPPT rule base is depicted in Figure 3. In the FLC design, the rule assigned to the MPPT block divides both the input and output variables into distinct levels: NB (negative big), NS (negative small), ZE (Zero), PB (positive big), and PS (positive small).

ΔV \ ΔP	NB	NS	Z	PS	PB
NB	PB	PS	NB	NS	NS
NS	PS	PS	NB	NS	NS
Z	NS	NS	NS	PB	PB
PS	NS	PB	PS	NB	PB
PB	NB	NB	PB	PS	PB

Figure.3: Rule-Based used in FLC

The variables supplied to the Sampling Sequence are aligned with the sampling time. During the Fuzzification process, numerical inputs undergo a conversion into linguistic variables based on membership functions [10]. The MPPT rule design revolves around the principle that a change in voltage contributes to an increase in power. The directional movement of the change is consistently maintained in the same direction in the event of an increase; however, if there is a decrease, the subsequent change occurs in the opposite direction. Following the theoretical design of membership functions, rules are fine-tuned by adjusting errors to achieve optimal performance.

A Permanent Magnet Synchronous Generator (PMSG) is a type of electrical generator that uses permanent magnets to generate the magnetic field required for the generation of electrical power [11]. PMSGs are commonly employed in wind turbines, where they play a

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crucial role in converting mechanical energy from the rotation of the wind turbine blades into electrical energy.

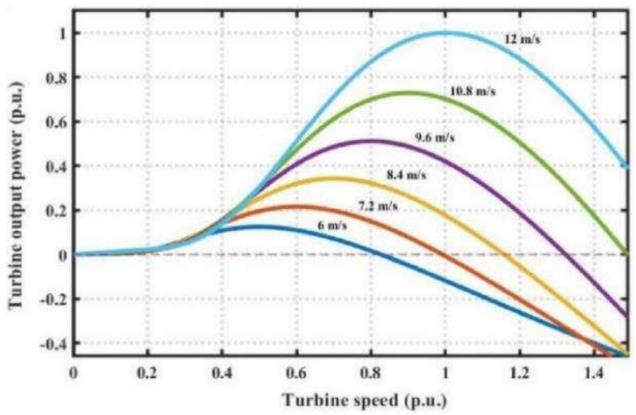

Figure.4. Mechanical characteristics of wind turbine for different wind speeds.

This system incorporates a wind turbine with variable speed functionality. The features of the wind turbine are depicted in Fig. 4, showcasing the power coefficient (Cp) across different wind speeds and pitch angles. To ensure low maintenance and operational costs, a permanent magnet synchronous generator is chosen [12].

The generator's output correlates with the wind speed. The generator's three-phase output undergoes rectification using a diode rectifier, and subsequently, a DC-DC boost converter is employed to elevate the voltage level.

2.3. BATTERY STORAGE SYSTEM (BSS)

The BSS comprises a lead acid battery paired with a bidirectional DC-DC buck-boost converter.

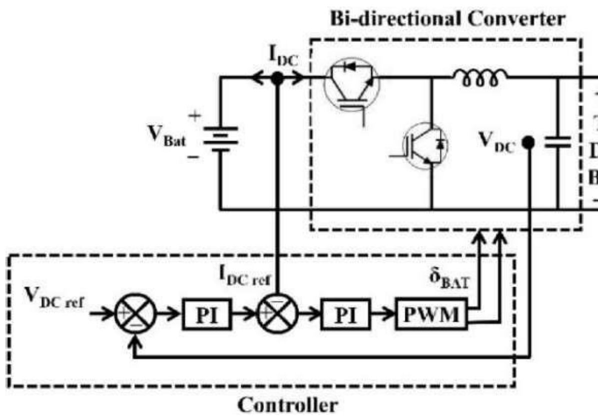

Figure.5. Battery energy storage system with controller.

This converter plays a crucial role in regulating the DC bus voltage, and it achieves this by employing a PI controller, as depicted in Figure 5.

The state of charge (SOC) is given as where Q represents the battery capacity, and Ibat denotes the battery current. The battery functions in two modes, namely charging and discharging, contingent on the power generated by solar and wind sources. Additionally, the battery's operation in these modes is influenced by energy constraints determined by the SOC limits.

2.4. LOAD SIDE CONTROL

The single-phase inverter, equipped with a controller, links the DC microgrid to a resistive load. To eliminate unwanted harmonic content, a R-L filter is employed at the output of the inverter.

2.5. ENERGY MANAGEMENT SYSTEM (EMS)

In a microgrid system, the Energy Management System (EMS) assumes the central role, acting as the primary controller to coordinate and control all actions within the system. The controllers of the individual converters, such as the boost converter in the solar energy conversion system, operate based on the directives provided by the EMS.

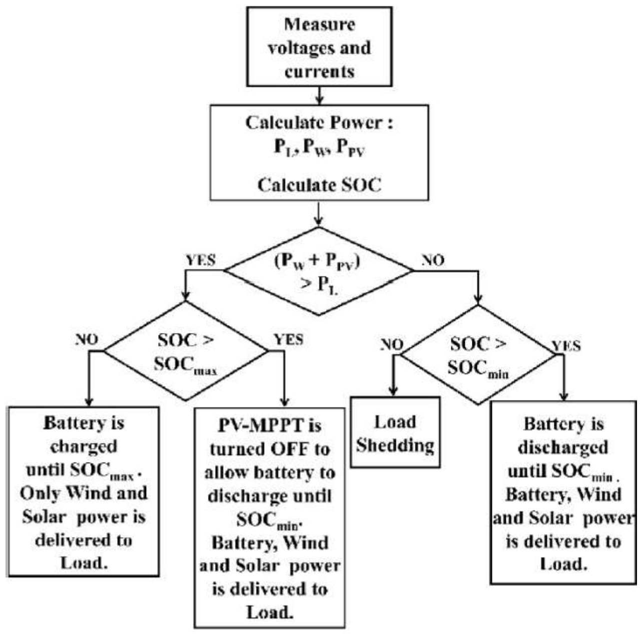

Figure.6. Energy management system.

Solar Energy Conversion System (SECS): Boost Converter Operation: Operates in two modes based on power generation: MPPT mode or off-MPPT mode. MPPT mode optimizes power generation from the solar panel by tracking the Maximum Power Point. In off-MPPT mode, solar power generation is adjusted or reduced based on system requirements.

Battery Storage System (BSS): Bidirectional Converter Operation: Operates in charging or discharging mode, based on the energy flow requirements. Maintains the DC bus voltage constant to ensure stability in the microgrid.

Wind Energy Conversion System (WECS): DC-DC Boost Converter: Operates in boost mode, increasing the output

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voltage to meet system needs. Maintaining balance in the microgrid power is essential amidst varying power generation from renewable sources and fluctuating load demands. This equilibrium is expressed through the power balance equation as follows:

The various modes of operation of the energy management system are presented in the flowchart in Fig. 6.

3. Simulation Results

Two distinct scenarios were executed on the hybrid renewable energy microgrid. In the initial case, the system operated under a consistent load condition while varying the input from solar and wind energy sources. Conversely, the second scenario involved adjusting the load demand while keeping the renewable energy sources constant. The experimental runtime for both cases extended to 70 seconds.

3.1. Variations In Renewable Energy Sources With A Constant Load

The primary goal of the initial case is to maintain a consistent power supply to the load under different generation conditions. The irradiance levels undergo variations at specific intervals 1000W/m2 at the beginning, followed by adjustments to 800W/m2 at 20 seconds, 400W/m2 at 30 seconds, and 600W/m2 at 50 seconds.

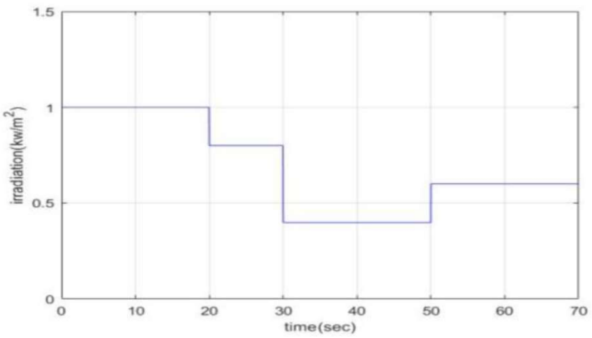

Figure.7: Solar irradiance levels

Simultaneously, wind speeds are modified at defined time points 12m/s initially, followed by changes to 8 m/s at 10 seconds, 11m/s at 20 seconds, 7 m/s at 40 seconds, and 11 m/s at 60 seconds, as depicted in Fig. 7 and Fig. 8. while the wind speed and solar irradiance variations in this scenario are represented as step changes, such abrupt alterations seldom occur in real-world meteorological conditions.

Additionally, the load is intentionally kept constant, a scenario that may not accurately reflect practical situations.

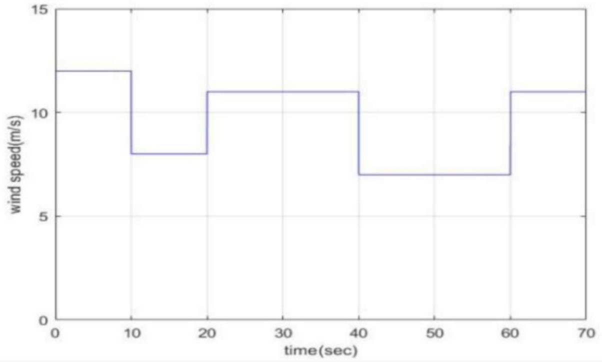

Figure.8: Wind speed levels

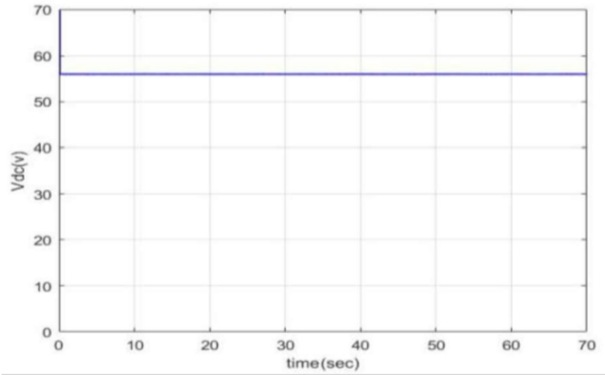

Figure.9: DC bus voltage for constant load with variable renewable energy sources

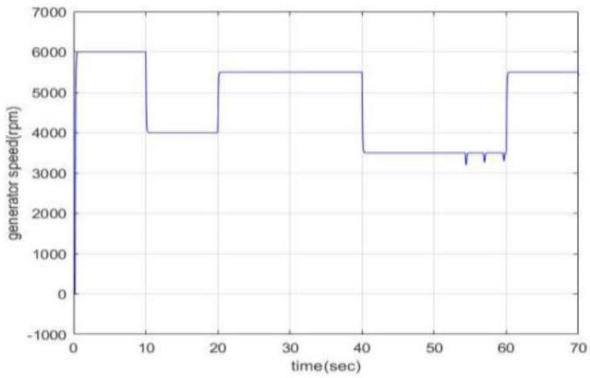

Figure.10: PMSG speed for constant load with variable renewable energy sources

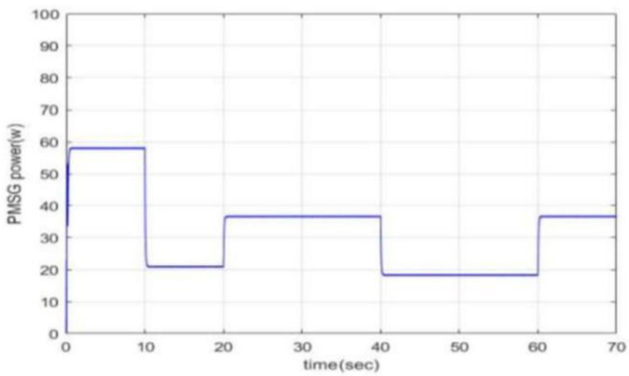

Figure.11: PMSG power

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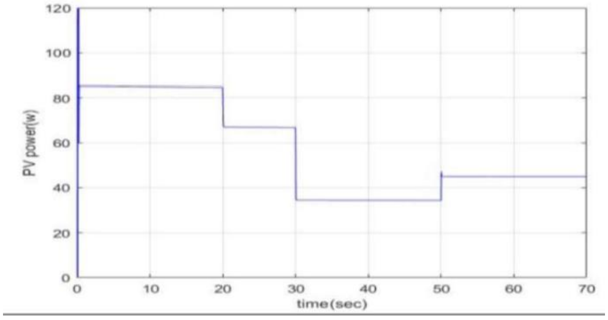

Figure.12: PV power

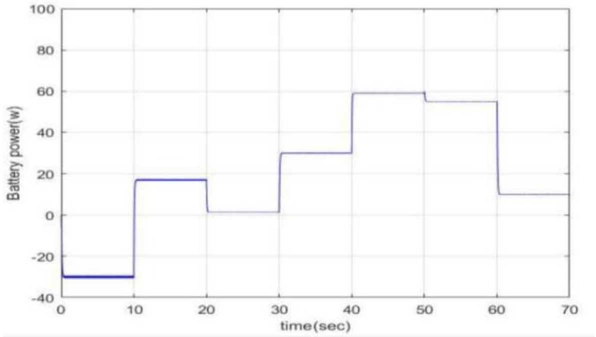

Figure.13: Battery power

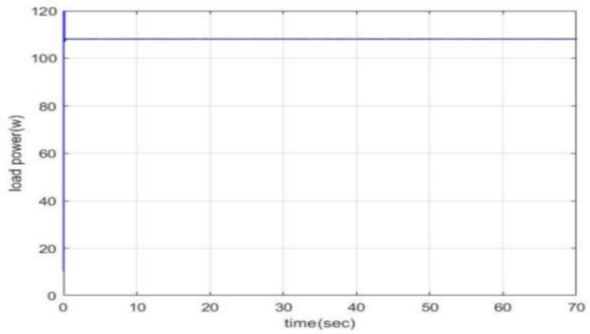

Figure.14: Load power

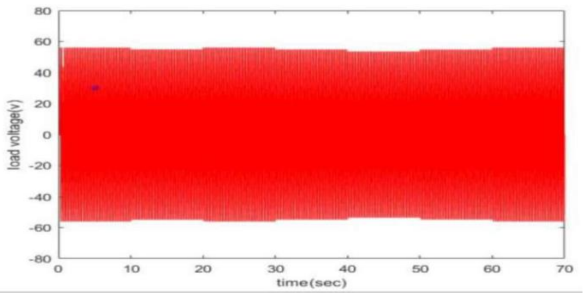

Figure.15: State of charge of battery for constant load with variable renewable energy sources

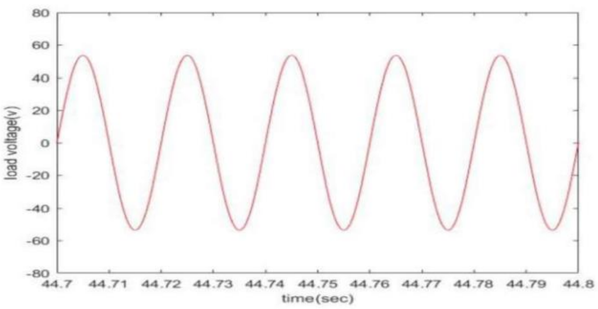

Figure.16: Load voltage for constant load with variable renewable energy sources

3.2. Variations In Load With Constant Renewable Energy Sources

In the second scenario, a stable solar and wind power generation is maintained, holding the solar irradiance at a consistent 800W/m2 and the wind speed at a steady 11m/s, illustrated in Fig. 18. The generator speed remains unwavering at 5280 rpm, aligned with the constant wind speed. The load undergoes alterations every 10 seconds, providing a dynamic variable load demand to assess the microgrid's performance under fluctuating conditions.

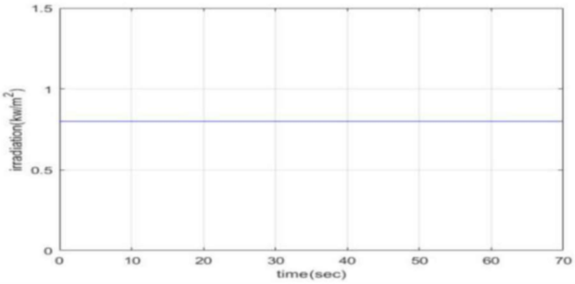

Figure.17: Solar irradiance level

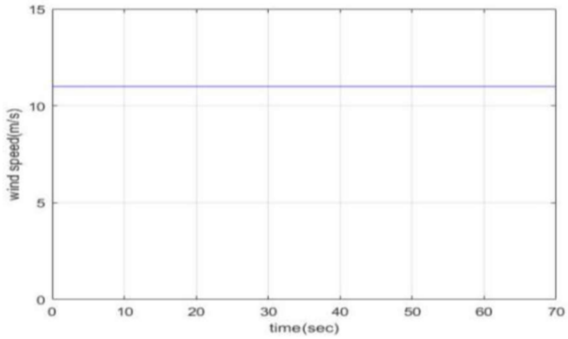

Figure.18: Wind speed levels

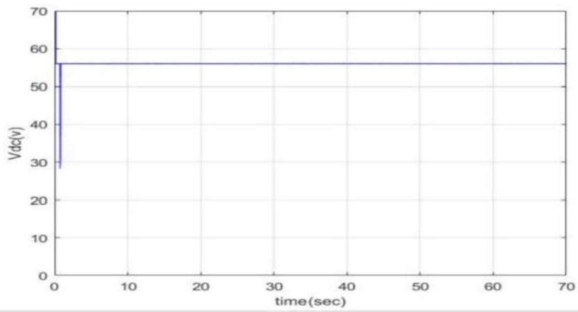

Figure.19: DC bus voltage for constant load with variable renewable energy sources

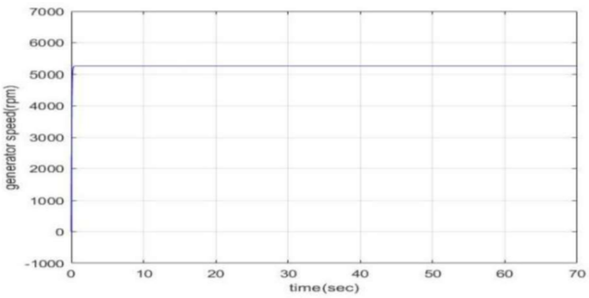

Figure.20: PMSG speed for constant load with variable renewable energy sources

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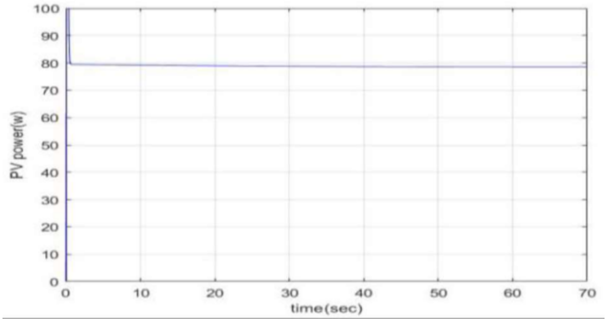

Figure.21: PMSG power

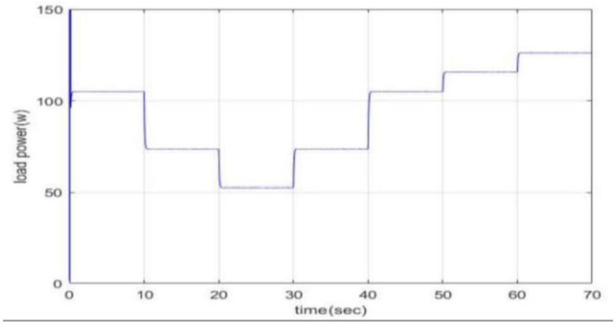

Figure.22: PV power

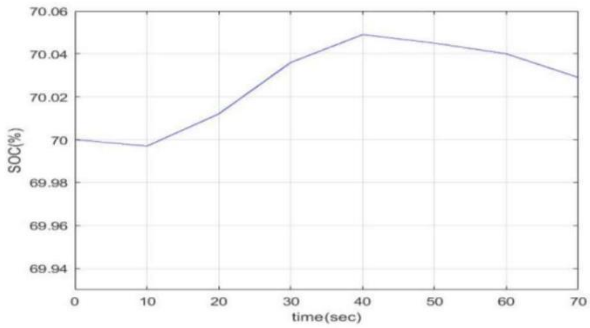

Figure.23 Battery power

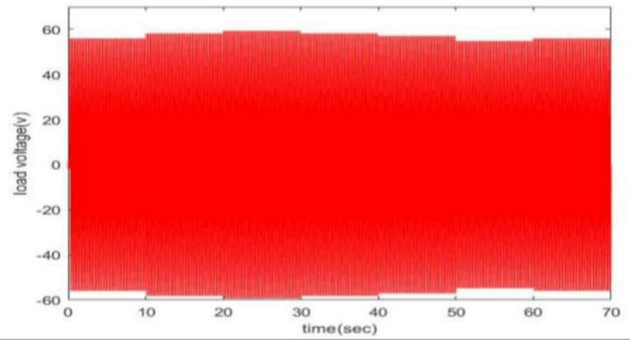

Figure.24: Load power

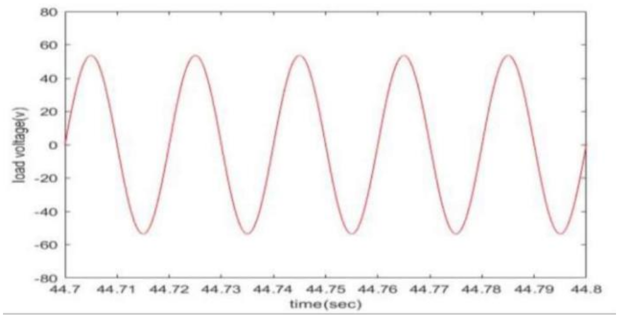

Figure.25 State of charge of battery for constant load with variable renewable energy sources

4. Conclusion and Future Scope

The Proposed energy management system for a hybrid microgrid is developed and implemented. The simulation outcomes demonstrated the system flexibility and its ability to adapt to diverse variations in renewable energy inputs and load demands. The fuzzy logic controller played a crucial role in effectively implementing the energy management system, ensuring smooth and reliable operation.

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