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Energy Management System for Small Scale Hybrid Wind Solar Battery Based Microgrid

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Abstract:In recent years, the power system has been evolved into micro grids, which are little pockets of self-contained entities. Different distributed, interconnected generation units, loads, and energy storage units make up a typical microgrid system. The increased energy efficiency of these units on micro grids is gaining popularity Day-by-Day. Because of their stochastic behavior,renewable generation causes an imbalance in the power system, which needs microgrid energy management. An efficient energy management system for a small-scale Hybrid Wind-Solar- Battery based microgrid is proposed in this paper. The wind and solar energy conversion systems and battery storage system have been developed along with power electronic converters, control algorithms and controllers to test the operation of hybrid microgrid. The power balance is maintained by an energy management system for the variations of renewable energy power generation and also for the load demand variations. In this system, for reliable and stable operation of a microgrid with multiple DGs, coordinated control of energy management system is proposed. The control algorithms of microgrid system are verified by Matlab Simulation.

Keywords— MPPT, EMS, SECS, WECS.

1.INTRODUCTION

There have been global initiatives for the promotion of self-sufficient renewable energy systems. This initiative hassled to the development of renewable power generating systems which are capable of providing self-sufficient power generation with the use of more than one renewable source of energy. The most commonly used hybrid renewable energy sources are solar and wind energy. Both these sources of energy are intermittent in nature; therefore, the use of an energy storage system (ESS) is standard in stand-alone applications .In hybrid renewable energy systems; there are multiple control techniques to provide an efficient power transfer. The system design depends on the type of energy conversion system and the type of converters used at different locations in the system, this needs a lot of technical attention and has attracted research in this area.

A hybrid energy system was simulated and the performance for different practical load demand profile and weather data was studied. The simulation system of a coordinated control for microgrid energy management in standalone and grid connected modes is discussed . A hybrid wind-solar-battery ESS system is simulated to test the state of charge (SOC) control. A scaled hardware prototype with battery SOC control scheme to improve the DC grid voltage control for stand- alone DC microgrid was developed. A hardware prototype of a low-cost hybrid stand-alone power generation system was developed. The objective of this research work is to design and develop a small-scale wind-solar-battery renewable energy based microgrid. An energy management system is proposed to maintain the power balance in the microgrid and provides a configurable and flexible control for different scenarios of load demand variations and variations in the renewable energy sources. The proposed system can be tested in real time environment with the use of rapid control prototyping. This test bench allows the validation of control algorithms in real time and therefore develop efficient renewable energy management systems.

System Description

The proposed system is shown in Fig. 1

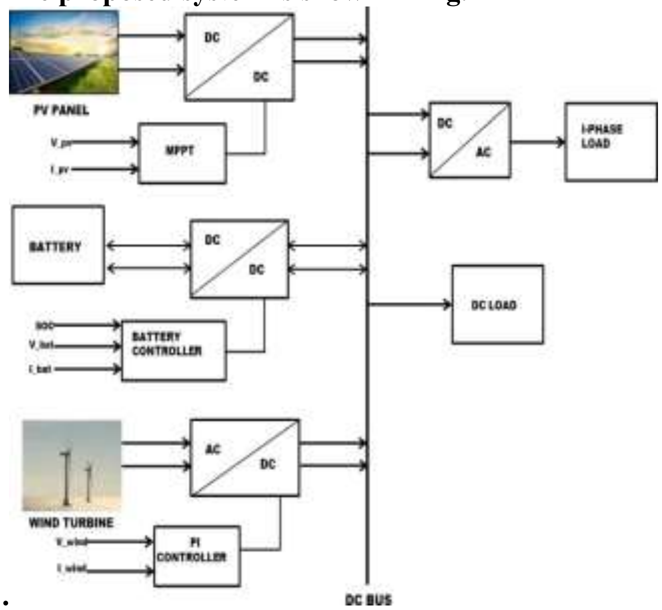

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Fig 1: Block Diagram of small scale hybrid wind solar battery based microgrid

It can be divided into three parts; i) solar and wind based renewable energy sources supported by a battery storage system along with their converters connected to the DC bus, ii) the load side inverter and single-phase load, iii) real time controller implementing the energy management system.[16] The wind energy conversion system consists of a permanent magnet synchronous generator (PMSG) based wind turbine. The solar photo- voltaic (PV) panel is operated with maximum power point tracking (MPPT) when the power generated by both PV and wind are less than the load demand.[20] When the power generated is more than the demand, the excess power is supplied to the battery and when it is no longer safe for the battery to be charged, the MPPT is turned off. The battery storage system is used to maintain the energy balance in the system. A n energy management system is used to control the power flow under different conditions in order to supply to the load through a single-phase inverter.

Short Circuit Current of Solar Cell:

The maximum current that a solar cell can deliver without harming its own constriction. It is measured by short circuiting the terminals of the cell at most optimized condition of the cell for producing maximum output. The term optimized condition is used because for fixed exposed cell surface the rate of production of current in a solar cell also depends upon the intensity of light and the angle at which the light falls on the cell. As the current production also depends upon the surface area of the cell exposed to light, it is better to express maximum current density instead maximum current. Maximum current density or short circuit current density rating is nothing but ration of maximum or short circuit current to exposed surface area of the cell.

$$J_{sc} = I_{sc}/A$$

Where, Isc is short circuit current, Jsc maximum current density and A is the area of solar cell.

Efficiency of Solar Cell:

It is defined as the ratio of maximum electrical power output to the radiation power input to the cell and it is expressed in percentage. It is considered that the radiation power on the earth is about 1000watt/square meter hence if the exposed surface area of the cell is A then total radiation power on the cell will be 1000A watts.[26] Hence the efficiency of a solar cell may be expressed as

$$\text{Efficiency} = Pm/\,Pin \cong Pm/1000A$$

MPPT charge controller:

A MPPT solar charge controller is the charge controller embedded with MPPT algorithm to maximize the amount of current going into the battery from PV module. MPPT is DC to DC converter which operates by taking DC input from PV module, changing it to AC and converting it back to a different DC voltage and current to exactly match the PV module to the battery.

DC-DC converter:

A DC-to-DC converter is an electronic circuit or electromechanical device thatconverts a source of direct current (DC) from one voltage level to another. It is a type of electric power converter. Power levels range from very low (small batteries) to very high (high- voltage power transmission).

A dc chopper converts fixed dc input voltage to a controllable dc output voltage.

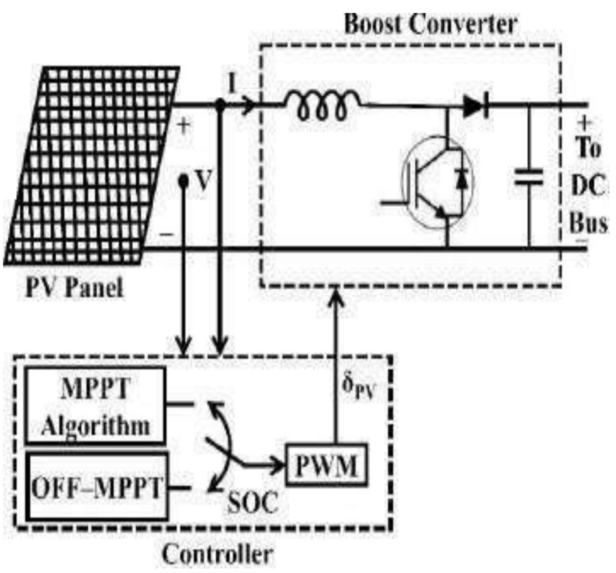
The chopper circuits require forced, or load commutation to turn-off the SCR.

For low power circuits we can use Power BJTs. Choppers are used in dc drives, battery driven vehicles etc.

The terms DC–DC converters and choppers are one and same. In the texts usually these terms are interchanged. The Choppers can be operated in either a continuous or discontinuous current conduction mode. They can be built with and without electrical isolation.

Solar Energy Conversion System (SECS):

The SECS consists of a solar PV panel, a DC-DC boost converter and an MPPT controller as shown in Fig. 2. Depending on state of charge of the battery storage system, the MPPT is operated under MPPT mode or under off-MPPT mode of operation[12]. The P-V characteristics of the solar panel with effect of irradiance.



P_{pv}=VI

Fig 2: Solar Energy Conversion System with Controller

PMSG MODELING:

The PMSG (permanent magnet synchronous generator) is proposed as a wind turbine generator due to its property of self-excitation (or by permanent magnet) which eliminates theexcitation loss i.e. excitation losses are not increases as number of poles doubled. Two phase synchronous reference rotating frame (SRRF) is used to derive the dynamic model of PMSG in which the q-axis is 90^0 ahead of the d-axis with respect to the direction of rotation.

The electrical model of permanent magnet synchronous generator in synchronous reference rotating frame is represented by as shown in figure

$$\omega_e = P\omega_g$$

$$e_q = \omega_e\lambda_0$$

$$T_e = 1.5[(L_d - L_q)i_d i_q + i_q\lambda_0$$

Where R_a is resistance of stator winding, $_e$ and $_g$ are electrical and mechanical rotating speed, $_0$ is flux produced by the permanent magnets, P is no. of pole pairs, u_d and u_q are d and q axis voltages, L_d and L_q are d and q axis inductances, T_e is electromagnetic torque and e_q is q-axis counter electrical potential.

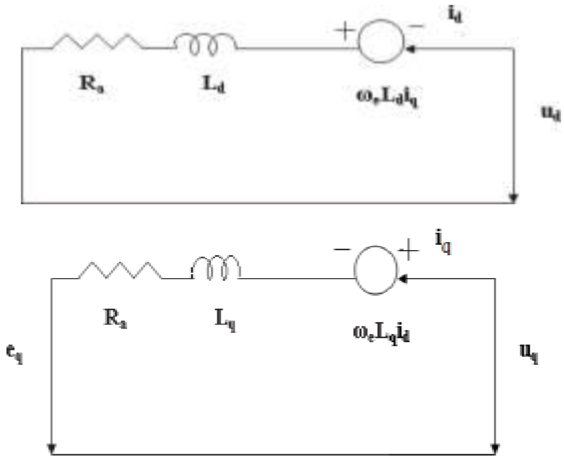


Fig. 3 PMSG Modeling

Energy Management System (EMS)

The Energy Management System (EMS) serves as the central controller that coordinates and supervises all control operations within the microgrid. It determines the operating modes of the various converter controllers described in earlier sections. The DC–DC boost converter in the solar energy conversion system functions in two distinct modes depending on solar power availability: Maximum Power Point Tracking (MPPT) mode and off-MPPT mode. Similarly, the bidirectional DC–DC converter connected to the battery operates either in charging or discharging mode while ensuring that the DC bus voltage remains constant. In the case of the wind energy conversion system, its DC–DC boost converter consistently operates in boost mode.

To ensure stable operation, the EMS maintains a power balance between generation and demand under varying conditions of renewable energy production and load requirements. The overall power balance relationship can be expressed as:

Pw + Pv=PL+Pbat

where

Pw: Power generated by the wind system

Pv: Power generated by the photovoltaic system

Pl: Load demand

Pbat: Power exchanged with the battery

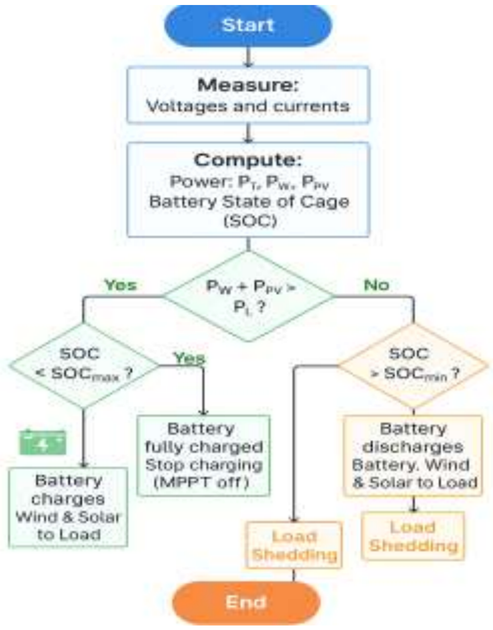


Fig 4: Energy Management system

Results and Discussion

11.1 Simulation Results

Two simulation case studies were performed on the hybrid renewable energy microgrid model.

Case 1: Variation in renewable energy sources (solar and wind) under a constant load condition.

Case 2: Variation in load demand with constant renewable energy inputs.

The total simulation runtime for both cases was 70 seconds.

Case 1: Variations in Renewable Energy Sources with Constant Load

In this scenario, the load was kept constant while the solar photovoltaic (PV) and wind turbine (WT) power generation levels were varied. The simulation circuit consists of a PV array, a wind turbine system connected through a boost converter, a universal bridge inverter, and a battery storage system. The DC link connects these subsystems to the AC load through the inverter.

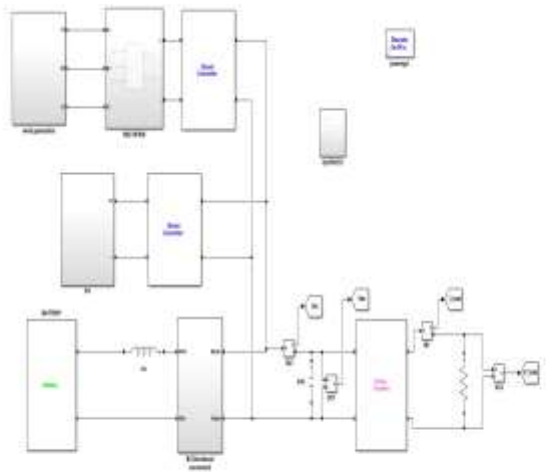


Figure 5: Simulation circuit diagram for the hybrid microgrid under constant load conditions with variable renewable energy sources.

Figure 5 illustrates the simulation connection diagram of a solar–wind–battery-based microgrid system. The primary objective of the first case study is to ensure a constant power supply to the load under varying generation conditions. Solar irradiance is altered by switching lamps on or off, thereby simulating different irradiance levels. However, it should be noted that the variations in wind speed and solar irradiance are represented as step changes, which do not realistically occur in actual environmental conditions, since meteorological parameters vary continuously over time. Moreover, in this case, the load is maintained constant, which also deviates from real-world scenarios where load demand typically fluctuates.

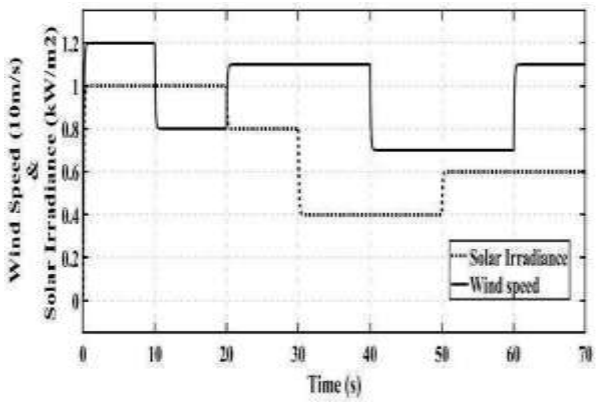


Figure 6: Solar Irradiance and Wind Speed vs. Time

The selected irradiance and wind speed values are chosen to vary within realistic operating limits of the system components.

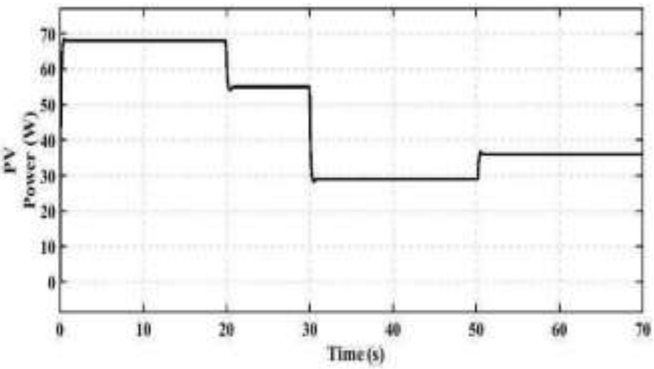


Fig 7: PV Power vs Time

The characteristics of PV power with changing solar irradiance by 1000W/m2, 800W/m2, 400W/m2 and 600W/m2 at the start, 20s, 30s and 50s respectively, is shown in Fig 7

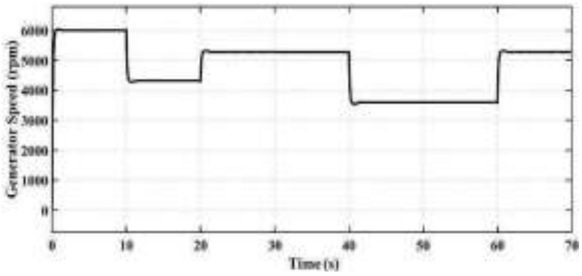


Figure 8: PMSG Speed vs. Time

Figure 8 illustrates the variation of the Permanent Magnet Synchronous Generator (PMSG) speed corresponding to different wind speed conditions.

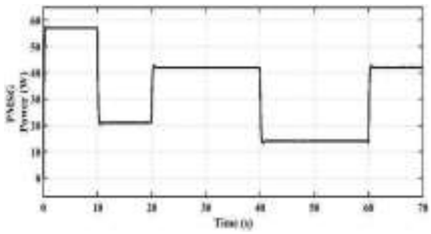


Figure 9: PMSG Power vs. Time

The variation in wind speed is achieved by adjusting the speed of the fan blower. The wind speed is changed sequentially to 12 m/s, 8 m/s, 11 m/s, 7 m/s, and 11 m/s at 0 s, 10 s, 20 s, 40 s, and 60 s, respectively.

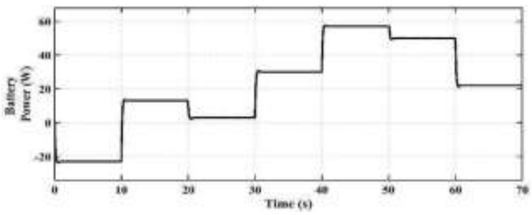


Fig 10: Battery Power vs Time

The battery is charged as the power generated by both the solar and wind energy conversion systems exceeds the load demand, as shown in Fig 10. after 10s the discharging starts and the level of discharge varies at different instants depending on the difference in the power deficit from the renewable energy sources.

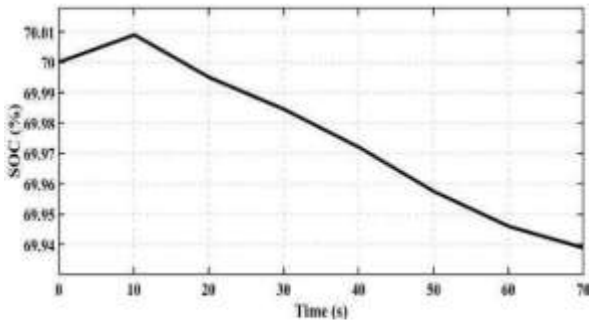


Fig11: Battery SOC(%) vs Time

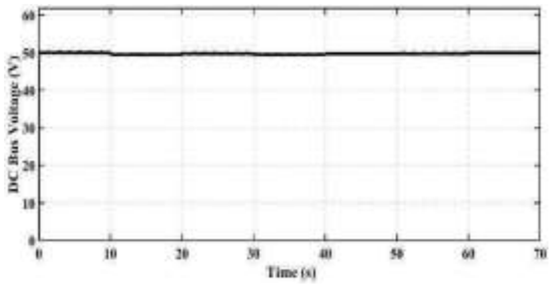


Fig12: DC Bus Voltage (V) vs Time

The power deficit is met by the battery is shown in Fig11, and the state of charge of the battery clearly shows the charging and discharging rate. The power balance is achieved by the energy storage device by maintaining aconstant DC bus voltage of 50V as shown in .Fig.12.

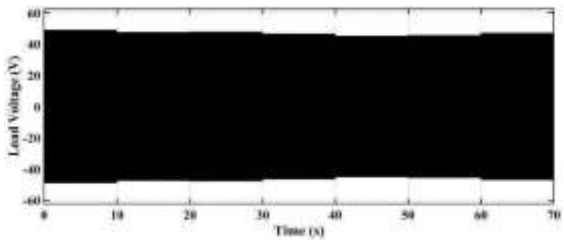


Fig 13: Load voltage (V) vs Time

Figure 13 shows that the load voltage remains nearly constant, with a minor drop between 40 s and 60 s due to higher battery discharge.

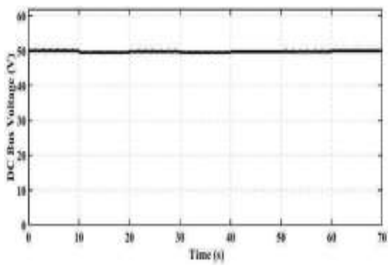


Fig 14: load power vr time

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Fig14:The load power is maintained constant to evaluate system performance under varying renewable inputs. This fixed-load condition enables clearer observation of the microgrid's response.

Case: Variations in Load with Constant Renewable Energy Sources.

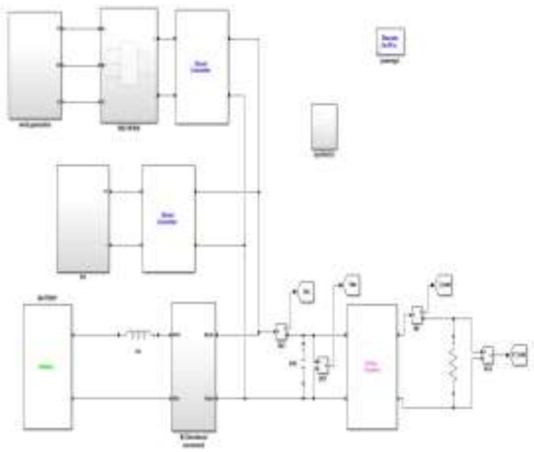

Fig 15: Simulation circuit diagram of Variations in Load with a Constant Renewable

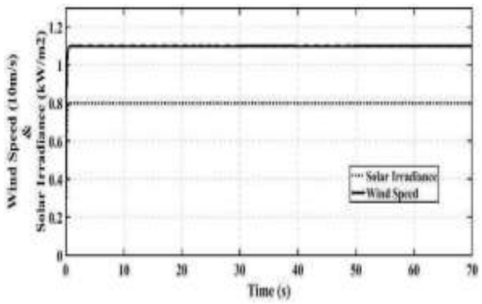

Fig 16: Solar irradiation &wind speed time

In the second case, both solar and wind generation are maintained constant, with solar irradiance fixed at 800 W/m² and wind speed held steady at 11 m/s, as illustrated in Fig. 16.

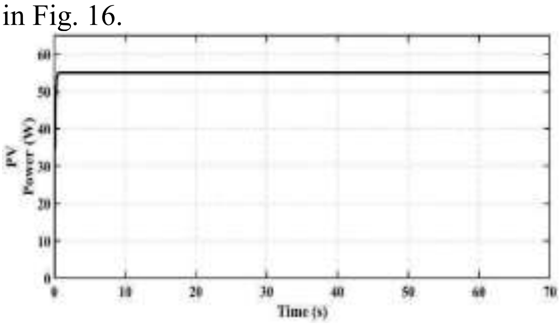

Fig17: PV power vs time

The energy management system effectively maintains power balance under constant renewable generation conditions, as illustrated in Figs. 16 and 17.

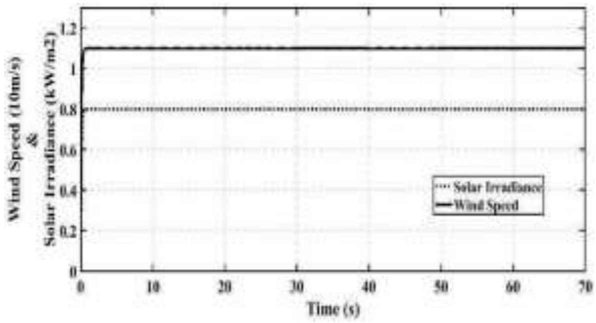

Fig 18 Generator speed vr time

The generator speed remains constant at 5280 rpm, corresponding to the steady wind speed, as illustrated in Fig. 18.

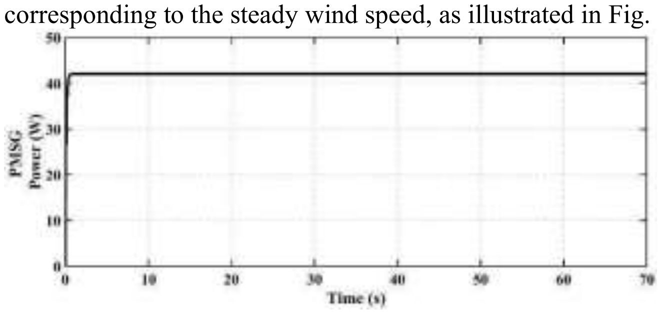

Fig19 PMSG power vr time

The constant wind speed results in steady power generation from the PMSG, as illustrated in Fig. 19.

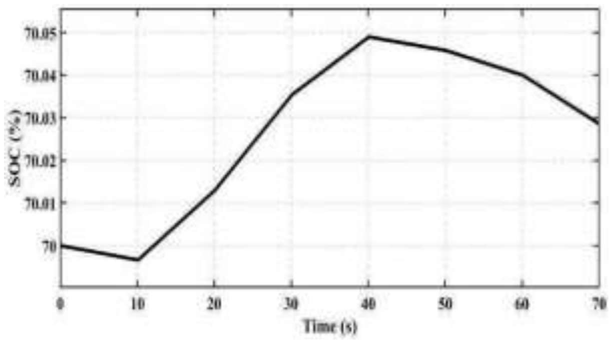

Fig20: SOC(%) vr time.

The SOC profile presented in Fig. 20 indicates the battery's discharging operation during the simulation period.

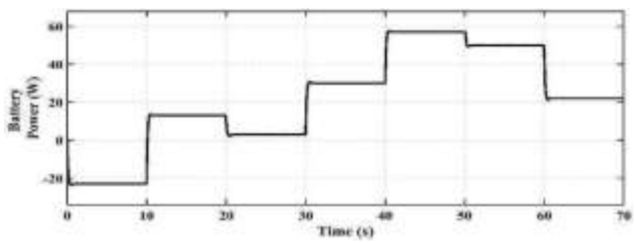

Fig 21, Battery vs time

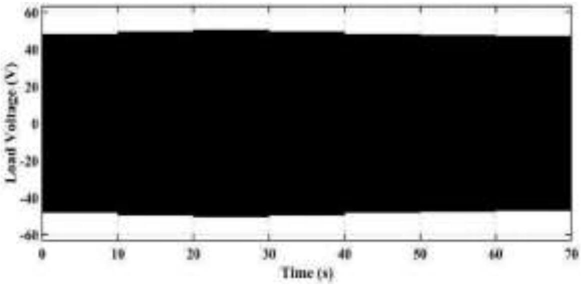

Fig 22: DC Bus Voltage VS Time

The power balance is achieved by the energy storage device which maintains aconstant DC

bus voltage at 50V as shown in Fig 22

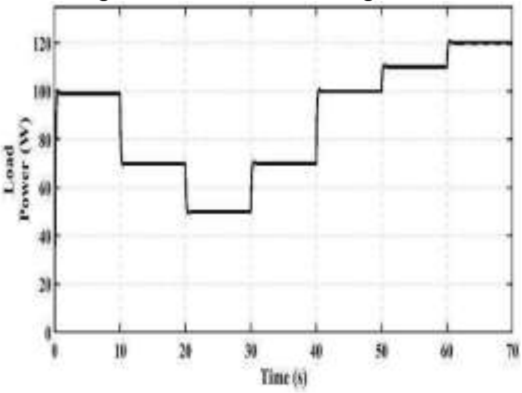

Fig 23: Load voltage vr time
As shown in Fig. 23, the microgrid maintains a stable load terminal voltage despite variations in load demand.
Fig.24 load vr time

The microgrid's performance was evaluated under a variable load, with changes occurring every 10 seconds. The power at different points within the microgrid is illustrated in Fig. 24. At the start, the load demand is 100 W, and the power generated from renewable sources is slightly below this demand, with the deficit supplied by the battery. From 10 s to 40 s, the load demand decreases, allowing the battery to charge from the excess renewable generation. After 40 s, the load exceeds the renewable supply, and the battery provides the additional power required to meet the demand.

3. CONCLUSIONS

The proposed microgrid energy management control strategy, incorporating a hybrid energy storage system, was evaluated under generation fluctuations, load variations, and fault conditions. Analysis of the DC microgrid indicates that the control strategy effectively maintains energy balance between the sources and load, while keeping the DC link voltage stable regardless of changes in generation or load. Both transient and steady-state power demands are efficiently met through the combined operation of supercapacitors and battery storage. Comparative studies with conventional control strategies demonstrate that the proposed approach outperforms traditional methods, offering faster DC link voltage regulation and improved overall system performance.

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