# 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 mostcommonly used hybrid renewable energy sources are solar and wind energy. Both these sources of energy are intermittent in nature; therefore, the use of an energystorage 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

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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.

## 2.System Description

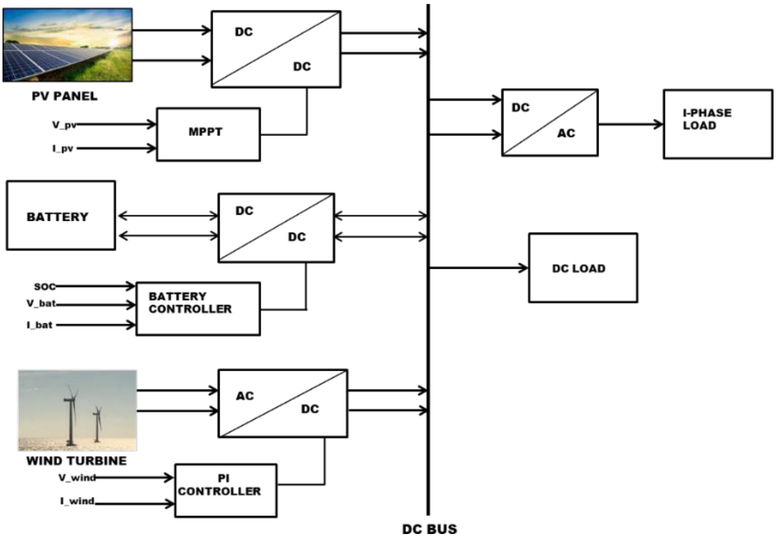

**Fig 1**: Block Diagram of small scale hybrid wind solar battery based microgrid

The proposed system is shown in Fig. 1. 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. An energy management system is used to control the power flow under differentconditions in order to supply to the load through a single-phase inverter.

## 3. 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.

$$Jsc = Isc/A$$

Where, $I_{sc}$ is short circuit current, $J_{sc}$ maximum current density and A is the area of solar cell.

## 4. 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

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

## 5. 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.

## 6. 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.

## 7. 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.

$$P_{pv}=VI$$

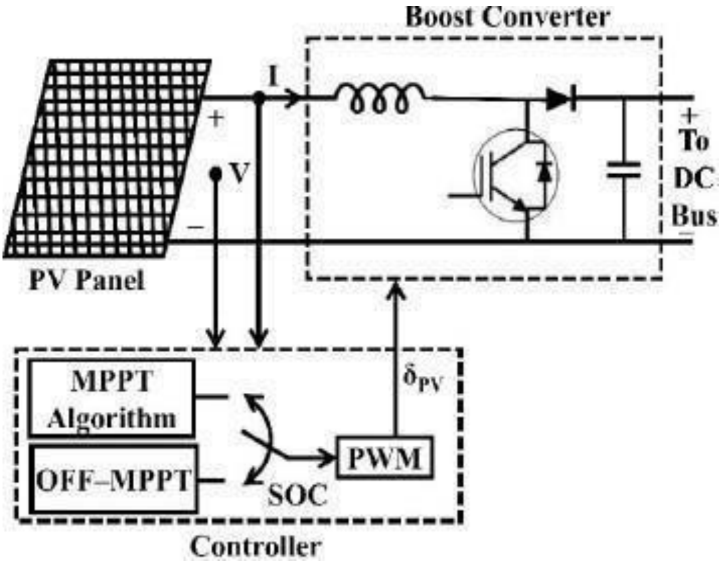

**Fig 2:** Solar Energy Conversion System with Controller

## 8. 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 the excitation 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 3.

$$\omega_e = P\omega_g$$
$$e_q = \omega_e\lambda_0$$
$$T_e = 1.5[(L_d - L_q)i_d i_q + i_q\lambda_0$$

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.

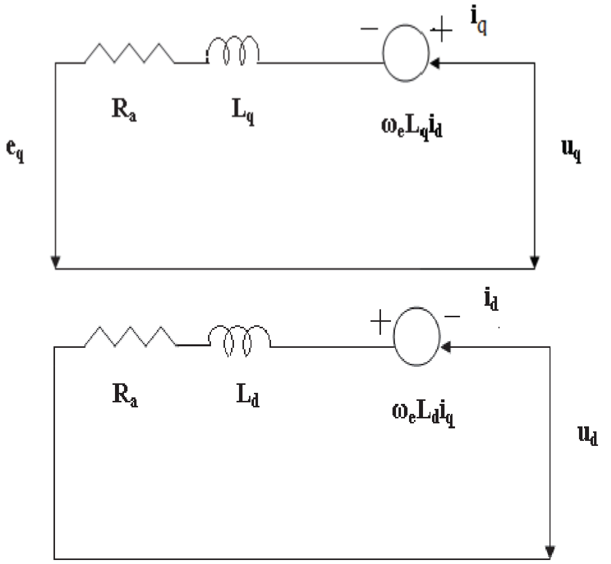

**Fig. 3** PMSG Modeling

## 9. WIND ENERGY CONVERSION SYSTEM (WECS):

The WECS consists of a wind turbine, a PMSG, a DC-DC boost converter andcontroller. The power extracted from the wind is [15] where $\rho$ is the air density in kg/m3,$A$ is the area swept by the rotor blades in $m^2$, and v is the wind velocity in m/s. $C_p$ is the power coefficient and is a function of tip speed ratio (TSR,$\lambda$) and pitch angle ($\theta$)

$$P_w = \frac{1}{2}\rho A v^3 C_p(\lambda, \theta) \tag{2}$$

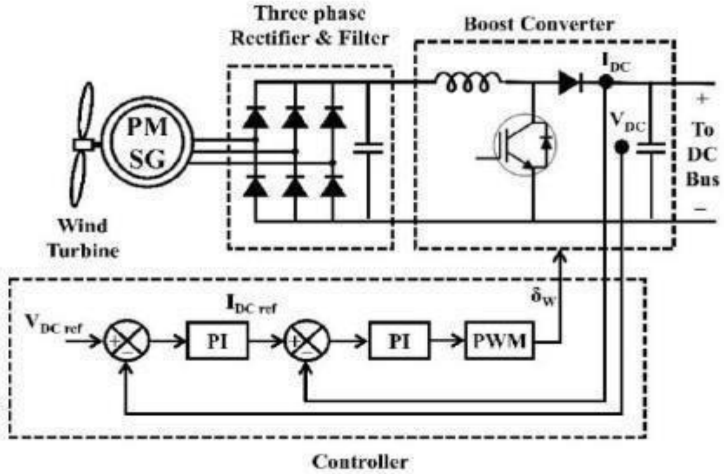

**Fig. 4** Wind energy conversion system with controller

A variable speed wind turbine is used in this system. A permanent magnet synchronous generator is selected for its low maintenance and low operational cost. The generator output is dependent on the wind speed. The three-phase output of the generator is rectified using a diode rectifier and then the voltage level isincreased with the help of a DC-DC boost converter as shown in Fig. 4.

## 10. Energy Management System (EMS):

The EMS is the primary controller which coordinates and controls all control action in the microgrid system. All the controllers of the converters in the previous sections operate based on the EMS control mode[8]. The boost converter of the solar energy conversion system operates in two modes depending on the power generation; MPPT mode/ off-MPPT mode.[6]

The Battery bidirectional converter operates in charging or discharging mode and maintains the DC bus voltage constant, the DC-DC boost converter of the wind energy conversion system operates in boost mode[16]. The power in the microgrid must be balanced under differ- ent generation of power from renewable energy sources and load demand conditions. The power balance equation is given as follows.

$$P_W + P_{pv} = P_L + P_{bat}$$

## 11. Results and Discussion

### 11.1 Simulation Results

There were two case scenarios that were carried out on the hybrid renewable energy microgrid. The first case was performed at a constant load condition and the solar and wind energy was varied. The second case was carried out for variations in load demand with constant renewable energy sources. The runtime for the simulation results for both cases is 70s.

*Variations in Renewable Energy Sources with a Constant Load*

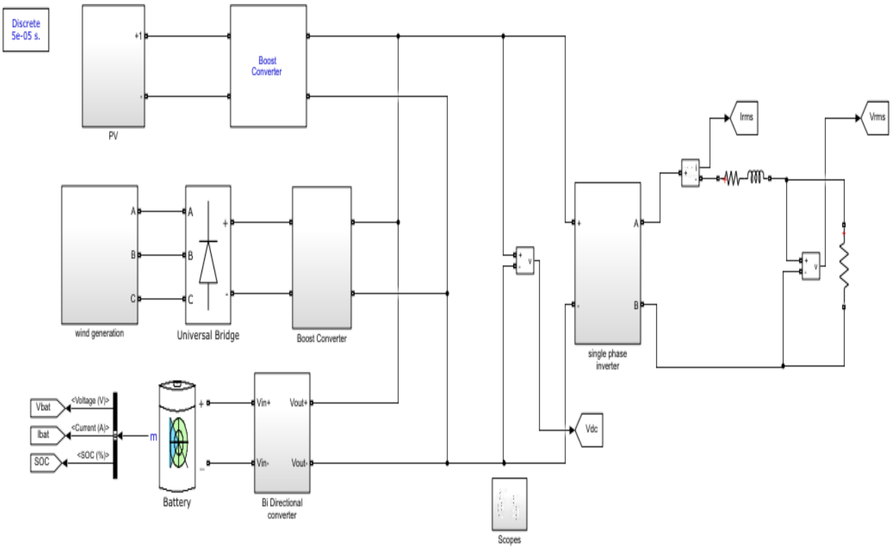

**Fig 5:** Simulation Circuit Diagram of Variations in Renewable Energy Sources with constant Load

The fig 5 shows simulation connection diagram of solar wind battery based micro grid. The objective of the first case is to deliver a constant power to the load for different generating conditions. The solar irradiance is varied by switching the lamps on/off and thus providing different irradiance levels. Though the variations in the wind speed and solar irradiance are only step variations which can never happen in the real world as the meteorological conditions are always changing. Also, in this case, the load is kept fixed which would not occur in a practical situation.

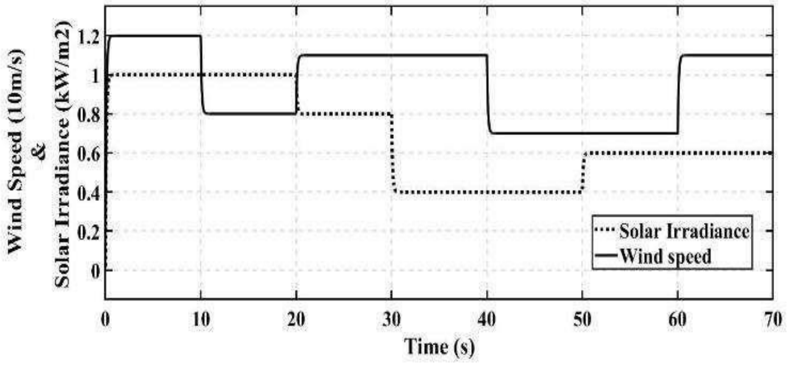

**Fig 6**: Solar Irradiance & Wind Speed vs Time

These values are selected in such a manner that they vary between the possible maximum and minimum range of operation of the PV panel and WT in order to check the system operation for these variations as shown in Fig 6.

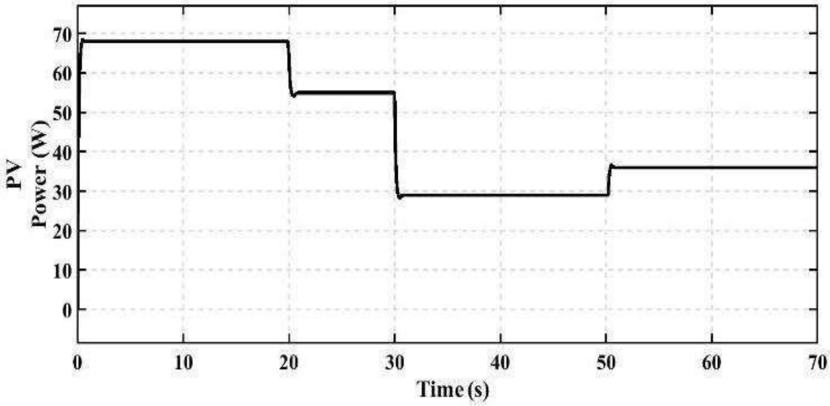

**Fig 7**: PV Power vs Time

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

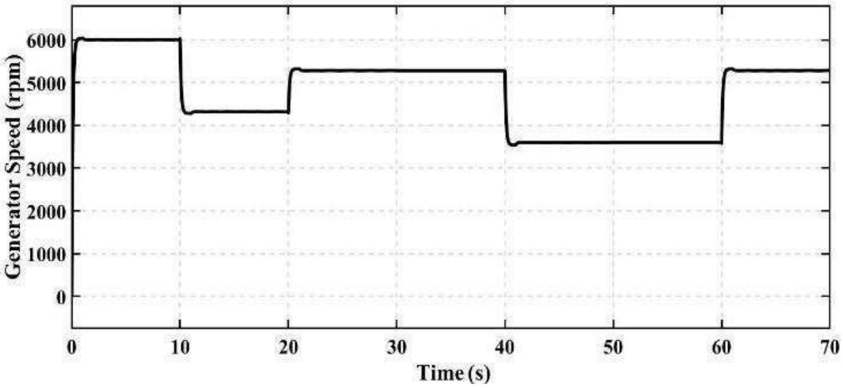

**Fig 8**: PMSG Speed vs Time

The generator speed for different variations of wind speed is shown in Fig.8.

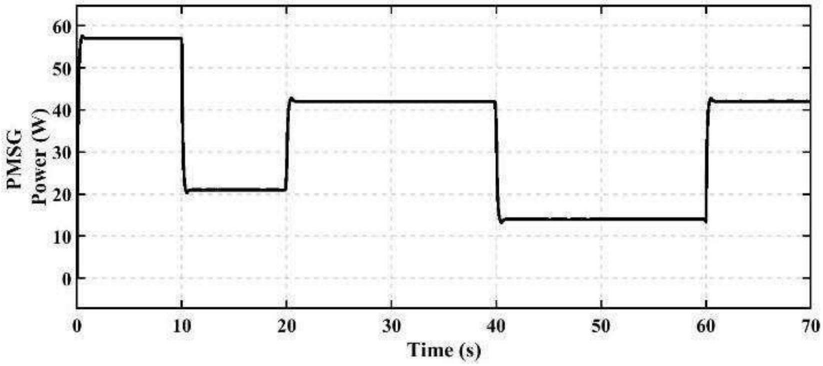

**Fig 9**: PMSG Power vs Time

The wind speed is varied by varying the speed of the fan blower. the wind speed was varied by 12m/s, 8 m/s, 11m/s, 7 m/s and 11 m/s at the start,10s, 20s, 40s and 60s respectively. Causes change in Wind power as shown in Fig 9

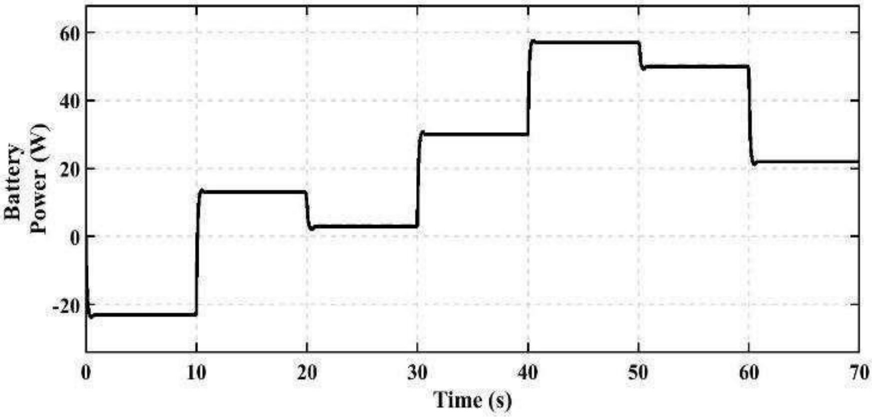

**Fig 10:** Battery Power vs Time

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.

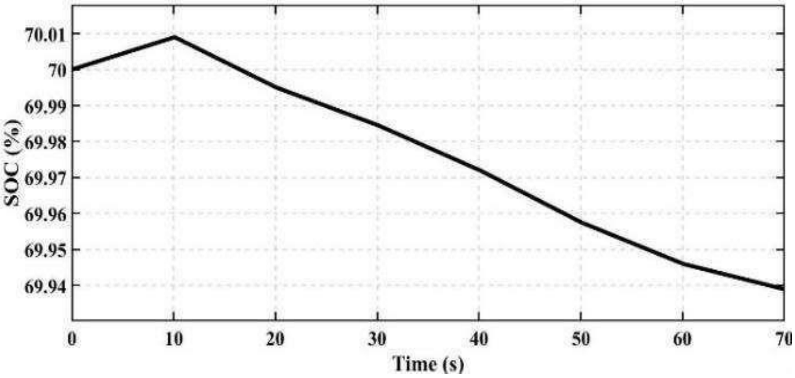

**Fig11:** Battery SOC(%) vs Time

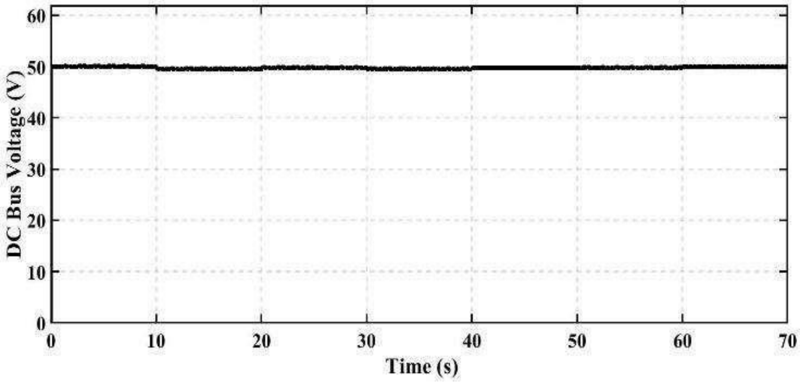

**Fig12:** DC Bus Voltage (V) vs Time

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 a constant DC bus voltage of 50V as shown in Fig.12.

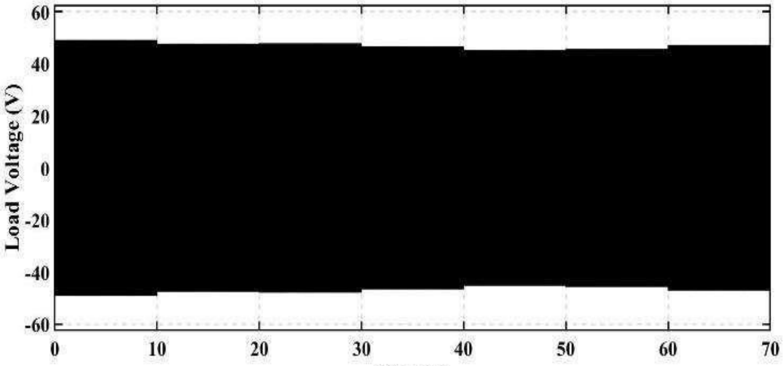

**Fig 13:** Load voltage (V) vs Time

The voltage is kept at constant at the load terminal as shown in Fig.13; for few instances the load voltage drops marginally as the battery discharge rate is higher between 40s to 60s.

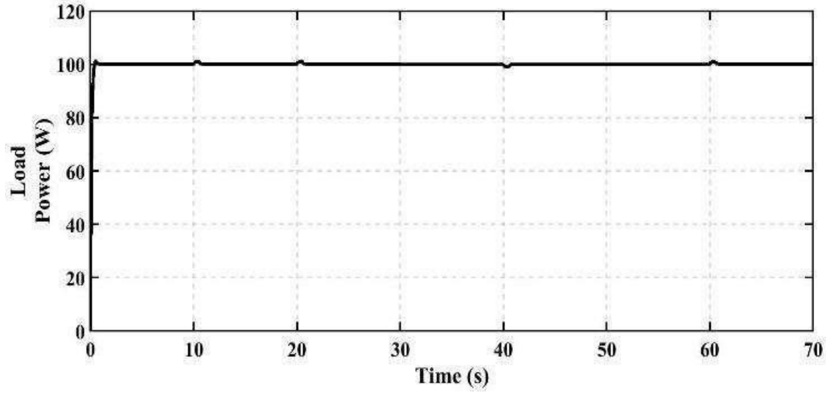

**Fig 14:** Load Power vs Time

But the load is kept fixed as shown in Fig 14. in order to observe the performance operation of the renewable energy conversion systems and the battery storage system for the variations in the power generated from the renewable energy sources, this will be difficult to observe if the load is constantly changing.

*Variations in Load with Constant Renewable Energy Sources*

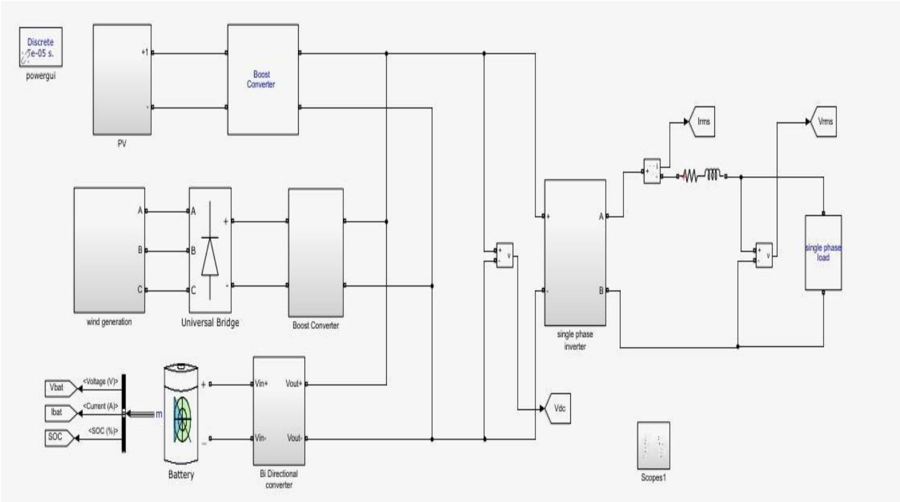

**Fig 15**: Simulation circuit diagram of Variations in Load with a Constant Renewable EnergySources

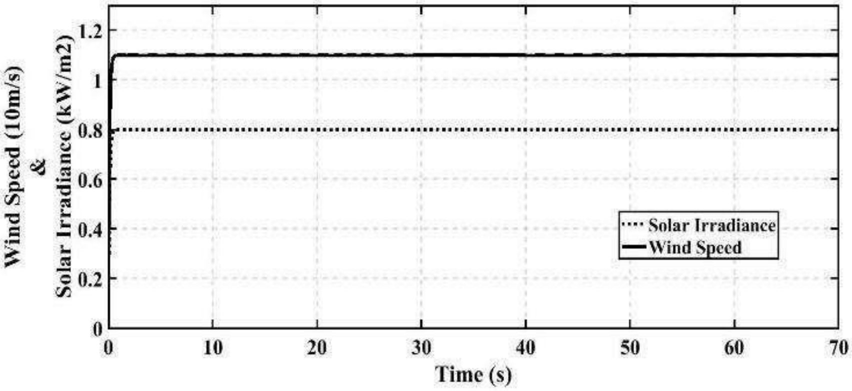

**Fig 16:** Solar Irradiance & Wind Speed vs Time

In the second case scenario, the solar and wind power generation is kept constant with the solar irradiance kept constant at 800W/m2 and the wind speed kept constant at 11m/s as shown in Fig. 16

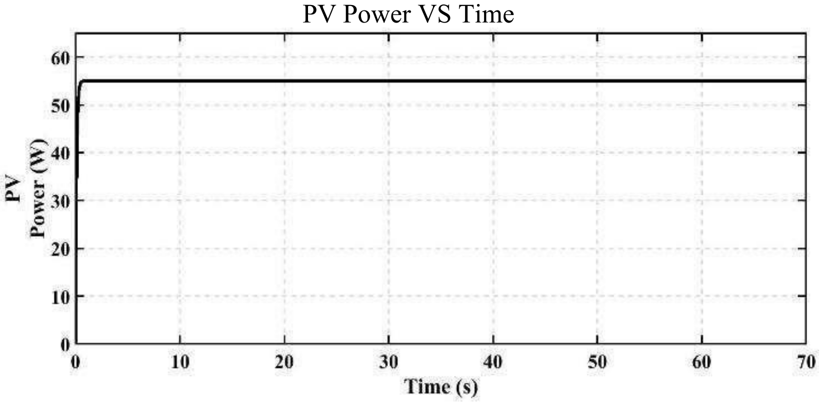

**Fig 17:** PV power VS Time

The energy management system maintains the power balance when the power from the renewable energy sources is constant as shown in Fig 16 and 17.

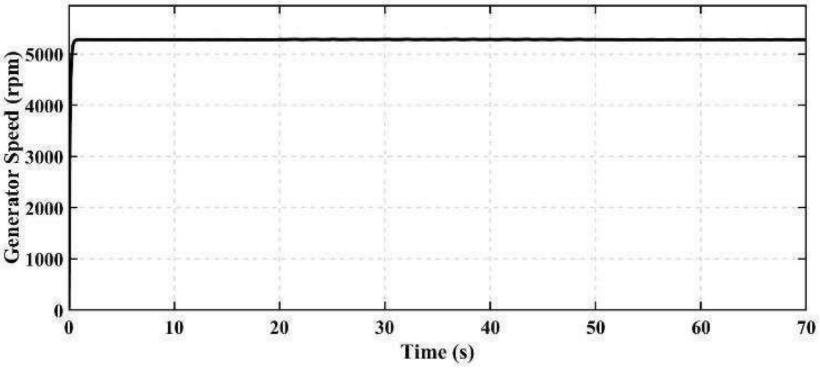

**Fig 18:** Generator Speed VS Time

The generator speed is constant at a speed of 5280 rpm as the wind speed ismaintained constant shown in Fig. 18.

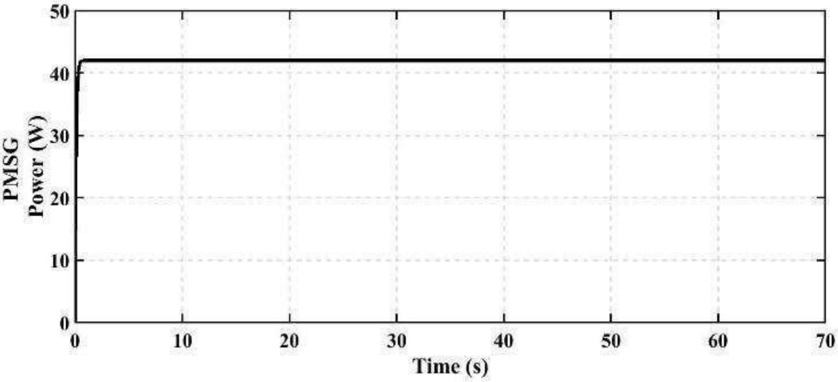

**Fig 19:** PMSG power VS Time

The power at constant wind speed generating constant wind power of the microgrid is shown in Fig.19.

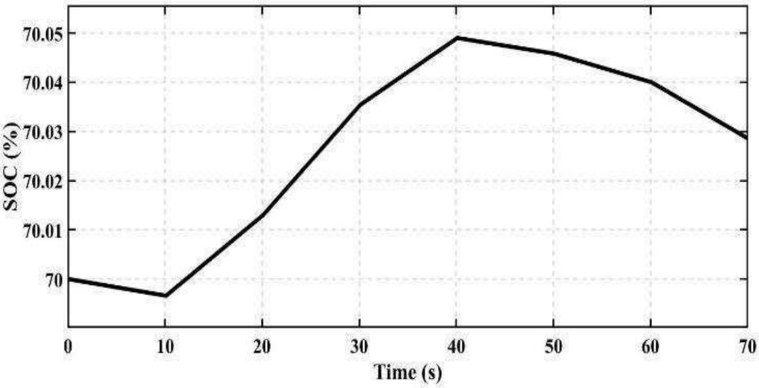

**Fig 20:** SOC(%) VS Time

The battery discharges and the variations in the SOC of the battery isshown in Fig.20.

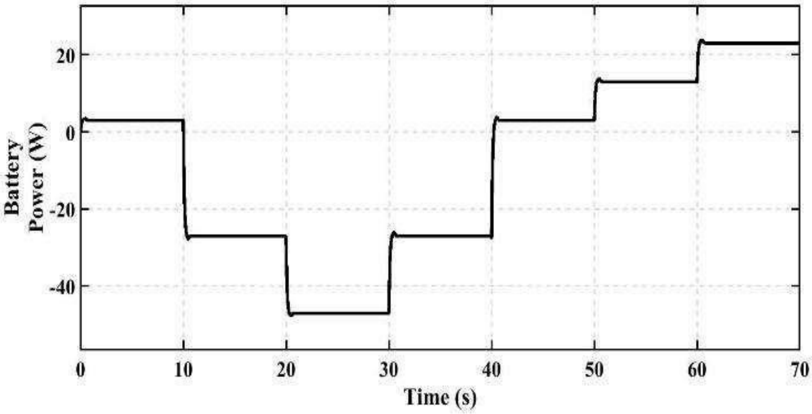

**Fig. 21:** Battery Power VS Time

For both lower load demands and higher load demands For lower load demands, the battery is charged and for higher load demands as shown in Fig 21.

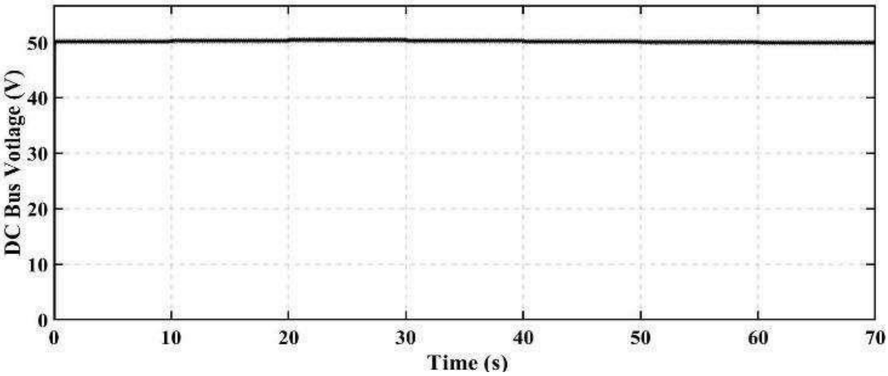

**Fig 22:** DC Bus Voltage VS Time

The power balance is achieved by the energy storage device which maintains aconstant DC bus voltage at 50V as shown in Fig 22

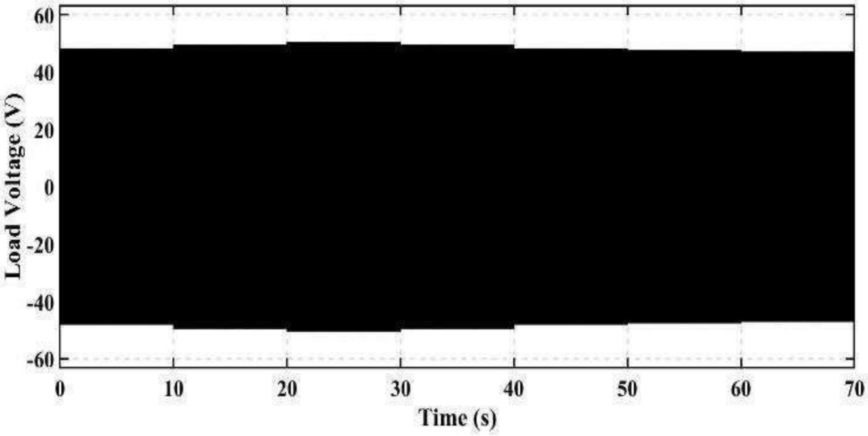

**Fig 23**: Load Voltage VS Time

The microgrid operates for a variable load but the voltage is kept constant at the load terminal as shown in Fig.23.

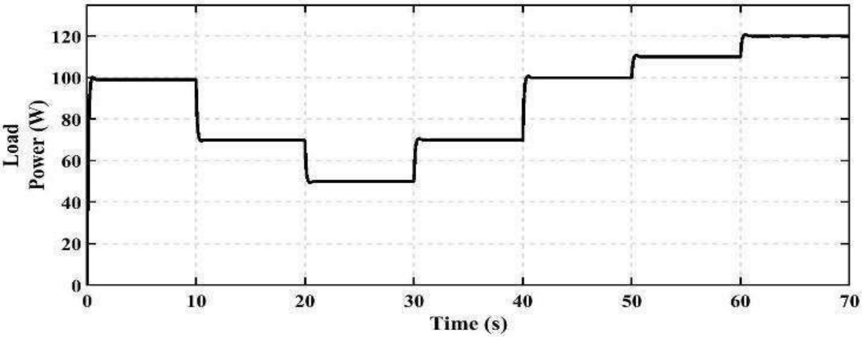

**Fig 24:** Load Power vs Time

The load is varied at every 10s and the performance of the microgrid is tested for a variable load demand. The power at different location of the microgrid is shown in Fig.24. Initially the load demand is 100W and the power generated from the renewable sources is slightly less than the demand and this is met by the battery. After10s until 40s, the demand is lower and during this time the battery is charged from theexcess power generation. After 40s, the demand is more than the supply and the battery supplies the additional power required.

## 12. Conclusion

The proposed Microgrid energy management control strategy with hybrid energy storage system is analysed for generation variation, load variation and under fault conditions. It is observed from the analysis of the DC microgrid, the proposed control strategy maintains the energy balance effectively between the load and source and also maintains the DC link voltage constant irrespective of these variation in generation and load condition. It is also observed that transient as well as average power requirements are satisfied effectively using super capacitor and battery energy storage systems. Comparative analysis of the system with the conventional control strategy shows that proposed system performs better in all cases and provides faster DC link voltage regulation.

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