Stability analysis of Renewable Energy Systems using Energy Storage Systems

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Abstract: **As there is a rapid increase in the demand for energy and pollution due to the non renewable sources the renewable energy sources are getting more impetus. The renewable energy sources are a constituent of distributed energy resources (DER), which when connected with the energy storage systems like battery can form a microgrid which can be operated in grid connected mode and isolated mode. Microgrid stability is one of the important aspects in control & smooth operation of power system network. A microgrid when operating in an islanded or off grid mode has issues like control, flow of active and reactive power and also the inertia of the DG sources. The energy and power balance is obtained by the employment of energy storage system. The excess energy can be stored when the energy production is high and can be used when the demand increases. The timely employment of storage system helps in maintain active and reactive power flow, voltage control and frequency control of the system. This paper analyses the steady state stability of the microgrid comprising of solar PV, wind turbine system and the effect of energy storage system on various types of loads.**

Key words: Distributed energy resources, Distributed generation, Microgrid, Storage system, Stability.

I. Introduction

Microgrid comprises of a network of DG sources, energy storage system, and controllable loads with access to a network. Microgrid is the future of power system to facilitate stand alone systems. The microgrid can be controlled by connecting it to the grid or by operating it islanded. The efficiency of the system can help in improved by microgrid [1],[2]. The DG is a novel concept which is used to cater to technical, environmental challenges of the conventional power systems [3]. DG power is the good way to generate and distribute electricity as well as enabling the integration of renewable energy. The microgrid can be used in grid connected mode and standalone mode [4]. Microgrid stability is focussed mostly on the mathematical means of analysis. In the grid connected mode the dynamics of the system are dictated by the grid that is they are controlled by the grid, whereas in the standalone mode the dynamics like inertia are governed by the micro sources or the DG sources [5]. Microgrid stability was previously classified based on the classification of conventional grid stability, the characteristics of microgrid were not considered. Meanwhile, the instability caused by large disturbances and means to improve the microgrid stability were not summarized throughly. In the traditional sense the microgrid stability is classified as the steady state stability, transient stability, small signal stability and the voltage stability. The steady state stability refers to as the ability of a system to bring itself back to stable configuration following a small disturbance in the network, like a slow increase in load. The transient stability refers to the ability of a system to reach the stable condition following a large disturbance in the network. It is related to sudden removal of load, braking, faults. The small signal stability refers to the ability to maintain the under small continuous disturbances [6]. The voltage stability refers to the ability to maintain steady state voltage at all times under normal conditions and after being subjected to a disturbance [7].

This paper discusses the steady state stability of the microgrid comprising of the renewable energy sources like solar PV, Wind Energy Conversion system (WECS) and battery energy storage system (BESS). The microgrid is operated in both stand alone and connected to the grid. The effect of changing of the loading conditions and source variation is observed with the energy storage and without the energy storage system. When energy storage system is incorporated it can enhance the system inertia through energy management properties [7]. It can also mitigate reliability issues of the systems like PV and wind power systems [8]. The paper is organised as follows Section I is the introduction to the paper. Section II describes the system model, section III contains the simulation results, section IV discusses the conclusion and section V gives the future scope .

II. System model

A. System Description

The system network is modeled in the Matlab/Simulink® environment to test for varying operating conditions. It comprises of solar PV system (50kW), WECS (40kW) ,BESS (20 Ah), inverter, transformer, load and grid. It has an AC bus and a DC bus. The loads are connected to the AC bus. The main voltage source inverter (VSI) links the AC and the DC bus which is important for power management.

The PV array is connected to a MPPT dc to dc boost converter to maintain constant dc bus voltage. Permanent magnet synchronous wind generator followed by a rectifier is used to convert variable speed wind (variable frequency ac voltage) to a constant dc bus voltage. It is then given to a boost converter with regulator to maintain the constant dc bus voltage. DC bus voltage is held constant by the dc/dc converters of wind, solar PV systems, battery energy storage systems and also by the main AC/DC bidirectional converter. This main converter is also responsible for maintaining quality of power at point of common coupling (PCC). The controller of main converter will allow power flow in either direction based on power mismatch on either AC/DC side. When the total generation on dc side is more than that of load, the main converter acts as an inverter and injects power from dc to ac side. The main converter acts as a rectifier when the total generation on dc side is not enough to cater loads on dc side. The system can operate in the grid connected mode, islanded mode and the hybrid mode.

The battery is not only used to support the system during power unbalance but also to provide support to the system under the fault. The microgrid should be able to island itself under faulty conditions. In grid connected mode the battery is fully charged to 100% (SOC). The SOC is an important factor in determining whether the microgrid is absorbing or injecting power prior to fault.

The system block diagram is shown in figure 1

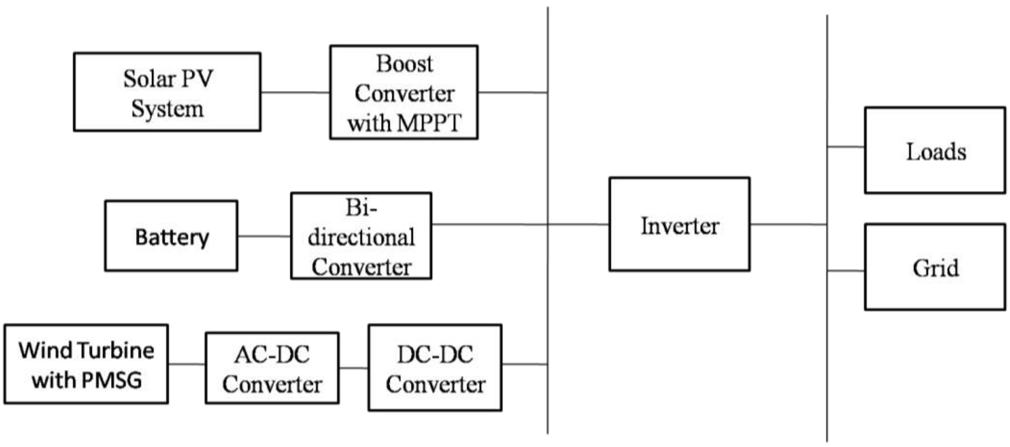


Fig. 1. Block Diagram of the Microgrid System

B. Modeling of Solar PV system

A simulink® model for a solar cell is available in Sim electronics® toolbox is not suitable for simpower system® environment. The solar PV model uses the one diode form of the model as shown in figure 2. The model has the rated power of 50kW. The series resistance resistance of the metal fingers, contacts and the parallel resistance represents the recombination effect. The insolation is turned into current gain and is given to controlled current source. Also the model takes the temperature change in the account.

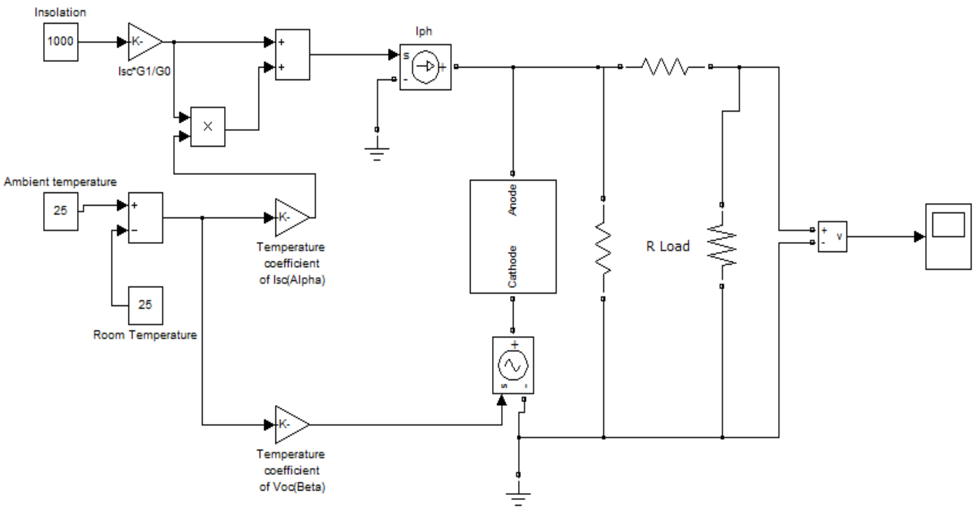


Fig. 2. Simulink model of the solar system

As the efficiency of the solar system is very less therefore it is necessary to extract the maximum power from the solar system. The MPPT algorithm used in the system is incremental conductance algorithm [9]. It is implemented using simulink blocks by using current and voltage signals from the solar PV system. An initial duty cycle is assumed and based on the MPPT control block the error signal is computed and is then given to PWM generator which gives the switching pulses. The output voltage is thus maintained to 500 V.

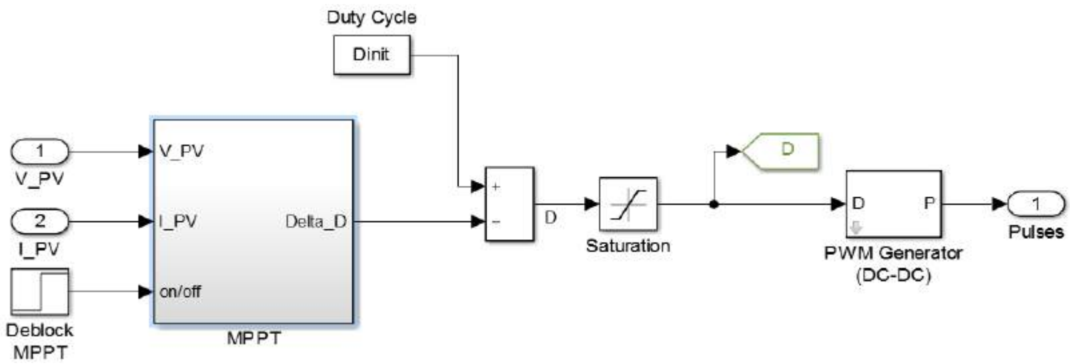


Fig. 3. Incremental conductance algorithm model in Simulink.

TABLE I
PARAMETERS OF A SOLAR PV PANEL

Symbol	Description	Value
P_{max}	Nominal Power	50kW
V_{oc}	Open circuit voltage	284.4 V
I_{sc0}	Short-circuit current at T_{ref}	180 A
R_s	Series resistance of a PV cell	0 Ω
R_{sh}	Shunt resistance of a PV cell	1MΩ
α	Temperature co-efficient of SC current	0.65×10^{-3}/ °C
β	Temperature co-efficient of OC voltage	-160 mV/ °C
N	Number of cells in series	5
M	Number of cells in parallel	33
n	Diode ideality factor	1.50
G	Solar irradiance level (Nominal)	1000 W/m^2
Q	Electron charge	1.602×10^{-19} C
E_{gap}	Energy band gap for silicon	1.1eV

B. Modeling of Wind System

The wind energy system consists of wind turbine coupled to PMSG [10] and then supplied to the boost converter in order to maintain the dc bus voltage to 500 V. The mechanical power of a wind turbine is given as

$$P = \frac{1}{2} * Cp * \rho * A * v^3 \; . \qquad (1)$$

Where v is the wind speed and Cp is the power coefficient which is a function of tip speed ratio (TSR) and wind speed.

TSR is given as $\lambda = \frac{\omega R}{V}$. (2)

The output of the wind turbine is given to the PMSG which then given to the uncontrolled rectifier or the diode rectifier. The dc output is variable and thus it is then given to the dc-dc converter which is controlled by a control loop comprising of a PI regulator. The output voltage is thus controlled and is maintained to 500V.

TABLE II
PARAMETERS OF WIND ENERGY CONVERSION SYSTEM

Symbol	Description	Value
$P_{generated}$	Rated Generator Power	40 kW
ω_{rated}	Rated mechanical speed	314 rad/s
R_s	Stator Resistance	0.05 Ω
L_{ds}	Stator d-axis inductance	0.635 mH
L_{qs}	Stator q-axis inductance	0.635 mH
Ψ_f	Permanent magnet flux	0.192 Wb
P	Poles	6
V_{w_rated}	Rated wind speed	14 m/s
R	Radius of wind turbine blade	5 m
N_b	Number of blades	3

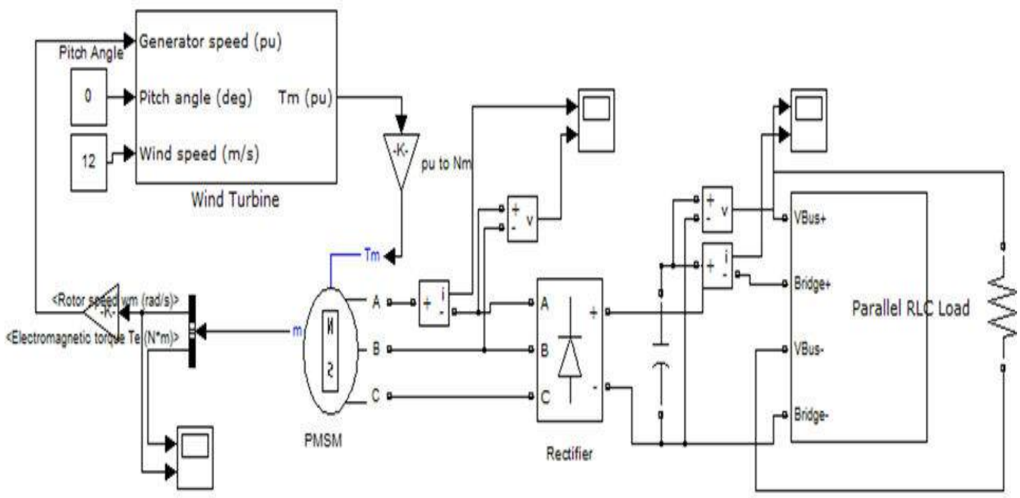


Fig 4. Simulink model wind turbine connected to the dc-dc converter

C. Modeling of Battery system

Battery is modeled using equations (11) and (12)

$$V_{batt} = V_0 + i_b R_b - K.\frac{Q}{Q - \int i_b dt} + A.\exp\left(-B\int i_b dt\right) \quad (3)$$

$$SOC = 100\left(1 - \frac{\int i_b dt}{Q}\right) \quad (4)$$

Where, V_0 is the open circuit voltage of the battery, R_b is internal resistance of the battery, Q is the battery capacity (Ah), i_b is the battery discharge current, K is the polarization constant (Ah^{-1}), A is the exponential voltage, and B is the exponential capacity ($(Ah)^{-1}$).

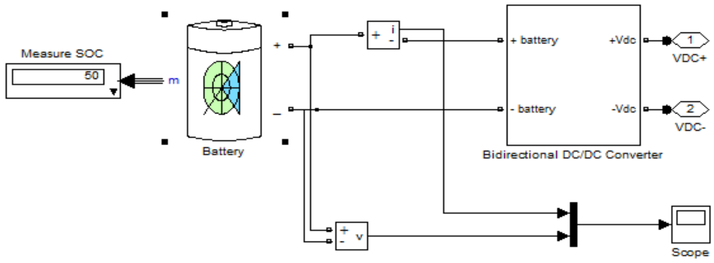


Fig 5. Simulink model of a battery system

The battery is connected to a bidirectional converter to facilitate the bi directional power flow. This is connected to the DC bus.

D. Modeling of VSI

The system employs a 3 level voltage source inverter with input voltage of 500V dc . The output voltage is then increased with the help of the step up transformer which can be then used to connect to the loads or the utility grid. The inverter is controlled by the PWM generator which is used to generate the gating pulses to the switches of the inverter.

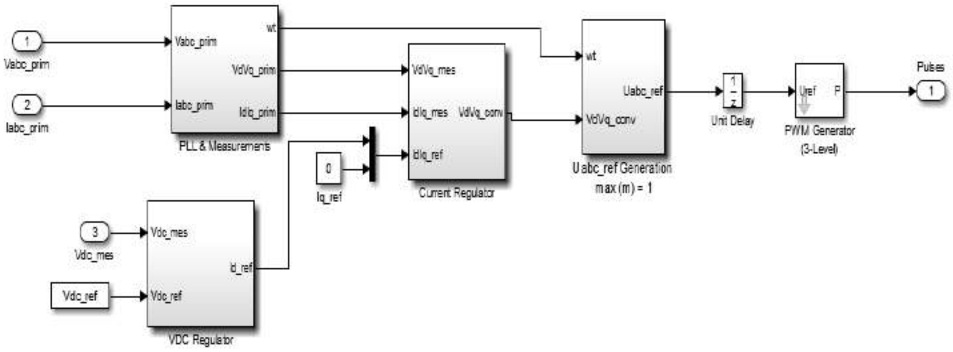


Fig 6. Simulink model of VSI PWM control system.

III. SIMULATIONS, RESULTS AND DISCUSSIONS

The system is modeled and tested using the simpower system toolbox of Matlab/Simulink®. The system is tested with the storage system connected and without the storage system connected for standalone operation for variation in the load. The test conditions include monitoring the dc link voltage or the dc bus voltage, performance analysis of renewable energy sources like wind, PV under variable loads and how battery system or BESS behaves when connected in the system i.e. to test for the SOC under different conditions.

A. DC link voltage

The DC link voltage should be at 500 V as the dc link serves the input to the main VSI which governs the loads. The voltage is maintained constant with the help of a dc-dc converters. These converters are controlled to regulate the voltage. The voltage is maintained at the same level even under the load and source variations.

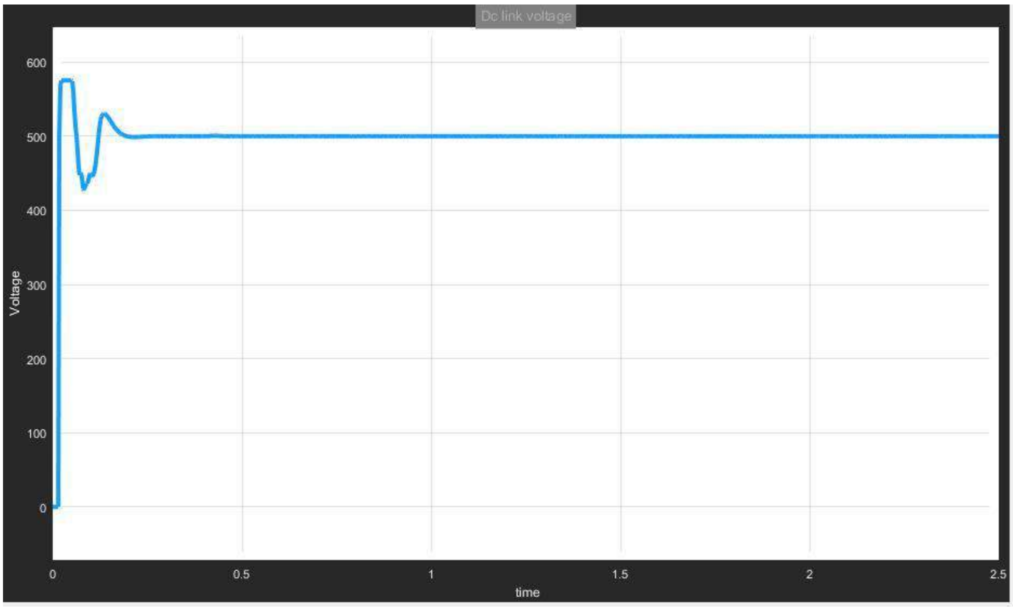


Fig 7. DC link voltage of the system

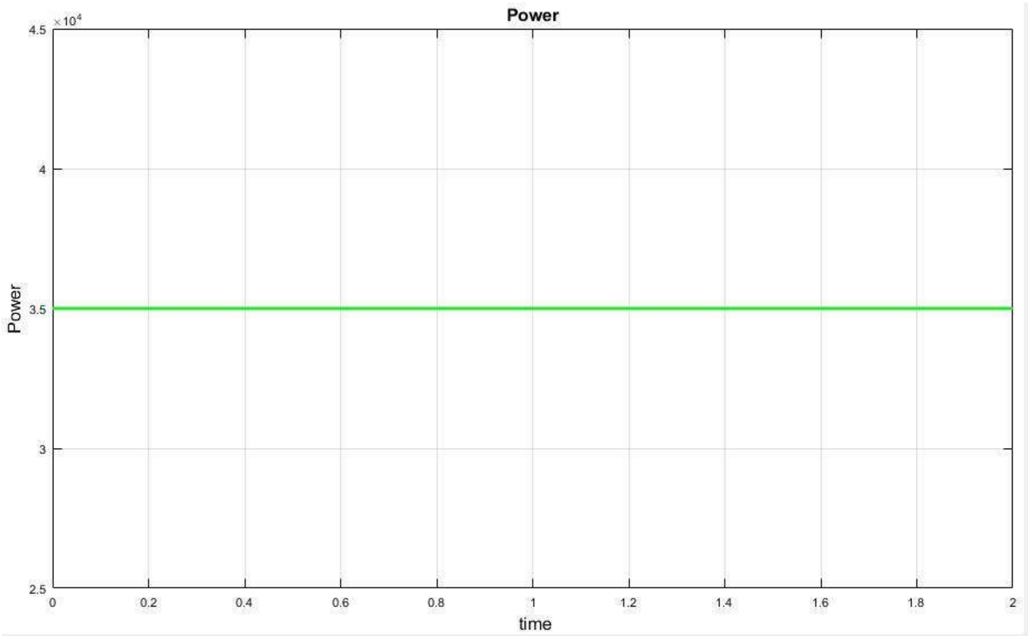
B. Renewable Energy Sources performance

A. Performance of the Wind Energy System

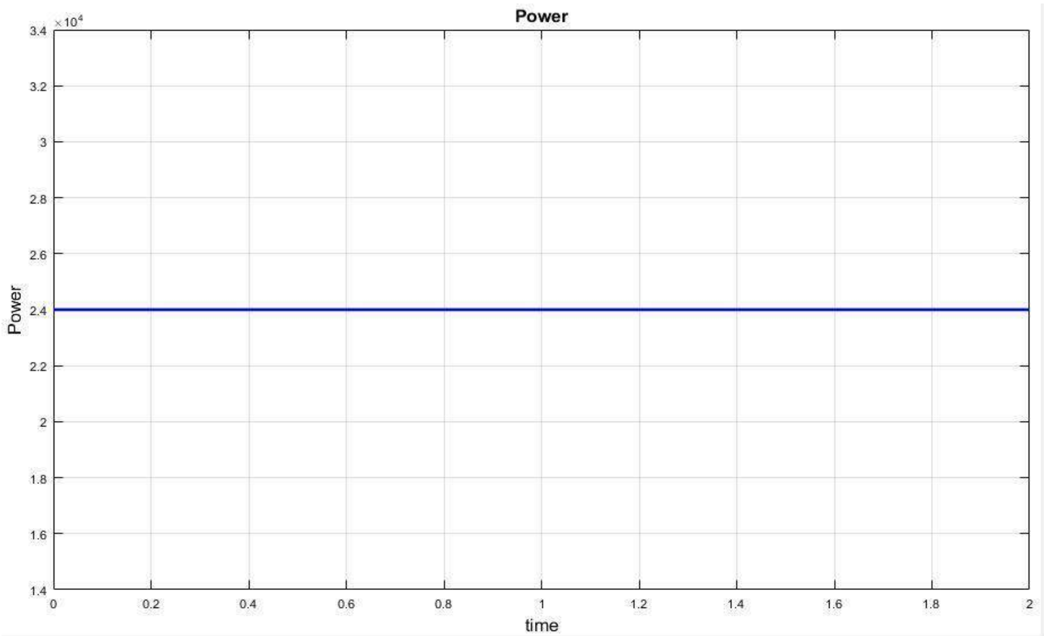
Power rating of the wind system is 40kW. The loads are considered as 30kW, 20kW and the power extracted from the wind system is noted. The power drawn by the source for these conditions is given in table III and simulink results of the same are shown subsequently.

TABLE III: Power generated by Wind System for different loads

Load (kW)	WECS (kW)
30	36
20	24



. Fig 8. Power by the Wind system for load of 30kW.



. Fig 9. Power by the Wind system for load of 20kW

B. Performance of the Solar PV System

The solar PV system is also tested in the same manner as the wind energy system. The rating of the solar PV system is 50 kW. The system is tested for loads of 45kW and 40kW. The table IV gives the loading conditions and the power generated by the solar PV system and also the simulink plots are shown subsequently.

TABLE IV: Power generated by PV for different loads

Load (kW)	Solar PV (kW)
45	50
40	45

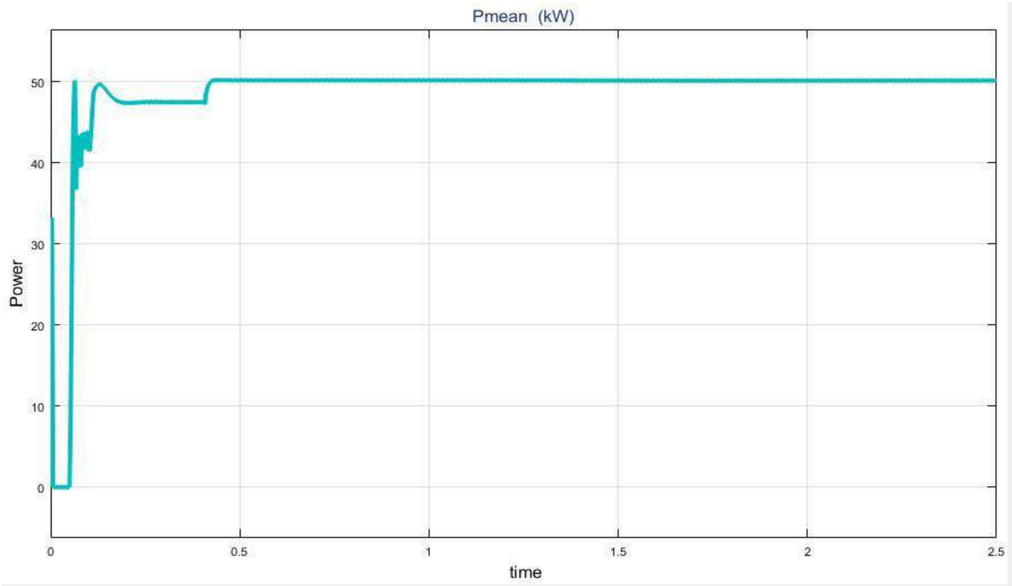
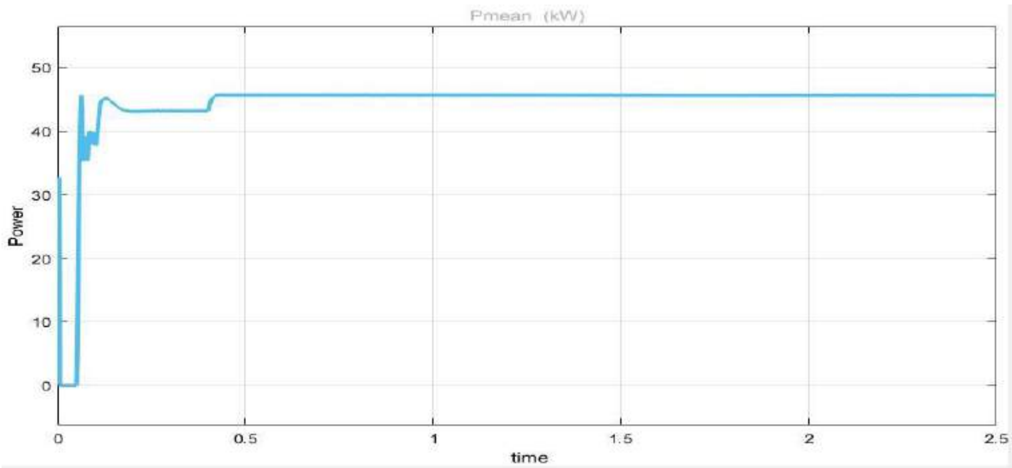


Fig .10. Power by the Solar PV system for load of 45kW



. Fig .11. Power by the Solar PV system for load of 40kW

The initial transients are due to time that the MPPT takes in order to track the maximum power point. It then reaches to the constant steady state value.

C. Performance of the Hybrid System

The hybrid system comprises of both solar PV and WECS operated in parallel and connected to a same DC bus. As the dc bus voltage for both systems is constant both sources can be connected together.

The power sharing by individual sources in response to loads is given in table V below:

TABLE V: Power Sharing in Hybrid System

Load (kW)	Solar PV (kW)	WECS (kW)
78	50	36

The following are the results of the simulation in the simulink:

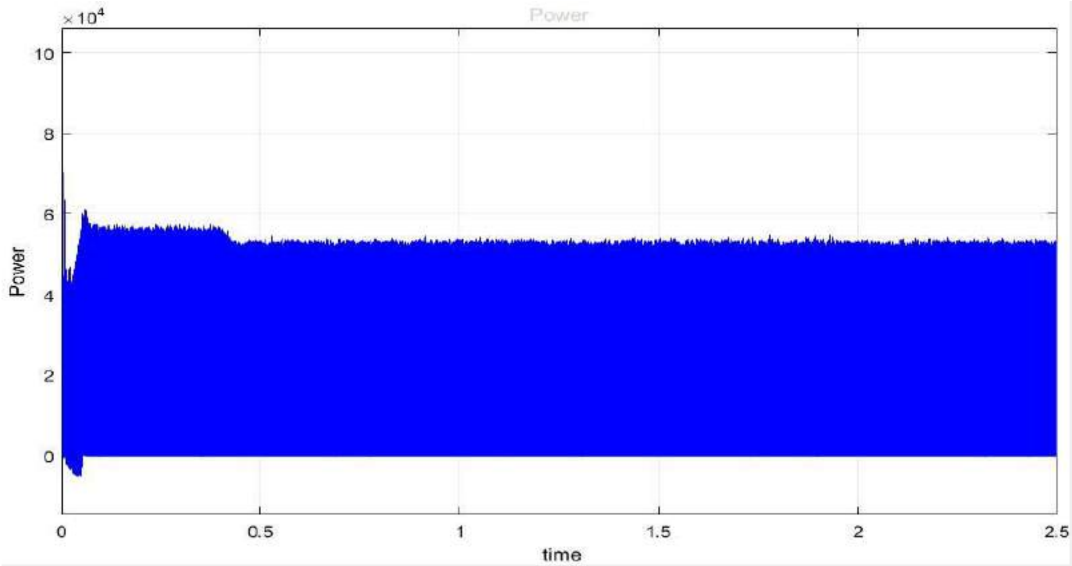


Fig 14. Power by the Wind system for load of 78kW

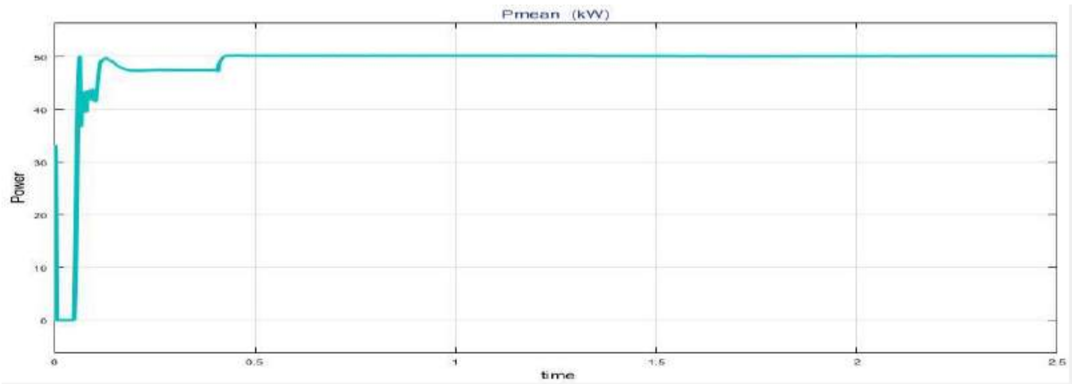


Fig 15. Power by the Solar PV system for load of 78kW

D. Renewable Energy Systems with energy storage system

Energy storage systems are important as they provide support to the system when there is a deficit of energy also it helps in maintaining the system inertia. The battery energy system is used in this system. The state of charge of the battery plays a crucial role in the performance of the system. The performance of the battery system is summarized in table VI and the subsequent plots.

TABLE VI: Performance Of Battery Energy System

Load (kW)	Solar PV (kW)	WECS (kW)	Battery SOC
90	51	43	Discharging
70	43	32	Charging

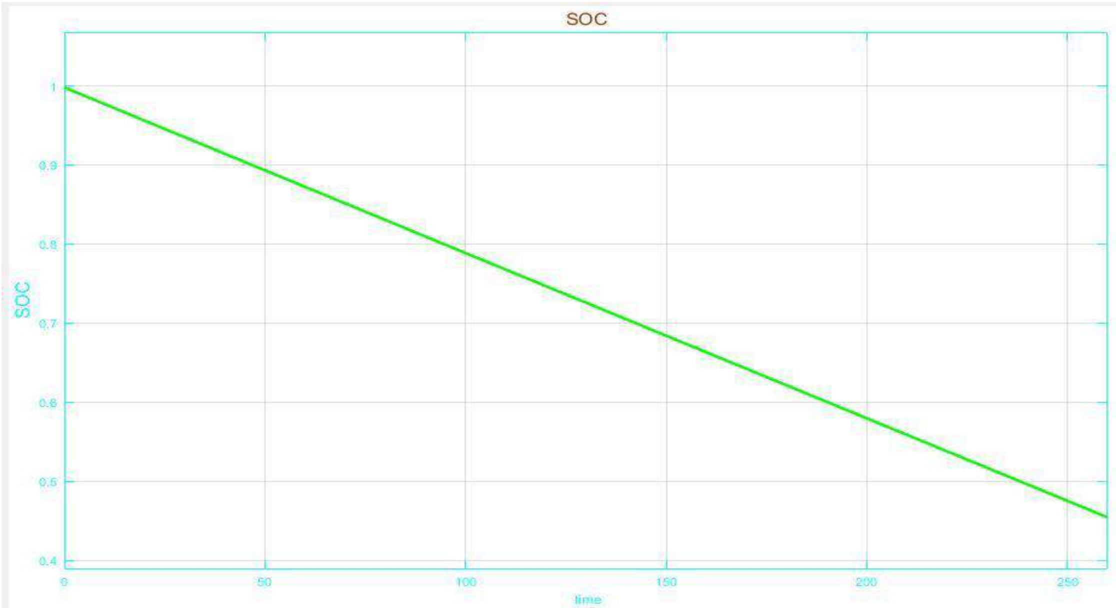


Fig.16. Battery discharging at load of 90kW as Pgen<Pload (SOC v/s time)

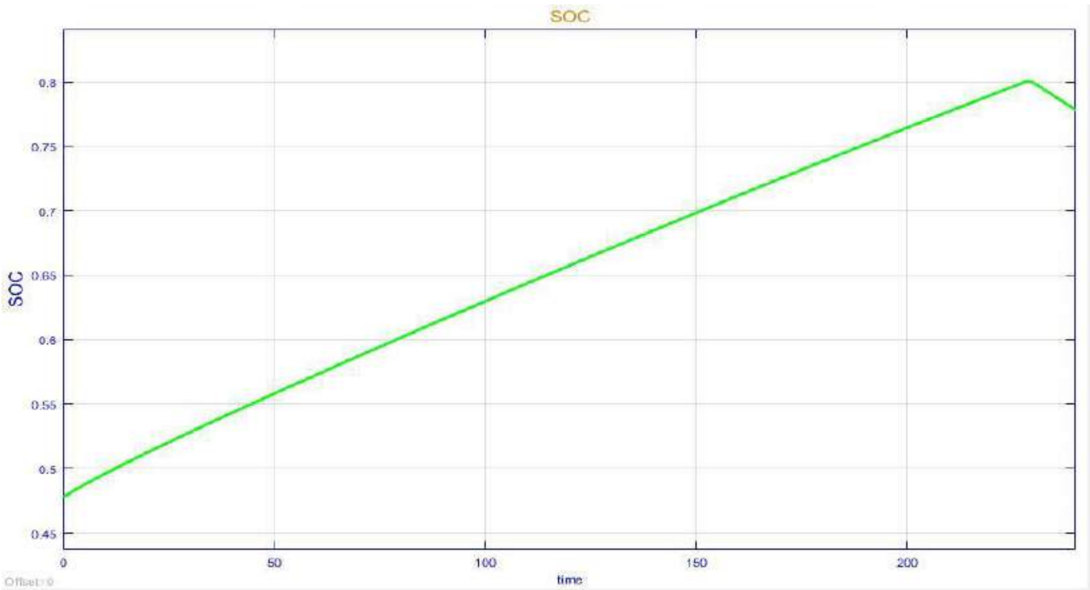


Fig. 17. Battery charging at load of 60kW as Pgen>Pload (SOC v/s time)

The state of charge of battery determines the power transfer. When the battery is charging Total generation> load. When the battery discharges Total generation< load connected.

IV. CONCLUSION

In this paper the steady state response of the renewable energy sources for different source and load conditions are tested. The models for solar PV system, wind energy system and battery energy storage systems have been developed. The hybrid models are also tested with and without energy storage. The energy storage system help to cater to excess load demand when generation is less than the load. A properly designed energy storage system can aid in the efficient and reliable operation of the microgrid. Timely application of the storage systems as developed in model helps to maintain the voltage and frequency within the limits.

V. FUTURE SCOPE

The system can be further tested for transient conditions by applying faults. Also dynamic stability can also be tested. The storage system like ultra capacitor can be modeled and used for the testing under the faulty or transient conditions. Also the best storage system for different conditions either steady state or dynamic can be suggested.

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