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Design and Control of PV Connected Microgrid

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***Abstract* — In this paper, control of energy management system (EMS) for microgrid with photo voltaic (PV) based distribution generation (DG) system. The DG units along with energy storage devices play a vital role in optimizing the performance and efficiency in the distribution system network. Hill Climbing technique is used as MPPT (Maximum Power Point Tracking) algorithm to extract maximum power generated from PV source and supplemented by battery based energy storage system during cloudy conditions. The load arrangements are divided into two categories, Secured and Non secured loads. An Uninterrupted Power Supply (UPS) unit acts as interface between grid and secured loads and ensures continuous supply during stand alone condition. The proposed EMS control operates by sensing the load demands under both grid connected and stand alone modes and switches the loads and energy storage devices accordingly. The validity of the proposed EMS methodology is verified with the simulation results.**

Key words— Energy Management system, Distributed Generation, Uninterrupted Power supplies, Battery Energy Storage System, Load Management.

I. INTRODUCTION

Distribution system is the interface between the power generation and consumption. The idea of microgrid is provided in Fig 1. A microgrid is a representation of low voltage grid which consists of low power electrical generators, loads and devices to store electrical energy (a microgrid have generation capacity of maximum 1 MVA). The microgrid provides supply to residential area, industrial site, theme park, shopping complexes, etc. The low voltage local loads are supplied by medium voltage grid by using a step down transformer. A switch is used to change the operational modes from grid connected condition and stand alone condition. The large power generation stations are replaced by renewable energy resources dependent on the weather conditions and it is much hard to predict the power generation and to maintain the grid power balance. The micro grids are used to increase the reliability of electric grid. The energy storage devices are gets charged in grid connected conditions and get discharged to supply the loads during stand alone condition. The micro grid also provides real and reactive power injection to the main grid in case of reduction in load demand or high power generation across the DG units. The mostly used energy storage devices such as batteries, fuel cells, flywheels, etc. combined with appropriate converter forms the Energy storage systems. Moreover, the transmission losses are reduced due to the presence of microgrids (nearby populated areas).

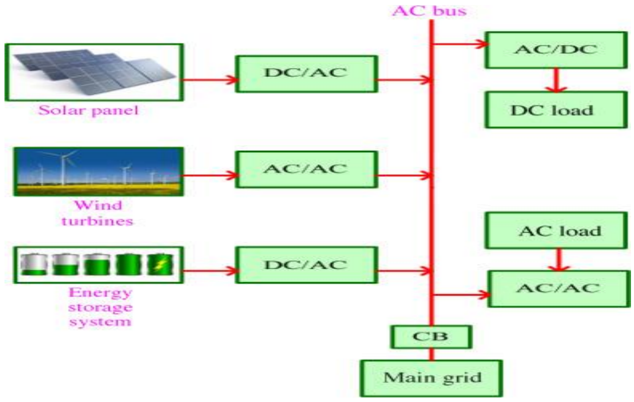

Fig 1: The main concept of a microgrid

The smart grids manages the loads by shifting the supply time according to the nature of the loads and thereby reduces the peak power consumption at any instance of time and also reducing the gap between power generation and demands. The PV source combined with battery provides the supply under variation of weather and load conditions [1]. In [2], the MPPT (Perturb & Observe algorithm) control based interleaved converters along with Neutral Point Clamped (NPC) inverters provides the supply from PV source and Battery energy storage system to the local loads. The coupling of energy storage devices and Distributed Energy Resources (DER) is achieved and tests are performed for various possible scenarios in [3]. The Active Demand Side Management (ADSM) is done to increase the reliability of the grid system with the help of MPC (Model Predictive Controller) in [4, 5]. The role of MLIs (Multi Level Inverter) in the micro grid is discussed along with improvement of modulation techniques [6]. A supervisory control is introduced along with local
control such as modified hysteresis control and averaging of power with low pass filters so that the hybrid power sourced microgrid operates in different modes [7]. Closed loop voltage control circuits with PI (Proportional Integral) controller are used in dc-dc converters in both line and load voltage regulations [8].

Inverter based DER system is used to control the sharing of power which is further improved with droop control on energy storage device [9]. The DERs are combined and coordinated with the combination of PQ control of inverter with MPPT and battery control circuits and tested with IEEE 13 bus system in both stand alone mode and grid connected mode [10].

In this paper, the PV based distribution generation unit is designed with Hill climbing MPPT algorithm to extract maximum available PV power and a BESS is coupled with PV connected to dc bus. An UPS system is connected to supply secured critical and non critical loads along with dynamic load. The non secured loads are supplied by PV and battery along with grid and also in standalone condition. The EMS control switches the loads according to the availability of generated power and required load demand. The local control units concentrates on maintaining the system voltage in their and nearby nodes.

II. PROPOSED MICROGRID CONFIGURATION

The proposed microgrid configuration is provided in Fig 2. In this PV source is combined with Battery energy storage system and forms a dc bus. A voltage source inverter is connected to the dc bus and provides supply to the loads along with the grid. A UPS system is included to the micro grid so that the loads get secured supply at any instant of time period.

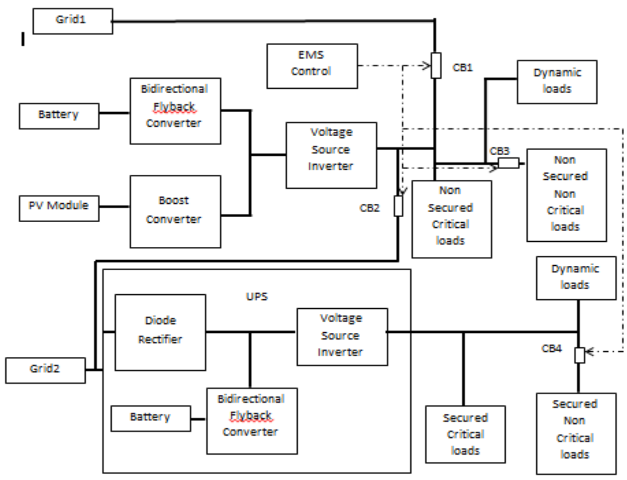

Fig 2: Configuration of proposed microgrid system

The dynamic loads are provided to verify the transient stability of the system. The EMS control provides the routing of grid to loads and also trip the non critical loads when the demand is much higher than supply.

The control circuit for voltage source inverter is provided in Fig 3. The inverter control circuit is responsible for maintaining the dc link voltage and injects required real and reactive power to the grid in grid connected condition and the power is to be delivered to loads in standalone condition. The control loop consists of two loops named as:

(1) DC link voltage control loop (Outer control loop) and
(2) dq current control loops (Inner control).

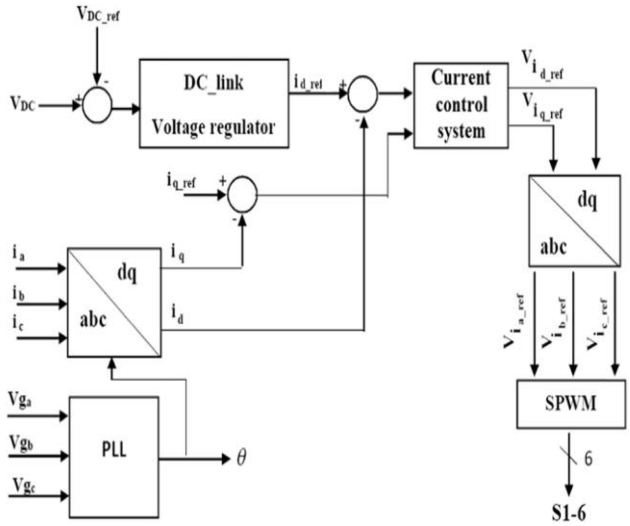

Fig 3 Control circuit for VSC

In the control circuit, the outer control loop generates the reference current (i_d*) for the d-axis current control loop. The inner current control loops provides the regulation of grid currents in order to maintain the dc link voltage as constant.

A. MODELING OF PHOTOVOLTAIC CELL

The Photovoltaic cell's equivalent circuit is provided in Fig. 4 as follows.

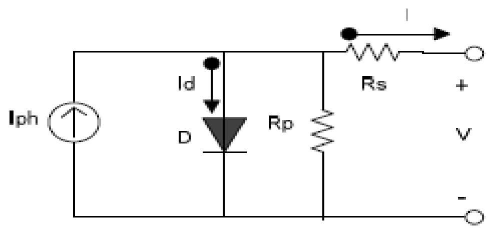

Fig. 4. Equivalent circuit of single diode model of PV cell

The solar cell single diode model is designed based on the five parameter model (R_p, R_s, n, I_o and I_{ph}).

Where

I_o - saturation current of diode (A)
I_{ph} - Photocurrent (A)
R_s – Resistance in series (Ω)
R_p – Resistance in parallel (Ω)
N - Diode factor (1 <= n<= 2)
In the above equation,

$$I = I_{ph} - I_o\left(e^{\frac{V+IR_s}{n_s v_T}} - 1\right) - \frac{V+IR_s}{R_p}$$

•R_s provides the internal losses and voltage drops.
•R_p provides the ground leakage current while the diode is reverse biased.

B. BOOST CONVERTER:

The circuit configuration for the boost converter is provided in Fig. 5 as follows.

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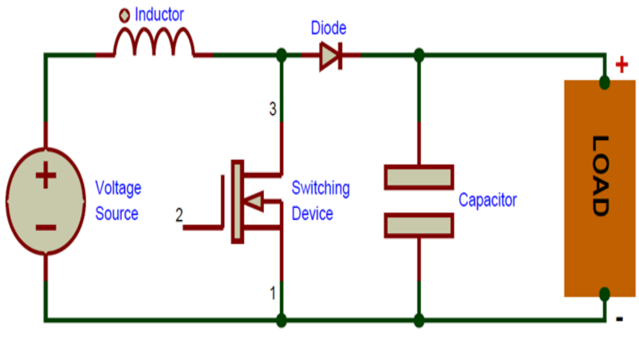

Fig 5 Circuit configuration of Boost Converter

The boost converter provides the load voltage higher than that of the input voltage with the help of duty ratio of the gate pulses provided for power electronic switches. The boost converter configuration consists of an diode, switch, inductor and capacitor. The working of the boost converter are provided in the following modes:

Mode 1:

The equivalent circuit for mode 1 operation of boost converter is given in Fig. 6. Initially, the power electronic switch S is turned ON and the inductor starts to charge during this ON time period.

The voltage equations for inductor and load are provided as follows:

$$V_L = V_{in}$$
$$V_{Co} = V_o$$

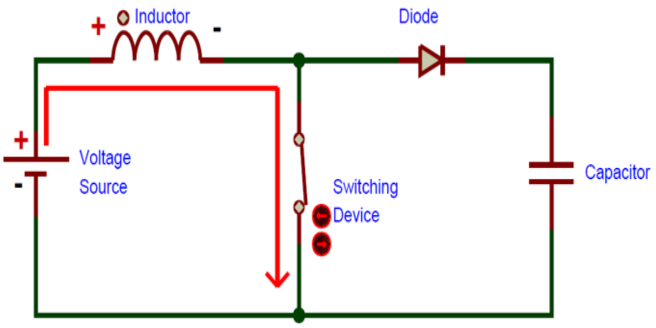

Fig 6 Mode 1, V_L=Vin

Mode 2:

The equivalent circuit for mode 2 operation of boost converter is given in Fig. 7. Here, the power electronic switch S is turned OFF and the inductor starts to discharge during this OFF time period and add up with input voltage in order to provide boosted voltage at load side.

The voltage equation for load is provided as follows:

$$V_o = V_L + V_{in}$$

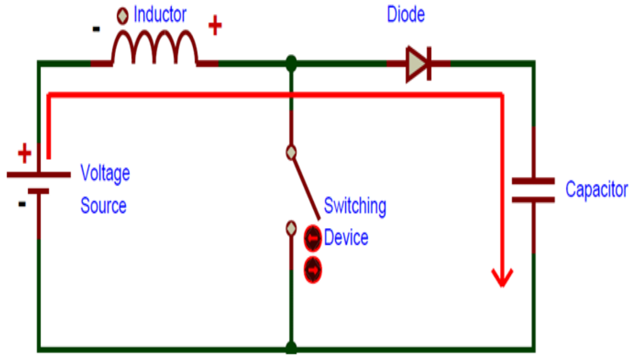

Fig 7 Mode 2, Vo=Vin+V_L

C. DESIGN PROCEDURE OF BOOST CONVERTER:

The boost converter parameters are designed with the help of following equations:

The pulse width of the gate pulse provided to the power electronic switch of boost converter is provided as

$$D = \frac{Vo}{Vo - Vin}$$

The inductor of the boost converter is designed using the following equation:

$$L = \frac{Vin * D}{\Delta Io * Fsw}$$

The inductor ripple current is calculated with the help of equation provided below:

$$\Delta I_L = 0.2 * \frac{Vo}{V_{in}} * I_o$$

The load side capacitance of the boost converter is provided as follows:

$$Co = \frac{\Delta Ioc}{8 * Fsw * \Delta Vo}$$

The load side capacitor ripple voltage is calculated using the equation provided below:

$$\Delta Voc = 2\% \; of \; Vo$$

D. HILL CLIMBING MPPT ALGORITHM:

Various techniques are developed for maximum power point tracking (MPPT) from PV source such as Constant Voltage (CV) method, perturbation and observation (P&O) method, Hill climbing method, Incremental Conductance (IC) method, short circuit current method, open circuit voltage method, Neural network, Fuzzy logic controller method, etc.

In this, the Hill climbing MPPT algorithm is highly used in PV systems due to its simplicity. The power generated from PV at present is compared with PV power in previous instant. As the sign of a ‘slope’ is either complemented or remains unchanged, the PWM output duty cycle is changed accordingly. The hill climbing algorithm is shown in Fig. 8.

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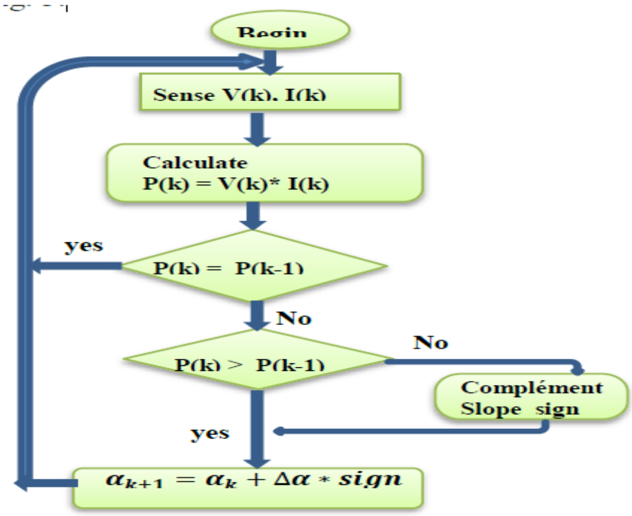

Fig.8 Flow chart of the hill climbing based MPPT algorithm

E. BATTERY ENERGY STORAGE SYSTEM:

The Battery Energy Storage System (BESS) possess the rechargeable batteries which are used as energy storage devices. In this, the Bidirectional Flyback Converter (BFC) topology is used for charging and discharging of the batteries according to the load demand.

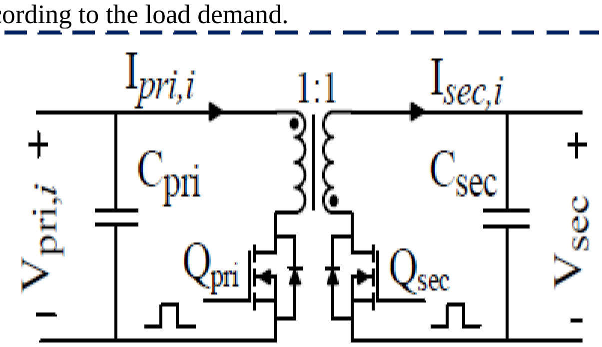

Fig 9 Circuit configuration of bidirectional flyback converters

The main idea of this control circuit is to keep the primary voltage and secondary voltage of the converters as equal and same. The duty cycle (*D*), input voltage (*Vpri*) and output voltage (*Vsec*) of proposed flyback bidirectional converter have the relation as follows:

$$V_{sec} = V_{pri} \frac{D}{1-D}$$

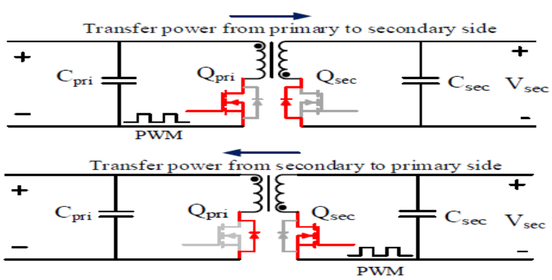

Fig 10 The operation principle of flyback converters in BESS architecture to balance the voltage

The energy is transferred from primary winding of the transformer to secondary winding of the transformer using the switch Qpri. In this, the secondary side switch *Qsec* is turned OFF, and the body diode of the power electronic switch is worked as the flyback diode.

In reverse power flow mode, Qpri is turned OFF where the secondary switch, Qsec is turned ON.

F. EMS CONTROL

In grid connected mode, the power generated is fed to grid depending on the load demand. For higher load demands, the DG units along with grid provides supply. In standalone condition, the power generation depends on load and battery conditions.

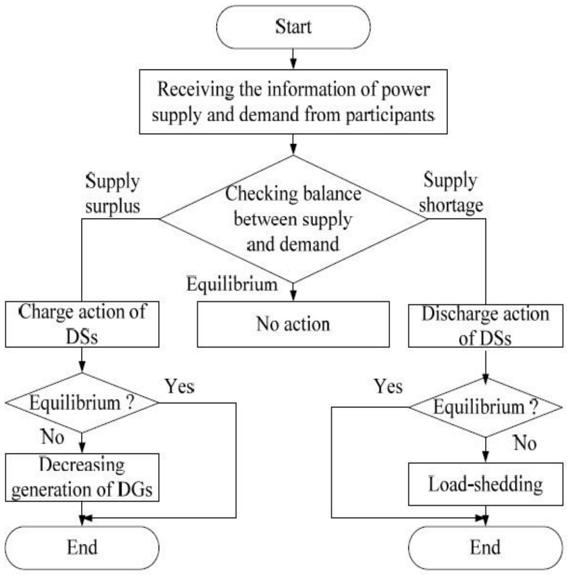

Figure 11: EMS control scheme for proposed microgrid system

If the generation is less than that of demand, the batteries will discharge and provide supply to the loads. In case, if the batteries are discharged completely, the non priority loads are tripped from the system.

In case if still after all non-priority loads are turned OFF, if the available power is not sufficient, the available power must be shared among the remaining loads. This control functionality is provided in Fig 11.

III. SIMULATION SETUP & RESULTS

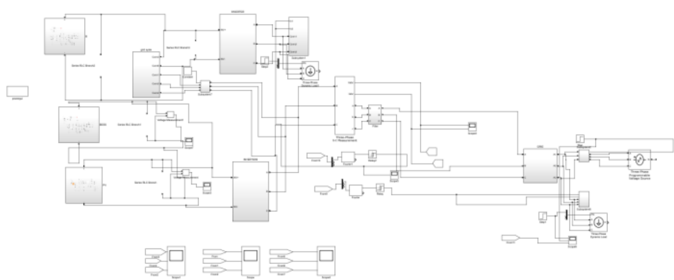

Fig 12 Matlab diagram of proposed system

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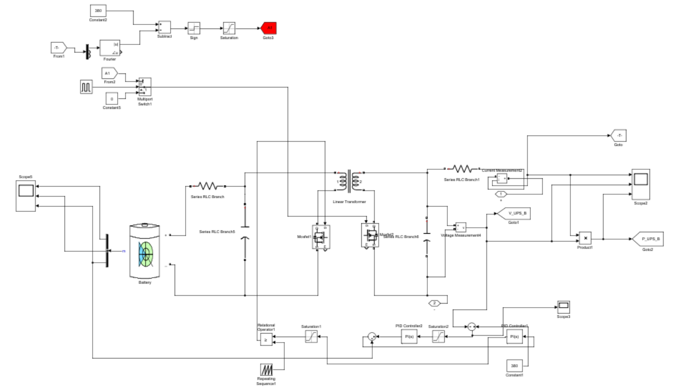

Fig 13 Matlab diagram of battery

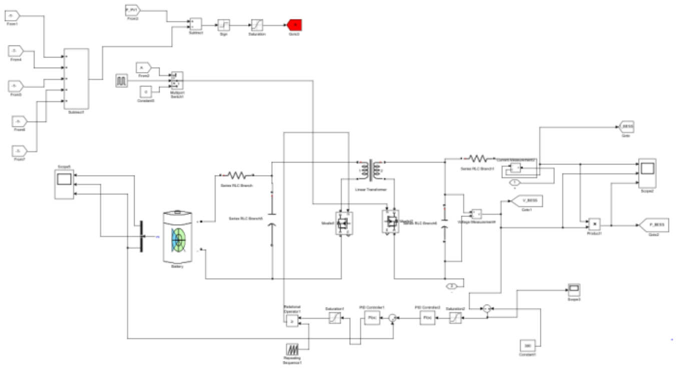

Fig 14 Matlab diagram of BESS

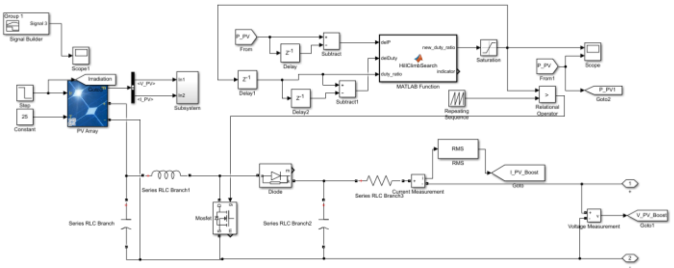

Fig 15 Matlab diagram of PV

The simulation parameters are provided in the following Table I:

TABLE I SIMULATION PARAMETERS

Parameters			Values
PV SOURCE	Voltage		100 V
	Power		2 KW
	BOOST CONVERTER	Inductor	0.73 mH
		Capacitor	18.7 mF
		Switching Frequency	1 KHz
Battery	Voltage		96 V
	Capacity		200 Ah
Grid	Voltage		415 V
	Frequency		50 Hz
Load Arrangements	Non Secured Loads	1-5	5 KW
		6	5 – 10 KW
	Secured Loads	1	1.5 KW
		2	2 KW
		3	1.2 KW
		4	3 KW
		5	1 KW
		6	1 - 3 KW

The PV source is connected to the BESS in dc bus and provided to inverter. The inverter along with grid supplies the load. The grid is disconnected initially and only PV provides supply along with BESS to the loads until t=3s. The PV power reduced as the irradiation reduced at t=4s. The load is increased at t=5s. The following graph shows the changes explained above:

Fig 16 Changes in Load power, grid connected and standalone mode and PV irradiation

The PV power and duty ratio tracked by MPPT is provided below:

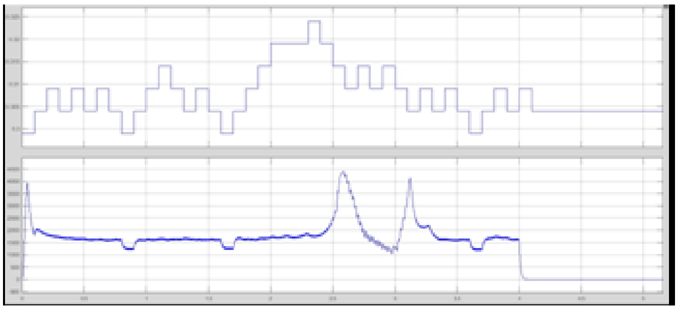

Fig 17 Changes in Load power, grid connected and standalone mode and PV irradiation

In this, the power reduced to zero as the irradiation reduced at t=4s.

The secured and non secured load voltage waveforms are provided below:

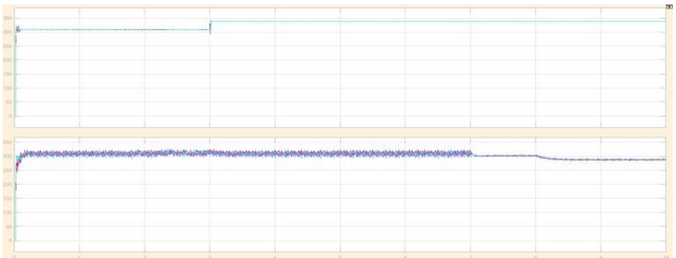

Fig 18 Secured and Non secured load voltages

In this, the grid is disconnected initially and the load voltage is around 300V. And at t=2s, the grid is connected and the load voltage increased to 310V. In secured load voltage, there is slight dip at t= 8s when the dynamic load is connected in stand alone mode.

The battery parameters of BESS and UPS system is provided in the following waveforms:

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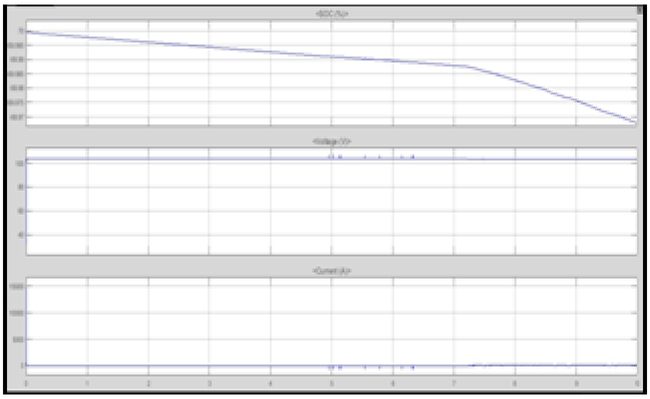

Fig 18.a UPS system battery parameters

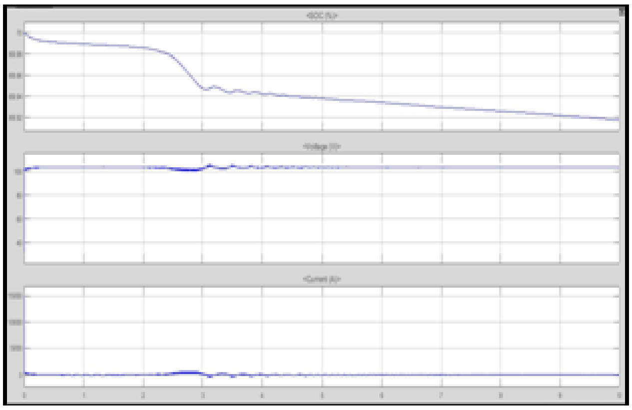

Fig 18.b BESS battery parameters.

The real power waveforms for non secured loads are provided below:

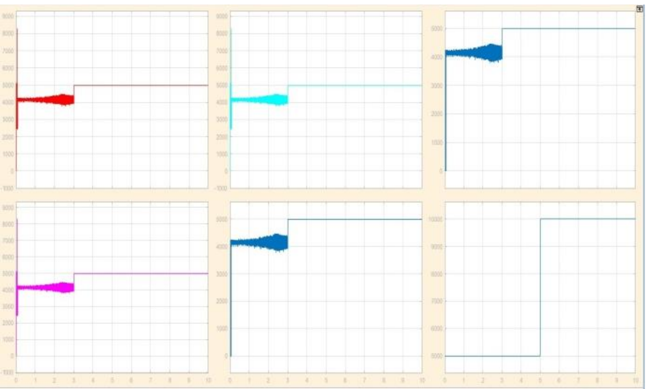

Fig 19 Real power for non secured loads

In this, initially the grid is disconnected and connected at t= 3s. The dynamic load is added from 5 KW to 10 KW at t= 5s. The real power waveforms for secured loads are provided below:

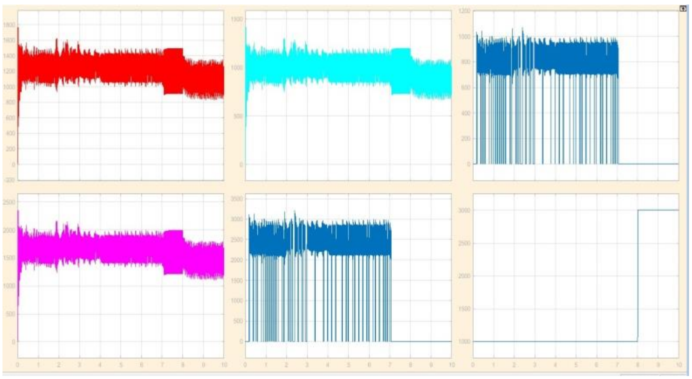

Fig 20 Real power waveforms for secured loads

The power consumed by the loads are provided in the above waveforms. The load 4 and 5 are non critical loads, so that it is disconnected at t = 7s, i.e when grid is disconnected from UPS. Still the dynamic load is connected to the UPS at t=8s.

IV. CONCLUSION

The PV based distribution generation unit was designed with Hill climbing MPPT algorithm to extract maximum PV power and a BESS was coupled with PV connected to dc bus. An UPS system was designed and the secured critical and non critical loads are supplied by UPS along with dynamic load. The non secured loads are supplied by PV and battery along with grid and also in standalone condition. The EMS control provided the switching of the loads according to the availability of generated power and load demand. The local control units concentrated on maintaining the system voltage in their respective nodes while EMS control managed the loads (secured and non secured) accordingly.

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