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Energy Management Storage for PV Connected Smart Microgrids

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***Abstract*— Penetration of renewable sources in the power system network has been increasing in the recent years. One of the solutions being proposed to improve the reliability and performance of these systems is to integrate energy storage device into the power system network. The main fact is that Renewable Energy Sources (RES) plants have to operate at the maximum possible output whenever technically possible. That the ancillary services could be provided by the distributed generators and the energy storage systems are expected to give great added value to the microgrid-based smart grid topologies. These services must be integrated into the control system of the microgrids. This paper presents an improved strategy for energy storage management and demand side management and its application to a microgrid-based smart grid topology that improving power supply reliability.**

Keywords*— Distributed generation (DG); Energy storage management (ESM); Demand side management (DSM); Renewable energy sources (RES); Smart grid; Smart Microgrid.

INTRODUCTION

The demand-driven energy production by solar, wind and other renewable energy sources and storage facilities should be achieved, without risking the power supply reliability and quality [1]. The solution to overcome this problem is the integration of energy storage systems and controllable loads to the grid and through the integration of improvements to the control algorithms. The weather-dependent RES plants have to operate at their maximum possible output whenever technically possible. Therefore energy storage system is very important for balancing the system or energy management of the system. One of the most important parts of future smart grids' topologies seems to be the microgrid, which is generally defined as a distribution grid including distributed generators (DGs), controllable loads and energy storage units [2]. The ancillary services that could be provided by the demand-side and the supply-side of a microgrid are expected to give great added value to the future smart grid [3], [4]. Demand-side management and Load levelization is extensively used in general to provide services like voltage regulation and energy saving for islanded microgrids [4], [5]. A grid connected/stand-alone solar PV system essentially consist of utility, PV array as primary sources, storage device as external leveling agents to balance the primary source power and load. By controlling the active and reactive power of solar PV facilities we can supply ancillary services to the grid [6]–[10]. Finally, during islanded operation of microgrids, the accurate estimation of data about the power produced and consumed and proper management of the state of charge (SoC) of energy storage systems are very important [11]–[16].

In this paper, an improved strategy for energy storage management and demand side management is presented and applied a microgrid-based smart grid topology that improving power supply reliability. These approaches are associated to a new iterative control algorithm of a microgrid. First, the smart distribution grid topology is described, highlighting its new control infrastructure parts that transform the utility grid to "smart grid." Then, a brief description of the proposed iterative control algorithm is presented, whereas in the next section, the details are supplied on the energy storage management and the PV plants active power control strategies. Finally, the simulation results reveal that the new microgrid control strategies improve power supply reliability in grid connected and islanded situations [17] and [18].

I. DESCRIPTION OF THE MICROGRID TOPOLOGY

In a microgrid based smart distribution grid topology, every generator, dc load, or energy storage device is equipped with its dc–ac inverter and connected to the ac microgrid via smart devices that are called special control units (SCUs) in this paper. SCUs are also necessary for the ac loads (or group of loads) and ac generators as shown in Fig. 1 [17], [18]. The SCUs are categorized in load SCUs (L-SCUs), generators SCUs (G-SCUs), storage SCUs (S-SCUs), and interconnection SCUs (I-

SCUs), for connecting the small grid of the ac-bus to the remaining grid (SD). All SCUs consist of a simple metering module, a communication module, an activation module (actuator), and a "smart" module that is responsible for the decision making of each SCU. The last module is integrated into software that runs on a microgrid- dedicated PC. Implementation of this smart distribution grid topology is shown in Fig. 2. The control infrastructure of the smart distribution grid should be compatible and properly interactive with energy storage systems and existing automation technologies that are mainly used to improve energy efficiency in the system.

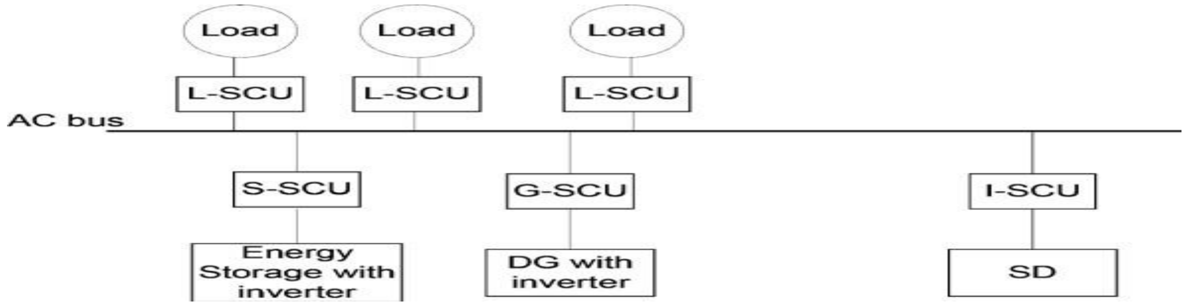

Fig. 1. Smart distribution grid topology incorporating SCUs.

II. IMPLEMENTATION OF THE SMART DISTRIBUTION GRID TOPOLOGY.

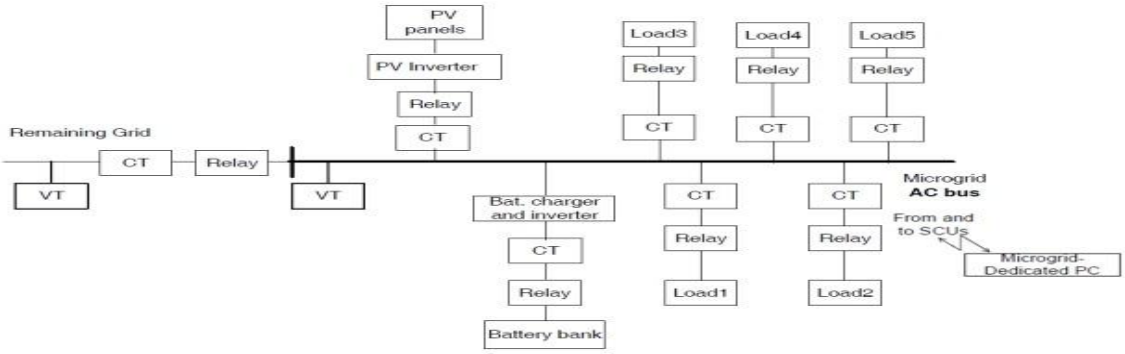

Fig. 2. Implementation of the smart distribution grid topology

The microgrid consists of PV panel arrays of 10KW with connected PV inverter, five loads of approximately 5KW maximum consumption, a 600-Ah battery bank with its inverter and rectifier-charger. The number of SCUs are needed is: one for the PV plants, five for the loads, one for the battery bank, and one for the interconnection to the remaining grid. Each SCU contains one current transformer (CT) for current measurement, one voltage transformer (VT) for voltage measurement, and one actuator- relay and communicates with the microgrid-dedicated PC via cables.

At the microgrid-dedicated PC, a software application processes the input data, incorporates the control algorithm in MATLAB and derives the proper output commands every duty-cycle.

In order to highlight the significance of the proposed energy storage and solar PV active power management strategies, especially during islanding [17], [18], they are compared to a different control strategy and topology [19], which is shown in Figs.3. It would be useful to explain the procedure being followed for load shedding in Fig. 5. The island-inverter can automatically switch off the loads, when the battery bank voltage becomes too low [12]. This is done by the load shedding circuit, which is installed between the inverter and the loads and it has a normally closed contact (NC).When the battery voltage and current have decreased to a SOC charge level of 30% and the system operates in an island mode, the relay is activated and all the loads are disconnected. The single dc-bus topology and the applied energy storage management strategy present serious disadvantages, especially during islanding.

These disadvantages are constant load switching, quick batteries charging and discharging, and insufficient renewable energy sources exploitation, even though careful matching of available supply, demand and storage has occurred [12]. The above undesirable behavior can be avoided by the proper coordination and the succeeding targeted control actions.

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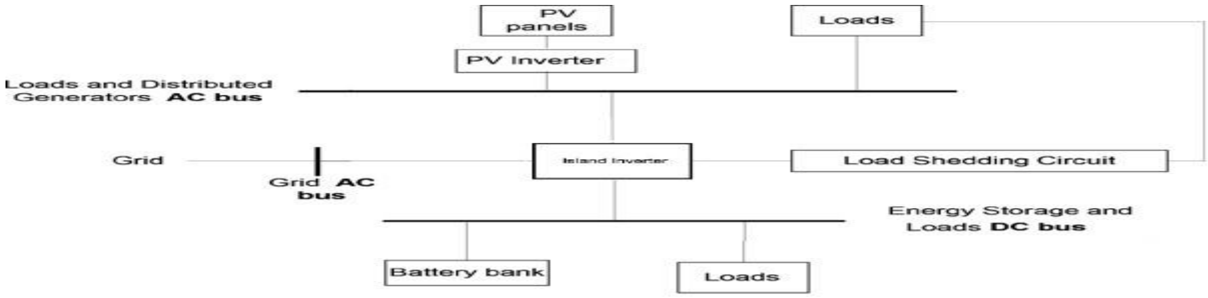

Fig.3. Implementation of the dc bus-based smart grid

The expansion of the topology of Fig.3 to a larger scale is rather difficult, since a dc-grid must be built; the development of a dc grid requires quite big investments. The expansion of the improved microgrid topology to larger scale is possible if the following limitations of the existing system in Figs. 2 and 3 are corrected: 1) wireless signal transmission instead of cables; 2) synchronization of grid voltage with the microgrid voltage during transition from the islanded to interconnected operation; 3) the use of PMUs; and 4) integration of the weather conditions measurements into the control algorithm. The I-SCUs actuators will also include tools for synchronized reconnection of island operated LV microgrids back to the utility grid.

III. DESCRIPTION OF THE ITERATIVE CONTROL ALGORITHM

The software application is responsible for the following tasks:

- Data sampling and transformation into rms values in every duty-cycle;
- Calculation of other electrical parameters (i.e. active power, reactive power, frequency);
- Incorporation of control algorithm in the MATLAB code;
- Data recording;
- Transmission of the commands derived by the control algorithm to the actuator - relay.

The inputs of the control algorithm are the real time measurements that are updated every duty-cycle by the application software and the output variables that are fed back into the control algorithm. The real-time measurements inputs of the algorithm are:

1) The array of the ac active power produced by the PV inverters (Pinv) value measured in watts;
2) The array of the ac reactive power produced by the PV inverters (Qinv) value measured in VAr;
3) The array of the ac active power consumed by the loads (PL) that consists of five values measured in watts;
4) The array of the ac reactive power consumed by the loads (QL) that consists of five values measured in watts;
5) The ac active power produced or consumed by the remaining grid at the interconnection point of the microgrid with the remaining grid (Pinter);
6) The ac reactive power produced or consumed by the remaining grid at the interconnection point of the microgrid with the remaining grid (Qinter);
7) The ac voltage of the microgrid ac bus (Vac);
8) The frequency of the microgrid in Hz (f);
9) The dc current of the batteries (Idcsto);
10) The dc voltage of the batteries (Vdcsto);
11) The critical loads vector (crV) that is the vector determining the degree of significance of the loads: it can set by the user while it can take values from 1 to 5, where 1 is the most critical and 5 is the less critical load—this vector is used by the algorithm in order to define the load shedding policy of the microgrid.

In the experimental microgrid's case, voltage fluctuations depend on active power flows and they consist of the theoretical basis of the following algorithm. The first part of the algorithm is the initialization of the variables, mainly of the upper and lower limits of the microgrid's voltage and frequency. In this paper the upper voltage limit is set to 430 V and the lower limit to 400 V.

The control algorithm consists of two major steps:

1) The real-time voltage and frequency surveillance and correction, as well as the interoperability with the remaining grid. This obtained by the grid tied inverter control.
2) The proposed energy storage management routine, which consists of the Data estimation routine of respective DGs power production & loads and Demand side management actions.

This part of the algorithm is divided in to different routines:

(1) If excess active power production from the remaining grid increases the microgrid voltage, island operation command is derived and the relative flag is activated. This means that the interconnection relay is set to be off (value 0).

(2)If the excess active power demand of the remaining grid decreases the microgrid voltage, island operation command is derived and the relative flag is activated. This means that the inter-connection relay is set to be off (value 0).

(3)If the produced active power is less than that needed to supply the loads and the voltage decreases, the interconnection relay is set to be on (value 1) in order to permit the remaining grid to supply excess power to the microgrid.

(4) If excess active power production by the RES increases the microgrid voltage, the interconnection relay is set to be on in order to supply the excess power to the remaining grid.

(5) If the battery is discharging then DSM technique activated based on predefined value of SOC, the relative flag is activated. Then the one or more active loads of the microgrid are rejected, starting from the less critical load or a more advanced demand-side management (DSM)

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technique can take place.

IV. OVERVIEW OF ENERGY STORAGE MANAGEMENT & CONTROL STRATEGY

The usage of energy storage system reduces the cost of electricity and improves the reliability in the power system.The grid connected PV system uses storage device to manage the optimal power flow in the system with minimizing overall cost at point of common coupling. The optimal placing of new distributed generation into the existing distribution network with the energy storage device is done for improved energy storage management. In distribution system, there are various renewable energy sources for generating power, the allocating renewable sources using probabilistic technique and also minimizing the losses in the power system network. The state of charge of battery is controlled by the iterative control algorithm. Over charging and over discharging will affect the life time of the battery. Battery is allowed to charge or discharge with the standard reference value which is mentioned by the manufacture under certain standard test conditions. The circuit diagram for the grid connected solar photovoltaic system is shown Fig.4 given below. The modeling of solar panel was done in order to get maximum power during the daylight time. The power output from the solar photovoltaic is variable and it is controlled through the inverter. The solar photovoltaic generation is connected to the power system through the switching device.

The energy storage device such as lead acid battery is used for two purpose, charging process take place when there is a maximum power output from the solar photovoltaic generation and discharging process take place when there is a less power output from the solar photovoltaic generation or power demand on the loads. At the instant, rate of charging and discharging is shown on the display. The utility grid with high voltage is reduced to low voltage by the potential transformer and it is connected to the fixed loads through switch and buses. Whenever there is a less or no energy supply from the solar photovoltaic generation, at that situation utility grid act as a supply for the load. The solar photovoltaic generation, storage device and utility grid consist of separate switches for connect or disconnect from the power system. The dynamic switching process is performed depends upon the power generation from the solar photovoltaic system.

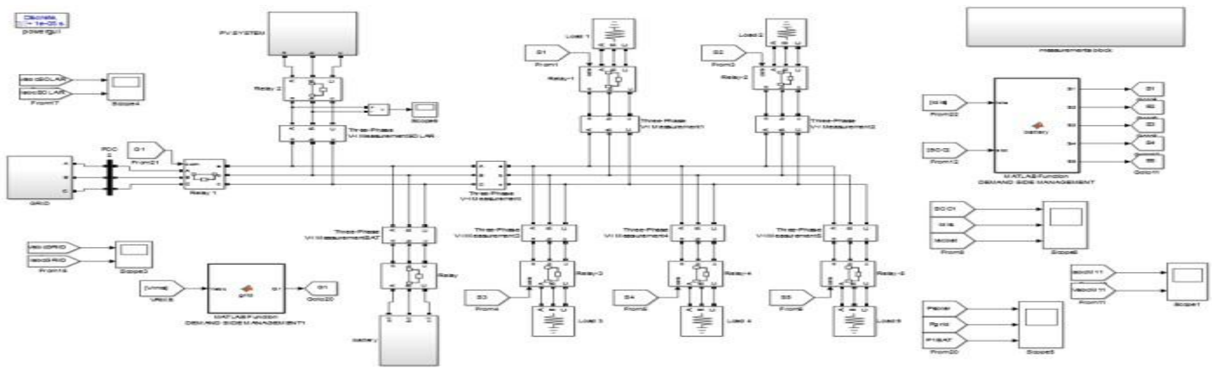

Fig. 4. Circuit diagram of solar PV connected smart microgrid.

V. DETAILS ON THE ENERGY STORAGE AND THE PV CONTROL STRATEGY

A. Energy Storage Management Strategy

The integration of energy storage will improve the availability and reliability of the power system. There are many energy storage devices used in the electrical power system such as battery, fuel cell, flywheels etc. Applications of the storage device depend on power generation and the load requirements, for example battery is used as solar photovoltaic generation, fly wheels are used at the shaft of the wind mills. In this paper the main parameter of managing the energy storage is state of charge in the battery for DSM; its operation depends upon the load and the source.

The state of charge is defined as the available capacity expressed as a percentage of its rated capacity. The success of energy storage management strategy depends very much on data estimation to increase power supply reliability and for the elections of various modes of operations such as grid connected electrical network and stand alone or islanding electrical network. Normally the battery charger which is in existence does not incorporate any of the state of charge measurements so as to limit the charging rate of the battery based on SOC to improve the life period of the battery. The operations of charging and discharging of the battery is stated in the embedded MATLAB function. Life lime and the capacity of the battery are improved by the parameter state of charge. The state of charge is determined by the following equations.

$$SOC(t) = Q(t)/Qn$$

Where, Q(t) is the current capacity of the storage devices with respect to time. Qn is the nominal current capacity which is represented by the manufacture. SOC (t) is the state of charge with respect to time. State of charge could be calculated from measured cell parameters, temperature and operating conditions. There are some methods for determination of state of charge; they are current at short circuit conditions, voltage at open circuit conditions, and chemical methods.

Based on the SOC and discharging current, the following load management actions are taken.

1) In charging situation the SOC is measured and given to control algorithm for protecting battery from over charging.
2) In discharging situation, the SOC value measured is given to the control algorithm and the DSM techniques are activated for saving energy during islanded mode and

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protecting the battery from deep discharge.

B. PV-Plant Active Power Control Strategy

The Solar PV grid connected system consists of Solar PV array, DC-DC Boost converter for MPPT and 2 level PWM VSI for DC-AC conversion. The MPPT algorithm is implemented in the boost converter to extract the maximum power available and ensure maximum available power flows into the DC link.

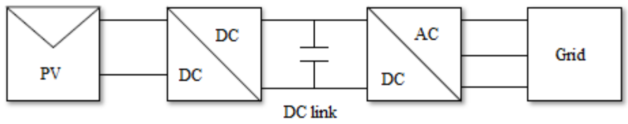

Fig. 5. Two stage converter topology of a PV-DG system.

The Grid connected converter (GCC) uses the vector control; this consists of a nested loop structure composed of a faster inner current loop and a slower outer loop. Because a conventional vector control has some limitations, we used the Direct current vector control (DCC). The dc-link voltage is regulated based on instantaneous power balance method of active power; the fundamental concept behind this theory is that the capacitor voltage depends on the energy balance of the power received by the VSI and the power delivered by it. If these two are equal, then the dc-link voltage will remain constant. If the power received by the VSI is greater than the power delivered by it, the extra energy will be put into the capacitance which in turn will raise its voltage. On the other hand, if the power provided by the VSI is greater than the power received, then the additional power is supplied by the capacitor, results in the reduction of its voltage.

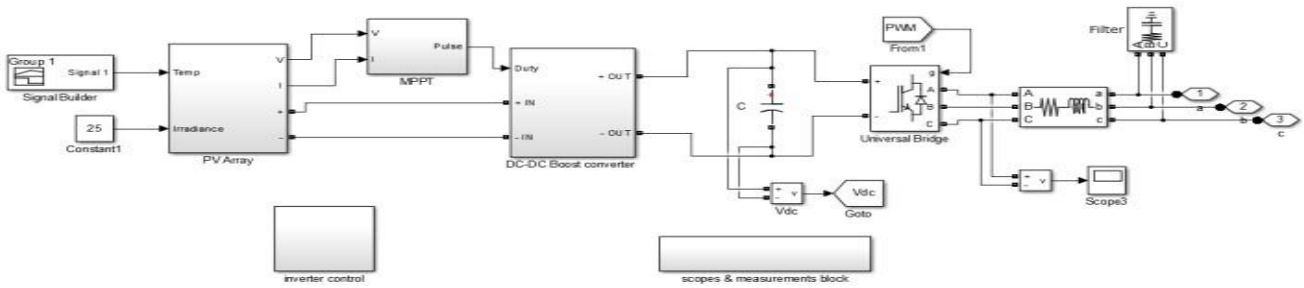

Fig.6. Circuit diagram of solar PV sub system.

VI. SIMULATIONS & RESULTS

The state of charge and state of discharge is shown above was the energy management for grid connected solar PV system. In this system lead acid is used as a storage device for better energy management between the source and the load. The state of charging and discharging occurs when the solar generation and remaining grid not able to supply the power or during the peak time of the demand.

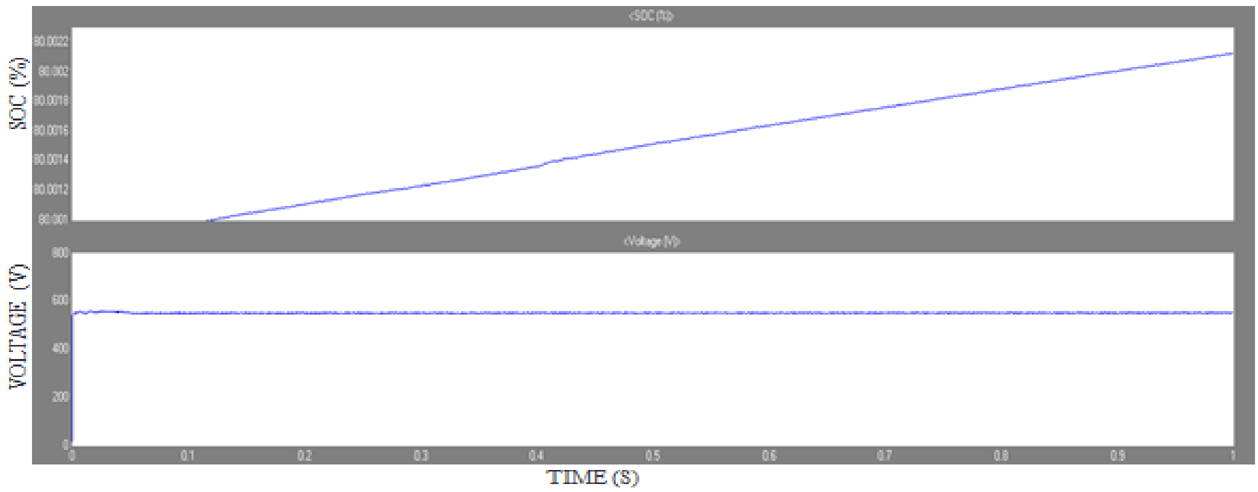

Fig.7. State of Charge

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Volume 04 Issue 14
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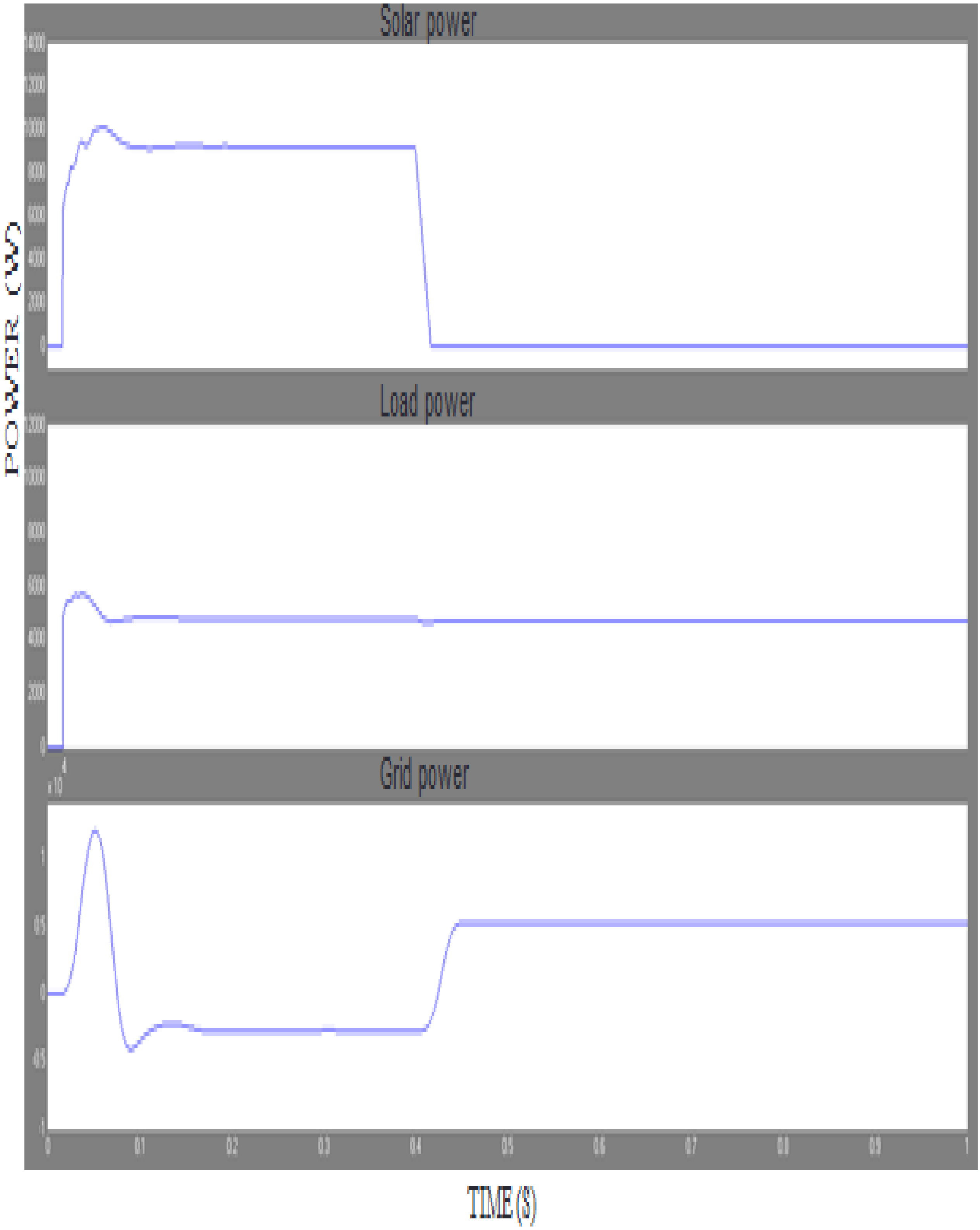

Fig.8. Solar power generated & load power & power given and taken from remaining grid

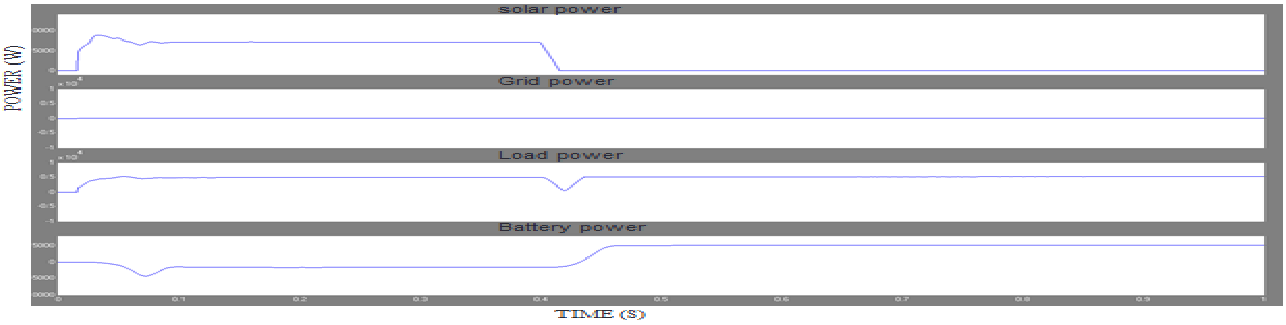

Fig.9. Solar power generated & grid power & load power & battery power

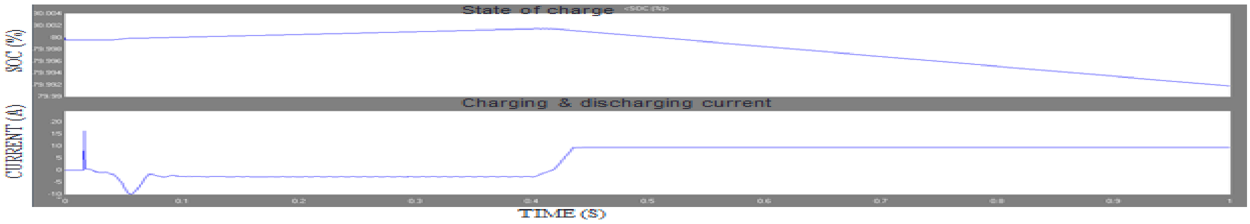

Fig. 10. State of Discharge

The modeling of the solar PV is to get the desired constant output of power and voltage. The converter/inverter is connected to the battery for storing the energy or deliver power to the load. Here the solar photovoltaic panel can able to generate power up to 10KW is a variable power output, power demand or variable power output is managed by the storage device during islanded mode. In the grid connected system proper switching operations was performed by using the embedded MATLAB function, this leads the system as uninterrupted power supply to the load. The maximum energy from the solar generation supply to the load; the minimum energy is drawn from the grid.

VII. CONCLUSION

The battery storage technology will play a major role in the reliable and economic operations of grid connected solar photovoltaic system especially during islanded operation. The cost of the electricity was reduced or maintains constant by the usage of energy storage devices and it required less maintenance, life of the battery depends upon the charging and discharging with in the specified SOC limit. The modeling of photovoltaic system is to regulate the power and voltage for the microgrid system, in order to improve the power supply reliability of the system. The simulation results tell that the energy is managed by the storage device will balance the microgrid.

In this paper, an event-based control for improved energy storage management strategy based on a demand-side management approach are presented in order to improve the reliability performance and energy saving for islanded microgrid. The dynamic switching process is performed by the EMBEDED/MATLAB function, thus the energy is managed in the microgrid connected solar photovoltaic system. The operation of the microgrid with the SCU's control infrastructure and the iterative control algorithm improved the power supply reliability performance.

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