Implementation of an Adaptive Control Strategy for Solar Photo Voltaic Generators in Microgrids with MPPT and Energy Storage

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Abstract- In the recent years, microgrids have become increasingly popular among the consumers due to its energy efficient mechanism, network benefits and improved energy reliability. However, when they are operated as autonomous systems, several technical problems related with its operations and control has emerged as a challenge. To overcome this impending issue, this paper proposes an optimized approach by implementing adaptive solar PV generators with MPPT control (maximum power point tracking) to support an islanded microgrid in a low voltage network. Due to improper control and high maintenance, the PV generator provides very low efficiency during conversion. Therefore, the proposed strategy offers an effective coordination between inverter V-f control (voltage and frequency) and P-Q control, MPPT control and energy storage control of the islanded microgrids to remove device fluctuations and deviations. Also, the control strategy employed take care of State of Charge (SOC) stabilization of battery unit. The simulation of the proposed model is carried out in Matlab/Simulink. The results clearly confirm the potency of suggested controlling and adaptive strategy.

Keywords- Microgrids, solar photovoltaic generator (PVG), MPPT, low voltage (LV) network, V-f control

1. INTRODUCTION

Microgrid is a concept that was built up to enhance the distributed energy resources (DERs) such that the energy can be stored and used when required [1]. It is a small power system that utilizes clean energy resources such as wind and solar by integrating multiple distributed generators, micro-resources, local loads and energy storage devices. Solar energy is used in microgrids to generate electricity using photovoltaic (PV) generator or array, but sometimes, depending on the climate conditions, sun light is not highly available. Solar photovoltaic generator is more sensitive to shading, even if there is a small amount of shading on a solar cell or array [2]. In such a case, the output of PV generator decreases drastically. This is due to the variation in sunlight that leads to a change in energy production with respect to time and climate. The stable energy storage device for storing such energy is a requirement that has come to light in the recent years. From energy point of view, a stable energy source dispatched at a desired time is required. As a result, the stored energy can be used later when there is a dire need of power supply at peak times [3]. The demand for energy storage devices has dramatically increased and solar energy sources have become more reliable energy sources. With energy storage, a technique that can place power dispatched at any time on request is highly desired. This results in improving the performance of solar PV generators in microgrids [4].

Integrating energy storage into solar PV array system can be done in two ways. Solar PV power conversion system can be either DC or AC side; as there are many conversions for the solar PV array system. The integration solution can be compared with many novel methods with respect to efficiency, flexibility and complexity.

Micro grid is usually referred as mini utility grid because of its group of interconnected loads and micro sources. The basic facts are addressed to Distributed Energy Resources (DER) which requires coordination and necessary support to maximize efficiency [5]. Certainly there is a large impact on Primary Energy sources due to the faults occurring from the inverters and Islanded micro grids which suffer from large disturbances with respect to durability and control [6]. As Distributed energy resources and micro grid have very small inertia and time constants between them, they often yield a large deviation in frequency and voltage variations in Emergency conditions. Photovoltaic generator (PVG) is best suited for delivering abundant energy resource in the coming future. This PVG is found in three different categories but the one which is best suited is grid connection that provides vast amount of energy without much disturbances. Microgrid can be enabled to operate in grid connected or islanded mode. Maximum Power Point Tracker (MPPT) is an electronic system which is employed in a PVG for adjusting the operating point of module and providing Maximum Power. PVG suffers from low energy conversion and voltage variations [7]. The

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storage devices and load shedding do contribute a large deviation in problems of function Implementation but still, it is best for Distributed energy resources. For evaluating the performance and operating conditions of PVG, three major factors are taken into considerations that are load Impedance, Ambient Temperature and Insulations.

It can be concluded that the work implemented so far discovers the difficulty with the device fluctuations and deviations occurring due to load shedding strategies in storage control [8]. The voltage and frequency control changes with transitions at various scenarios. Due to improper control and high maintenance, the PVG provides very low efficiency during conversion. This work depends on solar resource and ambient temperature while storing the state of charge (SOC) with Distributed Energy Resources. The strategies employed for controlling active power involves overcharging and over discharging of State of Charge (SOC) stabilization. Various appropriate Optimization algorithms can be utilized in charging and discharging frequency from the battery storage. However, this can be reduced to a certain level by adjusting the filter time constant. The real time SOC and Variable filter is used for avoiding the randomness and large fluctuations but it is still unable to reach a level of saturation [9]. All These elements require control algorithms with appropriate control strategies to have effective coordination between inverter V-f (or P-Q) control, MPPT control, and energy storage control.

Furthermore, an adaptive control method is best suited for dynamic changing conditions in Photo voltaic (PV) generator to maintain coordination and integrity of the Islanded Microgrid. The illustration of this problem statement describes that there is a need of a higher power quality, reliable energy, and stability for islanded micro grids. The algorithms and methodologies are however dependent on the battery storage, PV and external power grid conditions. If these parameters are upgraded and adaptively changed, then definitely there is a great scope for islanded micro grid power generation [10]. This paper, therefore, implements an adaptive solar PV generation system with MPPT control, V-f control or P-Q control in both islanded mode and grid-connected mode.

II. CONTROL OF MICROGRID

A. Microgrid Control issues

A uniform load sharing mechanism is required as the distributed generators are of unequal capacity. The DGs are responsible for supplying and governing all the load demand in the microgrids, therefore, a uniform load sharing is very difficult [8]. As the output voltage of each inverter is different, the inverters supply excess reactive power to achieve uniform sharing. This leads to reduced capacity for supplying active power [9].

The controlling challenges with the load shedding and energy storage devices are commonly faced by the islanded microgrids. There is voltage instability due to heavy load shedding due to excess generation of reactive power by the generators in microgrids [10]. Frequency decay is faced when the smart load control fails to stabilize the frequency in the case of a large power shortage [11].

B. Voltage and frequency regulation in micro grids

There have been various studies that have focused on attaining stable voltage, frequency and power attributes of microgrid systems. Some of the previous discoveries are further discussed in this paper. PWM converters can be efficient at improving the generators capability of creating active and reactive power neatly. They can be used for meeting the load demand and V-f stability when there is a change in voltage amplitude [12]. An application for efficient energy storage within a local power supply is designed that guarantees proper voltage regulation. The application is effective in cancelling harmonic deviations at the load site [13]. To overcome the impedance voltage drop effect and generators load effect, a reactive power sharing algorithm is proposed. This algorithm enhances the reactive power control and sharing accuracy [14]. For building a more reliable and stable low voltage microgrid system, a multiple converter scheme has been developed. The proposed scheme is a control strategy that supports the regulation of extra reactive power in the system [15].

Short circuit faults have been encountered in the islanded microgrids mode which intersects the distribution of power supply to the customers. To overcome the challenge, static synchronous compensator and battery storage system have been examined for stabilizing the voltage [16]. An efficient frequency regulation in the turbo and hydro generators in a microgrid is essential for attaining a more stable and reliable system. This has been achieved by designing and implementing distributed energy resources that exhibit an output frequency power that is similar to the speed power characteristics of the generators [17]. An integrated algorithm is proposed which constitutes of voltage source inverter ac side and MPPT algorithm at PV side for voltage and battery storage regulation. The control technique is useful in stabilizing the voltage in the scenarios of emergency [18].

III. THE CONTROL ELEMENTS IN THE SYSTEM

The proposed model is developed in Matlab/Simulink and model is shown in fig. 1.

1. Adaptive control loop for active and reactive power

This controller takes reference clock frequency from grid, active and reactive power from inverter and grid. It adjusts the PWM of inverter such that its output frequency (or voltage) became equal to Grid frequency. Inverter Active output power kept maximum and equal to solar panel maximum power by maximum power point tracking technique used in converter. Inverter and grid reactive power are also kept equal. Since the inverter output power is maximum, the power is injected from inverter to the grid. Fig.2 shows adaptive control loop for active and reactive power Simulink model.

2. Controller for active power

This controller takes solar panel output power as a reference and compare with current active power of inverter and provide a reference current Ip. This is regulated with an integral controller. Fig.3 shows active power controller Simulink model

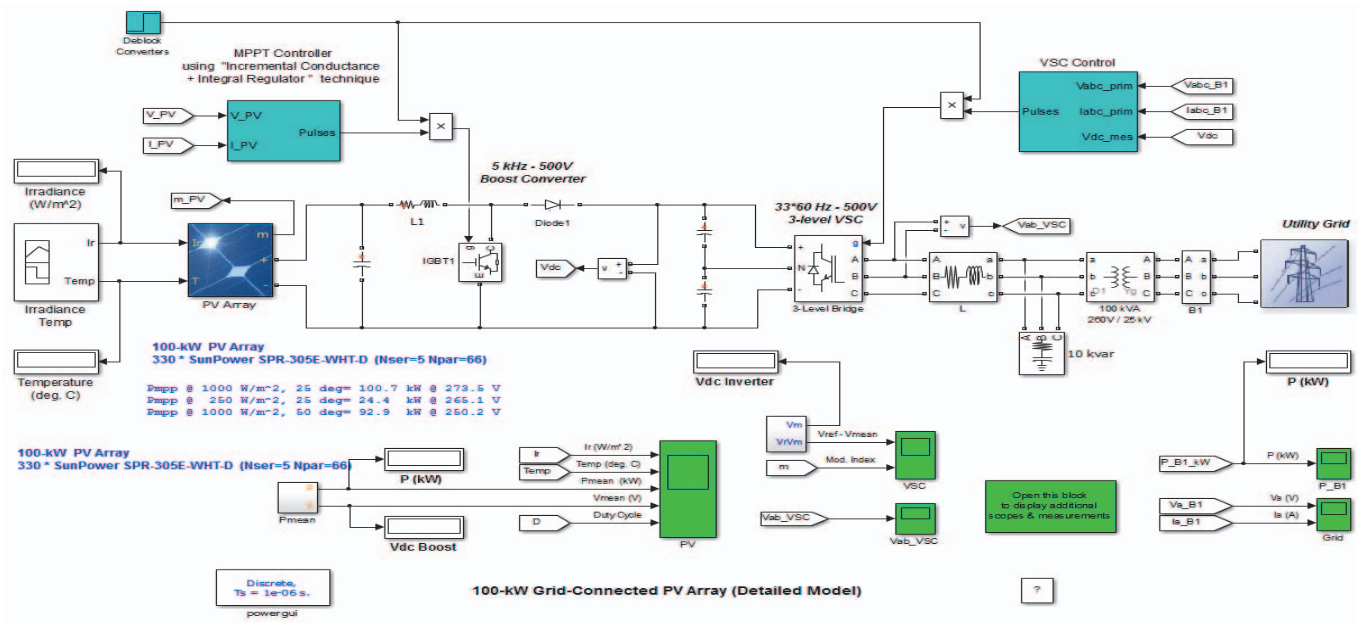

Fig. 1. Simulink Model of Microgrid with SPV System

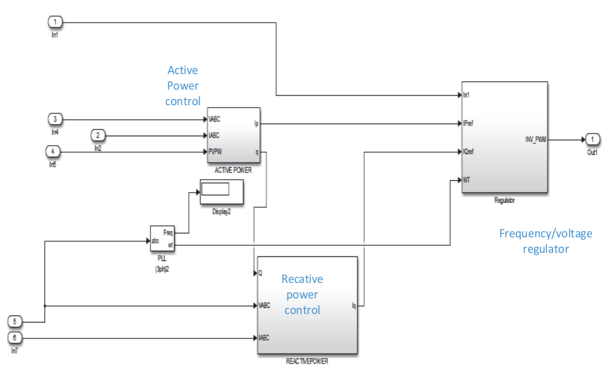

Fig. 2. Adaptive control loop

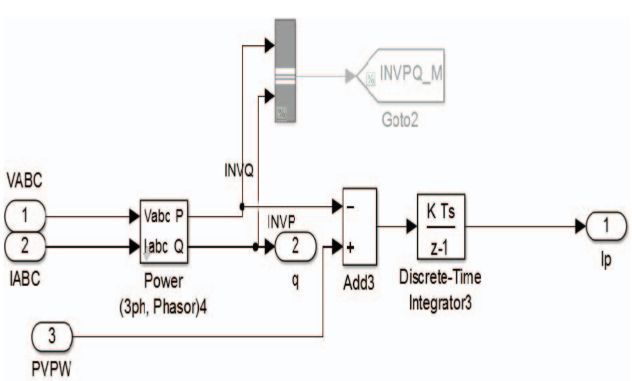

Fig. 3. Controller for active power

3. Controller for reactive power

This controller takes grid reactive power as a reference and compare with current reactive power of inverter and provide a reference current Iq. This is also regulated with an integral controller. The Simulink model is shown in fig. 4.

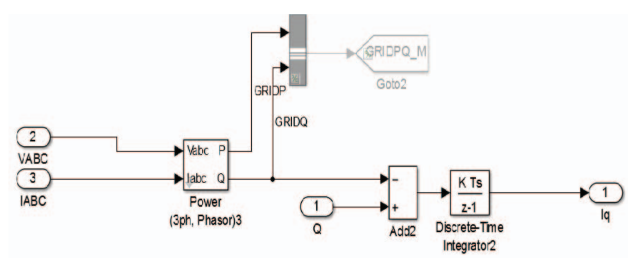

Fig. 4. Controller for reactive power

4. Inverter PWM control loop for active and reactive power

It takes the active current and reactive current as reference and compares the d-q parameter from inverter current and adjust the inverter active and reactive current. Here the grid frequency is also used which is regulated by PLL as reference. PI controllers are used here for controlling the parameter.

The control loop is sensitive to frequency and load change (active and reactive). So irrespective of load change, the inverter tries to maximize the output power of inverter and power is provided by solar panel.

5. Voltage control loop for island mode

In the island mode the grid is not connected to the system at all. So the inverter only needs to supply a regulated voltage to load. The frequency is also regulated locally for 3phase AC, so it can be 50 or 60Hz irrespective of grid in island mode. In Island mode the regulator is V-f regulator which regulates the 3phase output of inverter and its frequency. PI controllers are used for this purpose. Fig. 5. Shows the Simulink model of the controller.

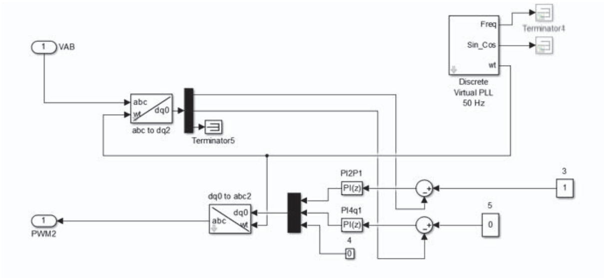

Fig. 5. Voltage control loop for island mode

6. Grid connection and synchronization.

During grid connected mode, the control strategy of microgrid is shifted to P-Q mode and now operates at its maximum power generation capacity. The frequency and voltage of the microgrids is controlled by grid during grid connected operation.

7. Solar output power control loop (MPPT)

This loop (controller) take the maximum power from panel specification as reference and compare with current output power and adjust the PWM of boot converter to draw maximum power from panel. Perturb and Observe algorithm is used to track the maximum power point.

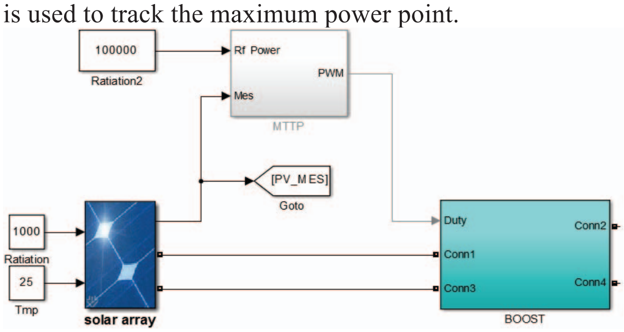

Fig. 6. MPPT control

8. SOC controller

SOC (state of charge) controller brings down the voltage output from SPV system and charge the battery. Battery voltage is kept at 220VDC.

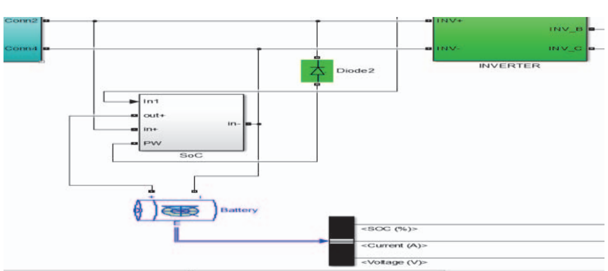

Fig. 7. SOC controller

SOC charger will take solar power as a reference and compare it with the power of battery and the inverter. A Buck-Boost converter is used which charge or discharge the battery according to the control signal from controller. The initial SoC of battery is kept at 60% and the control algorithm has developed in such a way that the converter act as buck converter when excess power available in microgrid during islanded condition. When power is deficit is there, the converter act as boost converter and deliver the power to microgrid load. During grid connected operation the controller kept the battery idle so that it neither charge from grid or discharge to grid. All the power requirement of the microgrid is satisfied by grid during this time.

IV. DISCUSSION OF RESULTS

In order to verify the efficiency and reliability of the adaptive control developed, different load conditions are applied to microgrid and main grid and simulated. The microgrid first operates in islanded mode and after 0.5s of simulation, it is connected to grid to verify the coordinated V-f and PQ control and SoC control.

1. Case I:

Initially both microgrid and grid are supplying power to their respective loads (80kW and 120kW) and microgrid is in islanded operation. The maximum capacity of the SPV system is set at 100kW using MPPT controller. As the power generated in the MG is greater than its demand, the excess power goes to battery and it charge during islanded operation. The initial SoC of the battery is set at 60%. The MG is synchronised to grid at 0.5s of the simulation and the adaptive control loop adjust the inverter frequency(50Hz) to Grid Frequency (60Hz).During grid connected operation, buck-boost converter of the storage system is deactivated and it neither charge nor discharge so that battery charge from renewable sources or discharge to support microgrid only.

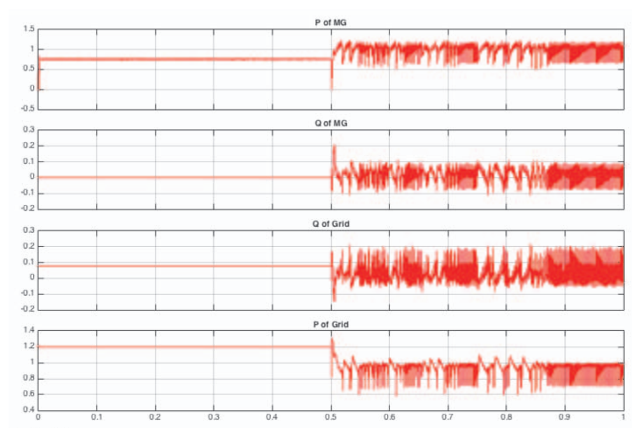

Fig. 8. Active and Reactive power of grid and inverter

Battery charges from the excess power of microgrid (100kW-80kW). When microgrid is connected to main grid at 0.5s, the controller has designed in such way that battery stops charging and excess power in the microgrid is supplied to main grid by considering the economic benefits.

The active and reactive power of the grid and microgrid is shown in fig.8. The battery SoC, battery current, battery voltage are shown in fig.10. The grid and microgrid voltage and current corresponind to case I is shown in fig.10.

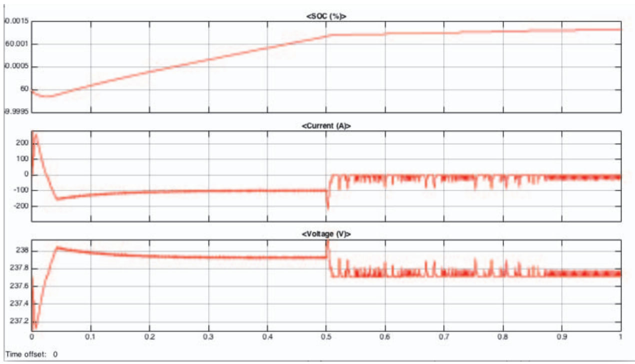

Fig. 9. Battery SoC, Current and Voltage plots

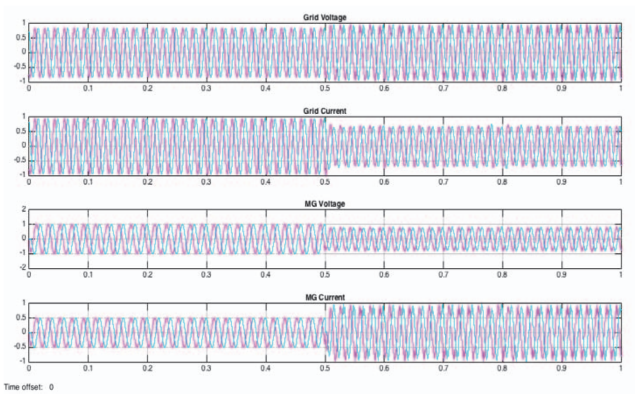

Fig. 10. Voltage and Current of grid and microgrid inverter

2. *Case II:*

In this case the microgrid power is reduced to a low value of 10kW. The grid power is set to 50kW. Up to 0.5 second of simulation, the grid operates in islanded mode and its huge excess power is used to charge the battery whose initial SoC is kept at 60%. At 0.5s, the microgrid is connected to grid and now the whole power requirement of the grid is supplied by microgrid power and power drawn from grid become zero as shown in fig.11. The charging pattern of the battery is shown in fig.12.

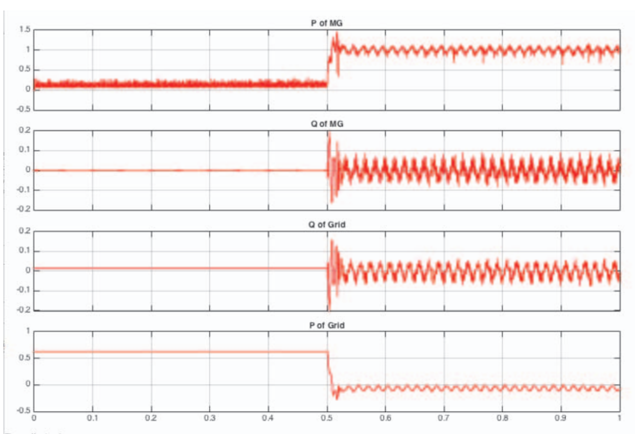

Fig. 11. Active and Reactive power of the grid and inverter

The battery charges only from microgrid power in order to take maximum utilization power available in nature free of cost. So during grid connected operation, the battery is kept idle. The negative charging current of the battery indicates the charging of the battery. The line current of the microgrid and grid are shown in fig.13.

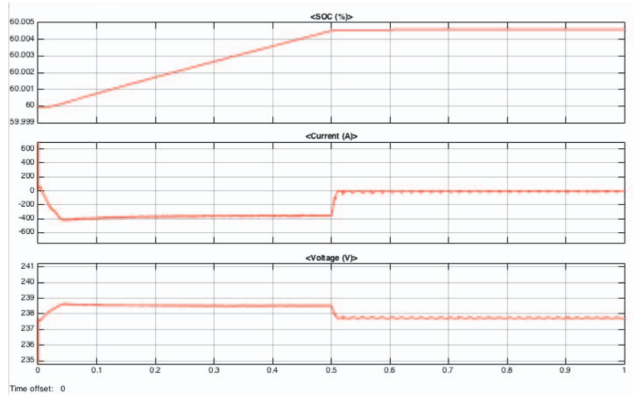

Fig. 12. Battery SoC, Current and Voltage plots

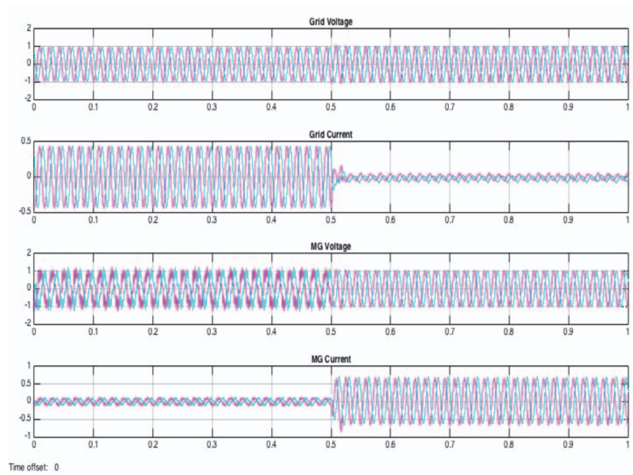

Fig. 13. Grid and microgrid Voltage and current

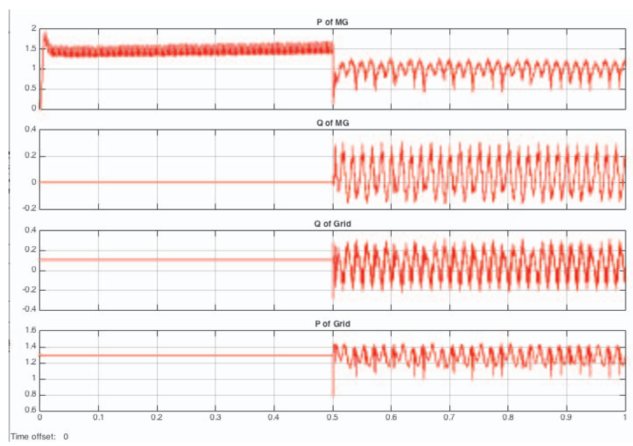

Fig. 14. Active and Reactive power of the grid and inverter

3. *Case III:*

In this case, the load connected to microgrid is set to 150kW and grid load is set to 200kW. Now the microgrid load is more than its generated power (100kW) and the deficient power (of 50kW) is supplied by battery. When the microgrid is connected to grid at 0.5s, the grid starts supporting the microgrid load and battery is relaxed. The fig.14 shows the active and reactive power of the microgrid and grid. The battery SoC, current and voltage are shown in fig.15. The corresponding grid and microgrid voltage and current are shown in fig.16.

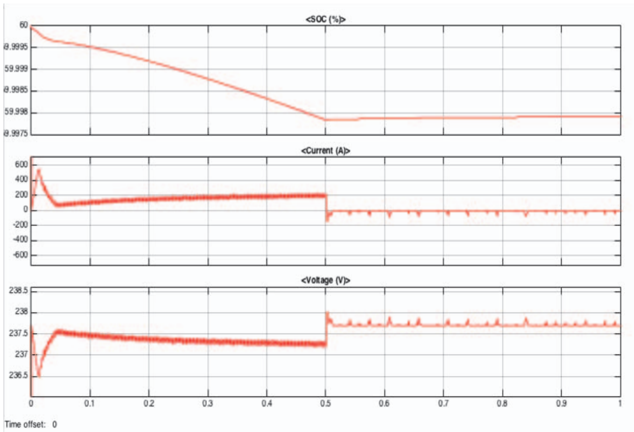

Fig. 15. Battery SoC, current and voltage plots

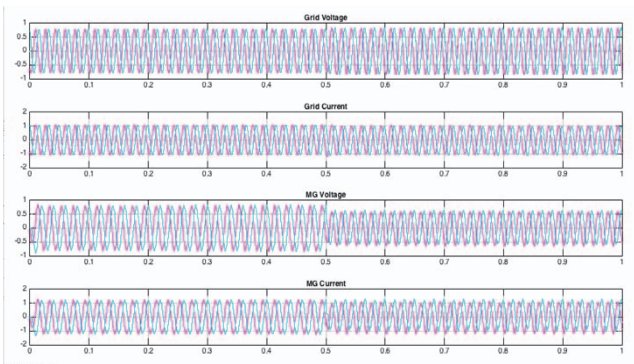

Fig. 16. Voltage and Current of grid and microgrid inverter

V. CONCLUSION

An efficient approach for coordinating V-f control and P-Q control for microgrids with energy storage capability has been proposed here. The results show that the proposed mechanism is efficient in providing coordination between V-f and PQ control, MPPT control and storage control within the islanded and grid connected microgrids. It is capable in overcoming any deviations and fluctuations

An adaptive solar PV generator with MPPT control for low voltage network has been proposed and implemented. The low voltage distribution networks are integrated with solar PV array, to effectively control the solar radiation and generate electricity. The results are positive and provide an efficient way for sustainable development of solar PV array for low voltage networks.

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