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Decentralized Control Strategy for PV Based Microgrid

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ABSTRACT: This paper concentrates on aspects of energy management in microgrid. The microgrid is a small scale grid which can be operated either in stand-alone mode or grid connected mode. The test system comprises of photovoltaic system, batteries and super-capacitor. The grid power demand is satisfied by the combination of the source and storage elements by efficient control strategy between the inverter (or) converter and the DC link. The ultra-capacitor (or) super-capacitor absorbs the high frequency changes in demand and the battery absorbs the steady state (low frequency) changes in demand. This helps in saving the battery from sharp increase in current and prolongs the life of the battery. The source and the storage elements are controlled in multiple modes by a multilevel control strategy using power electronic interface. Modeling and simulation of the test system is done using MATLAB/simulink.

KEYWORDS: Energy management, Microgrid, Multilevel control system, Ultra capacitor

I.INTRODUCTION

Increase in power demand, conservation of natural resources, such as fossil fuel, led to a new-trend of non-centralized energy production termed as Distributed Generation (DG). The renewable energy sources comprises of photovoltaic system, wind turbines and other non-conventional sources. DG is integrated into a localized microgrid, and the generated power is provided to near located loads. Distributed storage (DS) technologies are used in microgrid application, where the generation of microgrid cannot be exactly matched.

Adel Choudar (2014) discussed about the integration of DG into a localized microgrid. Abbey (2006) deals with an energy management scheme comprising a wind turbine generating system. Delille (2009) discussed various features of energy storage technologies for distributed system integration. The energy storage devices are Batteries and Ultra capacitor. Among these two different storage units lead acid batteries provide a long term electrical energy. Batteries can be protected by maintaining exact charging and discharging level in order to avoid over charging and discharging of batteries. The ultra capacitors are high power density devices and have extremely high cycling capability. The ultra capacitors are used for fast dynamic power regulation in microgrid.

Torreglosa (2014) discussed about the microgrid, which operates in island mode, where wide range of control, protection and power management scheme is also present to obtain optimal operation. In PV power limitation mode the PV power is greater than the grid demand and both storage units are fully charged. During this period PV operating point is moved from maximum power point to a limited power point. This action is incorporated in the incremental conductance algorithm.

The PV power is processed by MPPT based bi-directional DC-DC converter. The DC-DC converter handles the operation of charge and discharge for battery and ultra capacitor. All sources are connected to the same DC link. This configuration offers the system high flexibility and expandability as suggested by Lu (2009). The connection to the grid utility is performed by a three phase inverter according to the grid restrictions. This configuration is termed as an active generator or active PV system as presented by Lu (2008).

The multilevel control structure is used in APS operation by Lu (2010). In this method better solution to the control of APS operation is obtained. This system with hierarchical control structure consists of three control units.

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These are Power control unit, Automatic control unit and Switch control unit. These control units work in hierarchical structure and controls the APS network.

This paper focuses on enhanced energy management system for PV based active system. The objective is to maintain smooth power exchange with grid or APS, to achieve fast dynamic compensation of APS operation and to optimize the utilization of storage element.

II. REPRESENTATION OF PV BASED MICROGRID

The PV array, Battery and Super capacitor are the main sources of the grid. DC-DC boost converter is utilized to transfer the power from PV array into grid inverter. In day time, power can be generated by PV array. During cloudy or night time, it's not possible to generate power through PV array. DC-DC bidirectional converters are generally used as a buck boost converter. By using bidirectional converter, the battery and super capacitor can be charged and discharged at rated power from the grid. If the system operates in islanding mode these three components are helpful to compensate the required load demand. Multilevel control strategy is used to control the whole system. Block diagram for given system is shown in figure1.

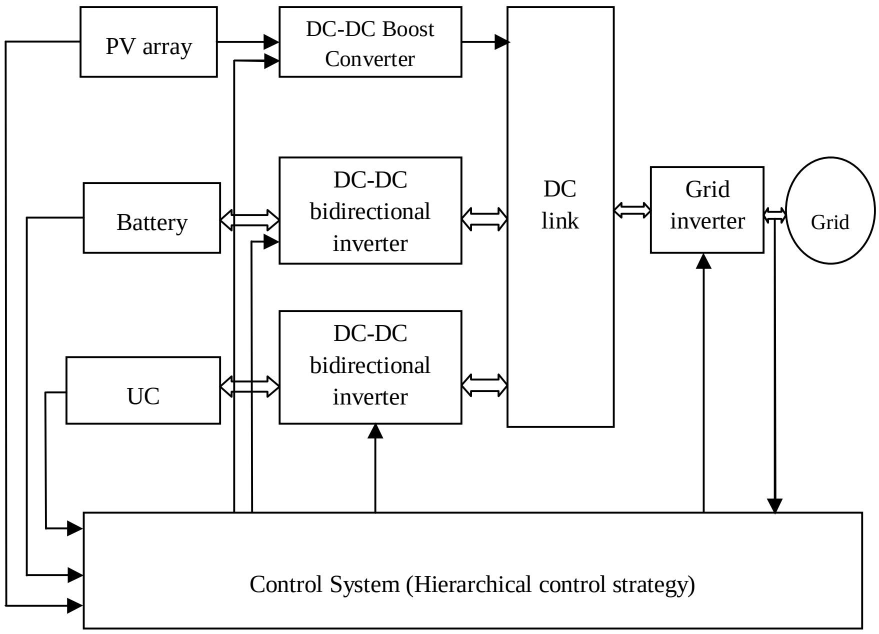

Fig.1 Representation of PV based microgrid

III.MULTILEVEL CONTROL SYSTEM

Multilevel control system is the better solution to control Active Power System operation. The multilevel control system block diagram is shown in figure. The multilevel control has three main units:

(i) Power Control Unit (PCU):
It controls the operating mode and it's used to calculate the variables.

(ii) Automatic Control Unit (ACU):
It allows the local controller to generate the required duty cycle to set the output.

(iii) Switch Control Unit (SCU):

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It is responsible for generating the switching patterns which depends on integrating modulation techniques.

Control of the operating mode:

In this work, operating modes are controlled by three major modes. They are normal operating mode, power limitation mode and islanding mode. Additional operating modes are taken into account.

1. **Normal operating mode:**

In this mode, the PV panels work always in MPPT. All storage units are in the normal range (available to enable a charge or discharge of power).

2. **PV limitation mode:**

When the power generation and energy storage elements satisfy the power demand and the excess power can be controlled by power limiting strategy. The limiting process can be achieved in two different manners. First one is to control the PV power production by increasing the photovoltaic voltage or by decreasing the PV voltage as required.

3. **Islanding mode:**

When the generating unit has low power and the storage units are also empty. The power is not supporting the grid. During this condition the sources are disconnected from the utility and the PV panel works in MPPT to change the energy storage elements.

4. **Full ultra-capacitor mode:**

The ultra-capacitor level gets increase more than the maximum level. The state of charge is operating in good condition. In this condition active power system works in full capacitor mode. In normal operating mode batteries is not needed, which the results in ultra-capacitor discharge the energy and return to the original state quickly.

5. **Empty ultra-capacitor mode:**

The ultra-capacitor level gets decrease more than the minimum level. The state of charge is operating in good condition. In this condition active power system works in empty capacitor mode. In normal operating mode batteries is not needed, so the ultra-capacitor recharges and get backs to normal condition.

6. **Full battery mode:**

When the state of charge of the battery is full and the ultra-capacitor is not full. The PV power is more than the required power, at this condition the PV system operates in such a way that the ultra-capacitor store extra power.

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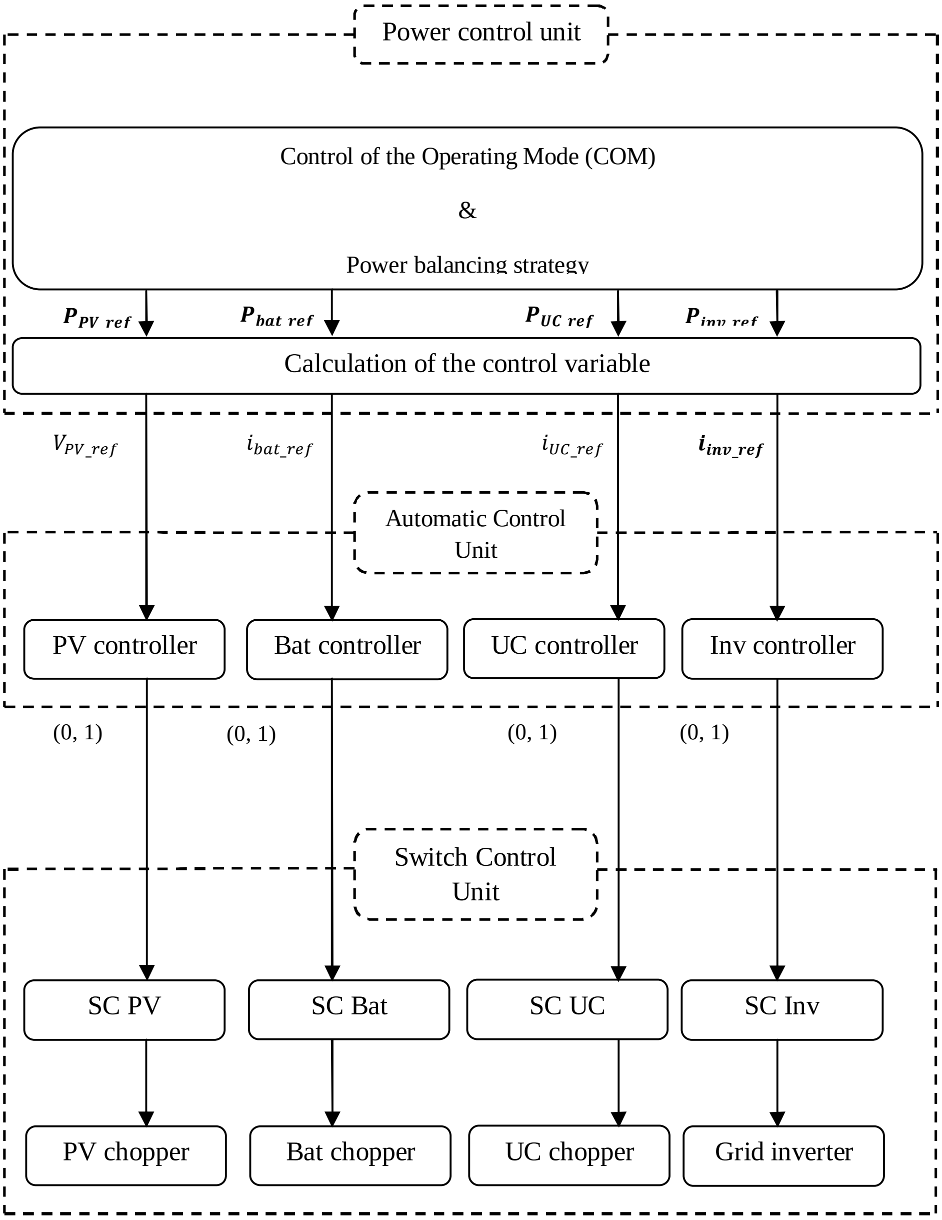

Fig. 2 Multilevel control system

IV.CALCULATION OF THE CONTROL VARIABLE

Grid connected strategy:

In this strategy, the line control loops regulate V_{dc}, where the control unit dispatches P_{sour}. This strategy is used in classical 'passive' PV generators.

When the normal operating mode happens, V_{dc} is regulated by adjusting the exchanged power with the grid, while the PV generator works in MPPT strategy.

$$P_{PV_{ref}} = P_{PV\_mppt}$$

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P_{dc_ref} is used to calculate P_{g_ref}

$$P_{g\_ref} = P_{sour} - P_{dc\_ref}$$

The source power is,

$$P_{sour} = P_{PV} + P_{sto}$$
$$P_{sto} = P_{bat} + P_{UC}$$

The storage elements complement the PV generator to satisfy the asked power. In steady state, P_{dc_ref} is zero therefore,

$$P_{sour} = P_{g\_ref} = P_{go\_ref}$$

The storage elements should supply or absorb the difference between the required power and the available PV power.

$$P_{sto\_ref} = P_{sour\_ref} - P_{PV}$$

However, P_{sto_ref} is a fast varying quantity due to the fluctuant PV power and the varying grid power. Moreover, the batteries have relatively slow power dynamics, and fast varying power reference is not suitable for their operating lifetime. To dispatch the power between batteries and ultra-capacitors, a Low-Pass filter is used.

$$P_{bat\_ref} = \frac{1}{1+\tau s} + P_{bat\_ref}$$

$$P_{UC\_ref} = P_{sto\_ref} - P_{bat}$$

Where the time constant of the LPF should be set by taking into account the dynamic of the batteries as well as the size of the ultra-capacitors. The ultra-capacitors have a short energy storage capacity. However, they have a fast power dynamics and can supply power peaks. They can be used to fill the power gaps during the batteries transients.

Power dispatching strategy:

The PV and storage units are used to control the DC link voltage. The required power is controlled by line control loops. The control approach is applicable for islanding mode. Suppose the renewable energy based system was disconnected from the utility the local control strategy is changed. In that situation the DC link cannot be controlled. The DC link can be controlled by combination of PV and energy storage elements.

$$P_{sour\_ref} = P_{dc\_ref}$$

The stored reference power is given,

$$P_{sto\_ref} = P_{sour_{ref}} - P_{PV}$$

V. AUTOMATIC CONTROL UNIT

Power limitation strategy:

When the storage units are full and the PV production is greater than the grid demand, the PLS must be applied. We can observe that, there exist two set point for the same power value. Hence, two possible ways to reduce the PV production; the first one is to translate the operating voltage into the right side from the MPPT by increasing V_{PV}, or shifting to the left side by decreasing V_{PV}. The control algorithm allowing PLS is depicted in the flowchart given in figure.

MPPT strategy:

A perturb and observe method is implemented in this work. Perturb-and-observe (P&O) method, also known as perturbation method is a type of MPPT algorithm. The concept behind the "perturb and observe" method is to modify the operating voltage or current of the photovoltaic panel until you obtain maximum power from it. It is often referred to as **hill climbing method**. Perturb and observe is the most commonly used MPPT method due to its ease of implementation. Perturb and observe method may result in top-level efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted.

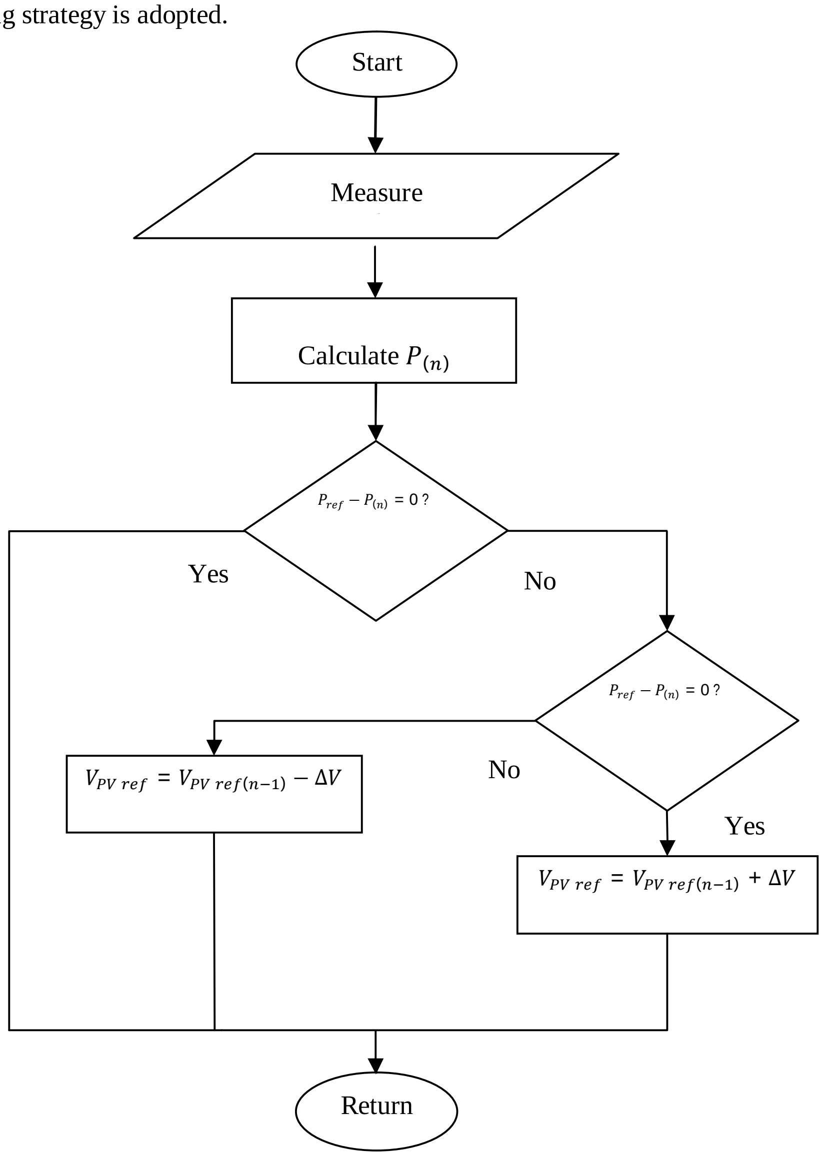

Fig. 3 Flowchart for MPPT perturb and observe algorithm

VI.DESIGN AND IMPLEMENTATION

A.THE DECENTRALIZED POWER MANAGEMENT SYSTEM

The general diagram of test system is as shown in figure 4 models of battery, ultra-capacitor and PV cell were obtained from simpower systems section and the parameters were modified as required. The control system as discussed in chapter 3 is established using the basic simulink model blocks. The overall system was simulated with a sampling rate of 50ms.

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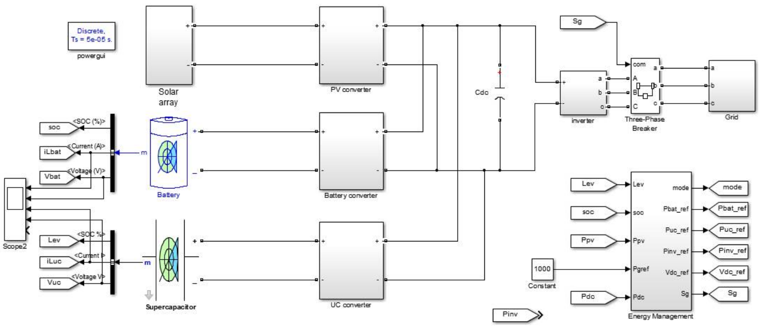

Fig.4 General Diagram for test system

B.BUCK-BOOST CONVERTER & CONTROL LOGIC SIMULINK MODEL:

The simulink model of the buck boost converter and its associated control are as given in figure 5. During boost operation, the buck switch will be in closed condition and boost switch will be modulated. During buck operation, the boost switch will be in opened condition and buck switch will be modulated.

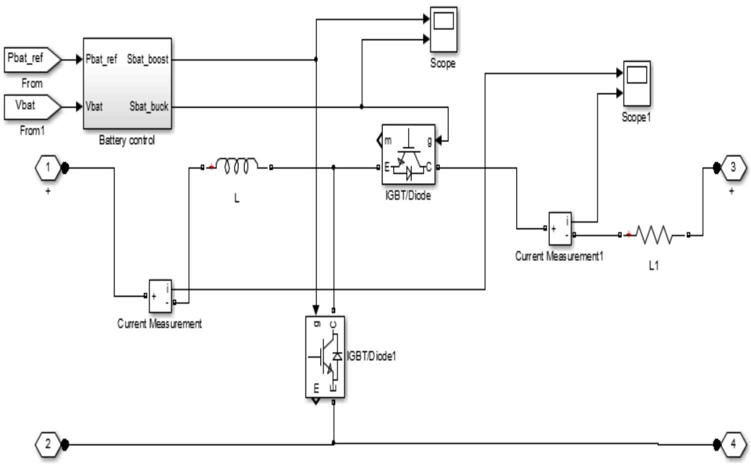

Fig.5 simulation diagram for buck boost converter and logic circuit

C.GRID INVERTER AND CONTROL LOGIC SIMULINK MODEL:

The simulation design of the grid inverter and associated control strategy is as shown in figure 6. From the real and reactive power error signals, the corresponding switching states are estimated by direct power control. The switching state of the inverter is selected from predefined set of switching states of the inverter the vector space.

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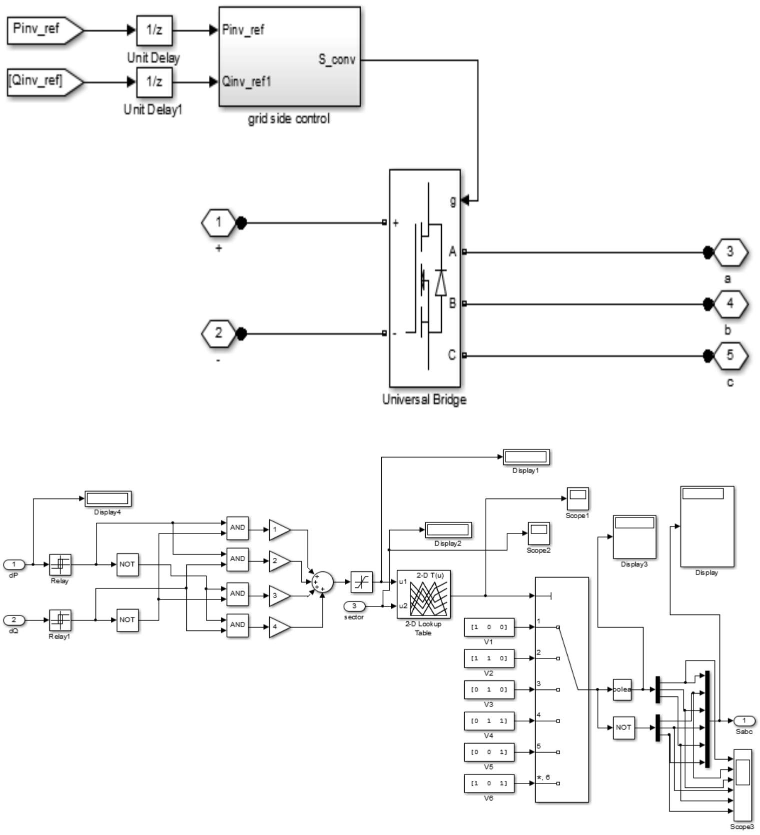

Fig.6 Simulation diagram for grid inverter and logic controller circuit

VII. RESULTS AND DISCUSSION

Case 1: Simulation result of voltage and current of the inverter in grid connected mode

Figure 7 shows the voltage and current waveform of the inverter in grid connected mode. It can be seen that the 3 phase voltage attains its steady state value at 235V and the 3 phase current attains its steady state value at 300 Amp.

In grid connected mode the value of reactive power is zero and the real power is found to be 100kW. Figure shows the real and reactive power waveform of the inverter in grid connected mode.

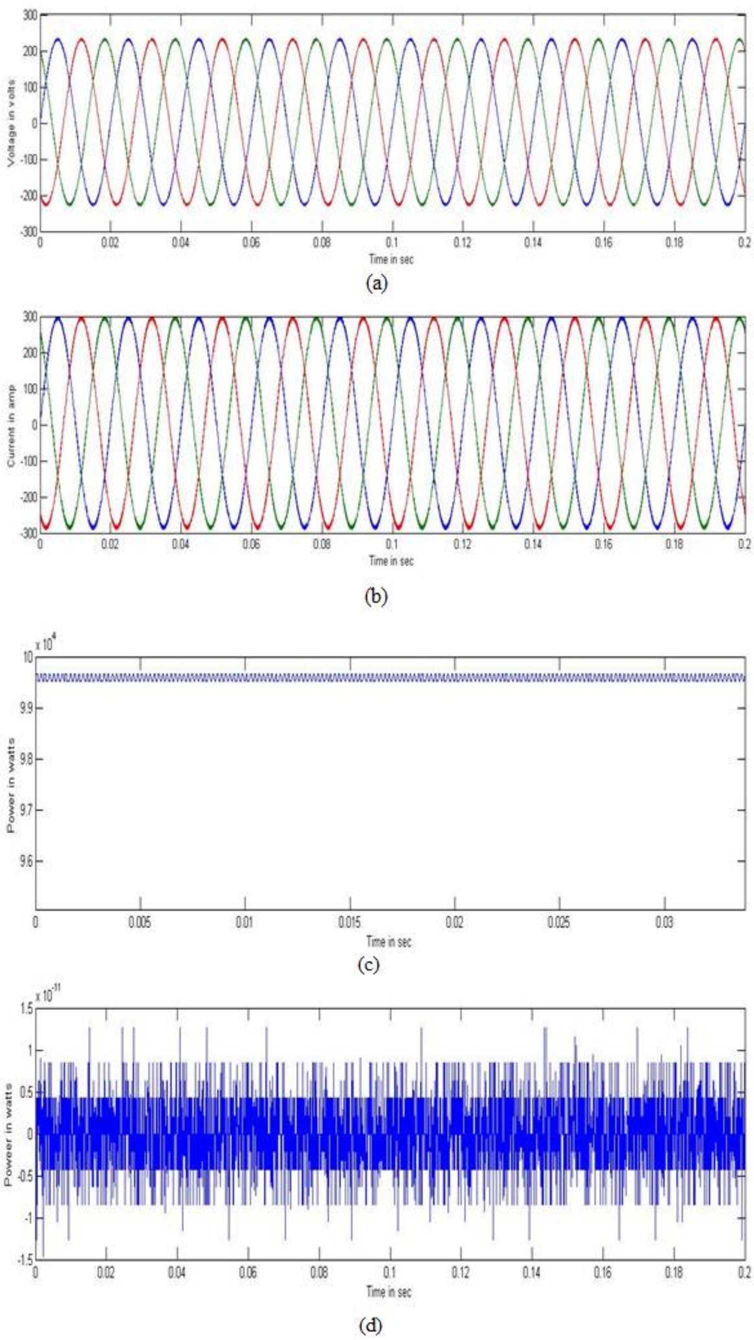

Fig.7 Simulation result for grid connected mode

Case 2: Voltage and current of the inverter in island mode

In island mode of operation the inverter is disconnected from the main grid. Figure 8 shows the voltage and current of the inverter in island mode. In inverter the voltage and current value is zero.

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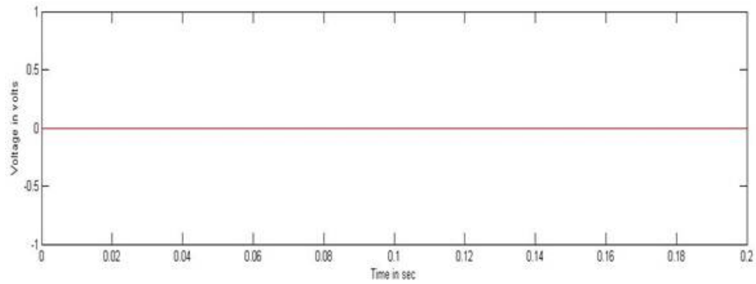

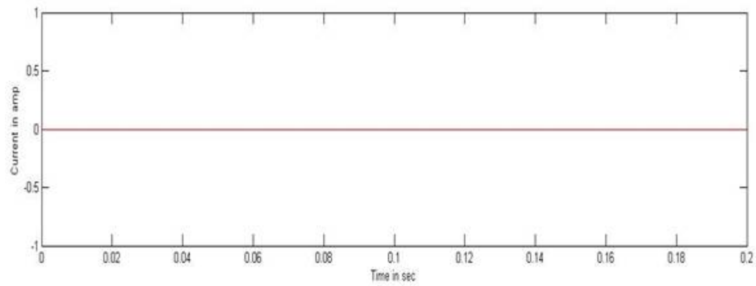

Fig.8 Simulation result for islanding mode

VIII. CONCLUSION

In this paper the control strategy for PV based microgrid is presented. Different levels of the control system are studied and organized in a multilevel control structure. From the calculated reference power, electrical reference (voltage and current) are realized by the various control strategies. Finally simulation results show that the energy management strategies such as smooth power, fast dynamic compensation, and optimum utilization of storage elements are achieved.

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