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Model Predictive Control Approach for Power-Quality Improvement in Distributed Generation Inverters

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Abstract: *In this project a Microgrid consisting of different distributed generation (DG) units are presented. These distributed generation (DG) units are connected to the distribution grid. The distributed energy resources are necessary to saving the energy for future use. Here an Energy-management algorithm is implemented to coordinate the operations of the different DG units in the Microgrid for grid-connected and islanded operations. The control of DG inverters is achieved by using a newly developed model predictive control (MPC) algorithm. The advantage of this method is that it has faster computational time by enhancing the steady-state and transient state control problems separately.*

The proposed Microgrid consists of a photovoltaic (PV) array, a proton-exchange membrane fuel cell, a lithium-ion storage battery. Photovoltaic array act as the primary generation unit of the microgrid and the proton-exchange membrane fuel cell is used to supplying power for preserving the output voltage of primary generation unit within a range. A lithium-ion storage battery is helps in reducing the amount of energy purchased from the main utility grid during grid connected operation and also maintaining the shortage of power by supplying power during islanded operation in such a way that it helps in maintain the stability of the distribution network.

Keywords: *Distributed generation (DG), energy management, microgrid, model predictive control (MPC)*

1. INTRODUCTION

The fast developments of sustainable energy resources and the distributed generation units are integrated to the distribution grid this helps to reducing the amount of energy utilized from the distribution grid. This method is used in developing Microgrid. Microgrid is an electrical system consist of distributed generation units, energy storage devices and loads which are electrically connected with each other and controlled results into two different operation called grid connected and islanded mode of operation. By the usage of Microgrid system we can improve the energy reserves and also it helps in improving the power quality of the distribution system. The distributed generation units are used to store and generate energy from small renewable energy resources. There are so many distributed generation units are available, such as solar, wind, bio-mass, bio-gas, tidal energy, battery, fuel cell etc. Among these DG units only solar and wind generation are mostly used in microgrid. Large amount of power can be produced by integrating these energy sources into the Microgrid. However, these energy sources are not continual in their generation because of their atmospheric conditions. We need to compromise the reliability and stability of the distribution network. As a result the energy storage devices, such as batteries and ultra capacitors, are required to compensate the shortage of power generated by the renewable energy sources. These energy storage devices also help in handling the peak demands and changes in the load demand.

The proposed microgrid consists of a photovoltaic (PV) array, a proton-exchange membrane fuel cell(PEMFC), a lithium-ion storage battery. The fuel cell used as a backup unit to compensate the shortage of power generated by the PV array. Storage battery is used to provide peak shaving during grid connected operation and it supplements power during islanded operation and also to maintain the stability of the distribution network. An energy management algorithm is used in the microgrid to coordinate the sharing of power among different DG units.The non linear loads in the microgrid will produce harmonics. This harmonics will reduce the power quality of the distribution system. Here we are using a MPC algorithm, which enhance the steady state and transient state problems separately to eliminate the harmonics from the load current in such a way that the power quality of the system is improved and also computational time is reduced. This paper gives a proper solution for the operation of a microgrid which will supply real and reactive power during both grid connected and islanded mode of operation.

2. SYSTEM DESCRIPTION

Fig.1 shows the circuit diagram microgrid used in this project. Which will operate either in grid connected or islanded mode. Here we are using 40-kw photovoltaic array and 15-kw PEMFC as the DG units in the microgrid. The PV array act as the primary generation unit of the Microgrid and the fuel cell act as the backup unit of the PV array. PV array and PEMFC connected in parallel to the DC side of the DG inverter 1 through a dc/dc boost converters.

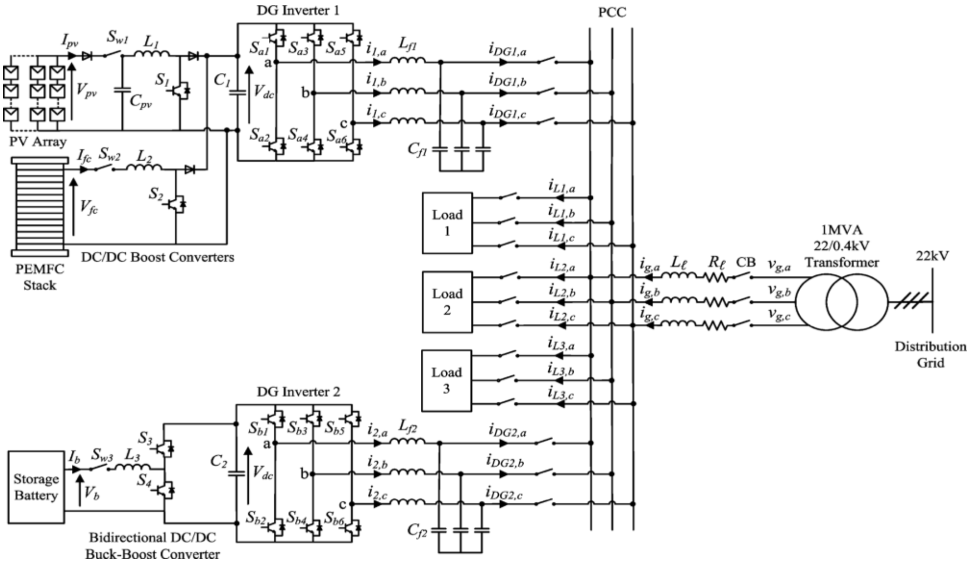

Fig. 1. *Overall configuration of the proposed microgrid architecture*

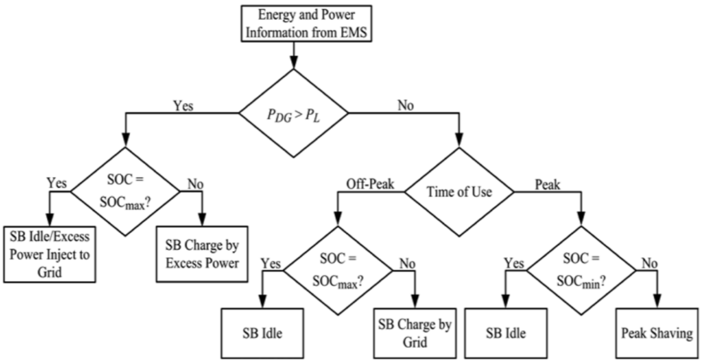

Fig. 2. *Operation of the SB during grid-connected operation.*

Here the dc/dc boost converter is used to supplying necessary power for adjust the dc-link voltage of the DG inverter at a specified level. When there is abundant sunlight, the PV array operates in maximum power point

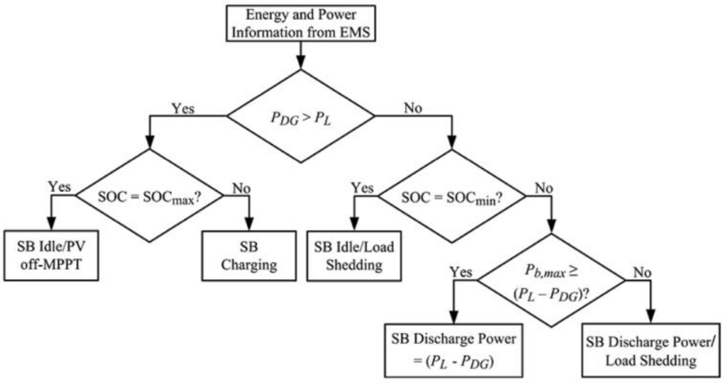

Fig. 3. *Operation of the SB during islanded operation*

tracking mode and it delivers maximum dc power to DG inverter. The output voltage of the photovoltaic array is allowed to vary within a range for the proper operation of the DG inverter. if any small deviation from that range ,the PEMFC will supplements power for satisfying the load requirements. If the output voltage of the PV array falls below a present limit, The PV array will disconnect from the DG inverter, then the PEMFC will act as primary generation unit of the microgrid for supplying required power. Here a 30Ah lithium ion battery is used as the backup generation unit of the microgrid. It is connected to the dc side of the DG inverter 2 through a bidirectional buck boost converter to make easier charging and discharging operations. During islanded operation SB is used to control the power balance in the microgrid which is given by

$PDG+Pb=PL$, Where PDG is the power supplied by the main DG unit .Pb is the SB power which is subjected to the charging and discharging operations given by

$$Pb \leq Pb,max$$

And PL is the real power delivered to the loads. The energy limits of the SB are determined by the state-of-charge(SOC) conditions. Which are given as

$$SOCmin < SOC \leq SOCmax.$$

The SOC of the battery is very difficult to find, we cannot able to measure it directly. The operation of the battery during grid connected and islanded mode of operation is shown in the flowchart below in fig2 and fig3.

The operation of the SB is mainly depends upon the output information obtained from the energy management system during grid connected and islanded mode of operation. The energy management system monitors, controls, and enhances the performance of different units in the microgrid.

During grid connected operation microgrid is connected to distribution grid at the point of common coupling through a circuit breaker. The main DG unit is used to give local power and voltage support for the loads. This will helps to reduce the burden of generation and delivery of power directly from the distribution grid. In microgrid, the load current might be distorted due to presence of harmonics. These harmonics are produced from the power electronics equipment and non linear loads connected to the microgrid. The DG units also used for eliminating harmonics from the load current that produced due to non-linear loads, so that the harmonics will not enter into other electrical devices connected to the PCC. Normally the power generated from the PV array is varied based on atmospheric condition. So that there will be a difference between the power generated by the PV array and the power required by the loads. If the power generated by the main DG unit is greater than the total load demand in the microgrid, The extra power is used to charge the battery or injected into the distribution grid, based on SOC of the battery. That is shown in Fig.2.If the generated power from the main DG unit is less than the load requirement, the SB will charge by the grid or provide peak shaving based on the time of use of electricity and SOC of the battery. During peak periods, That is the cost of electricity generation from the grid is high and SOC of the battery is above SOCmin means, SB will deliver power to grid for providing peak shaving. During off peak periods, if SOC of the battery is below the SOCmax. , SB will charge by the grid .This time Main DG unit and the utility grid will supply power to the loads.

During Islanded mode of operation the microgid is disconnected from the distribution grid by opening the circuit breaker. The circuit breaker is opens when any fault occurs in the Distribution network.Then the main DG unit and the SB will supply power for satisfying the load requirements. During islanded mode of operation, if the generated power from the DG unit is unable to meet the load demand, the SB is required supplement power for satisfying the load requirements. The operation of battery during islanded mode is shown in Fig.3.If the total load requirements is exceeds the power supplied from the main DG unit and the SB, The EMS will detect the change in frequency and shedding of noncritical load also start by opening the CB. In this way the SB is maintaining the power balance and stability of the microgrid.

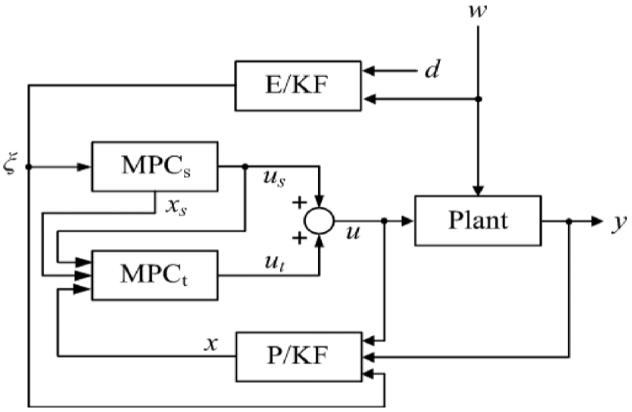

Fig. 4. *Overall MPC controller for the DG inverter with E/KF denoting the exogenous Kalman filter and P/KF denoting the plant Kalman filter.*

In this paper the control of DG inverters is achieved by using a MPC algorithm.MPC algorithm is a newly developed algorithm mainly used for fast sampling systems to track the periodic signals so as to provide dual mode operation of the Microgrid. This algorithm optimizes the transient state and steady state problems separately. This results in reduced computational time.

3. SIMULATION STUDIES

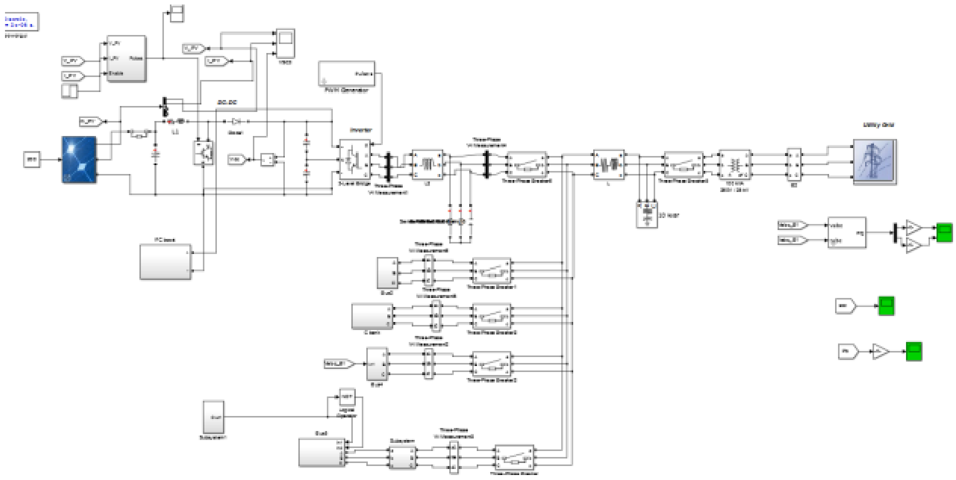

Fig:5 *Simulation circuit of the proposed Microgrid.*

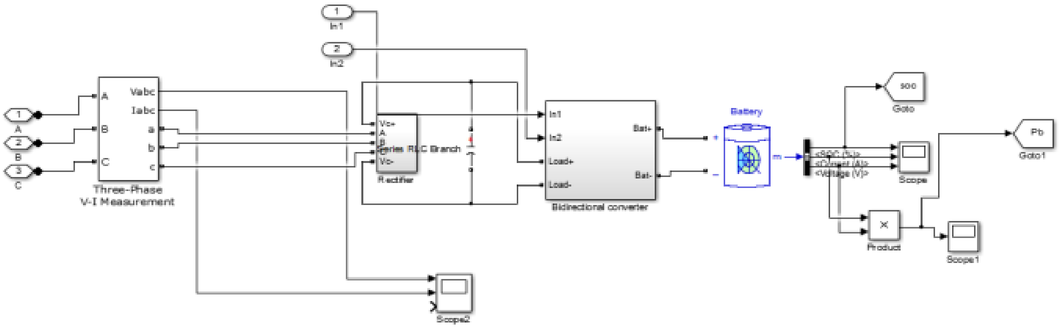

Fig: 6. *Circuit for the charging and discharging operation of the battery.*

The simulation model of the microgrid shown in Fig. 1 is realized in Matlab/Simulink. The Microgrid is tested under various conditions for determining the efficiency of the Microgrid under various operating conditions. The Microgrid consisting of three different types of loads .Load one and two are linear loads and load three is a non linear load which will supply power under emergency conditions. Load one is a inductive load and load two is a three phase RL load and Load three is a three phase induction motor that is non linear in nature. The total real and reactive power consumed by loads during case 1 is P=50kW and Q=28 kVAr.

Table I. *Parameters of the Proposed System*

Parameter	Value
Distribution grid voltage	V_g =230V
DC link voltage	V_{dc} =400V
Distribution line impedance	R_l =.002Ω,L_l=250µH

The simulation circuit for Microgrid is shown in Fig.5. Fig: 6. Shows Circuit for the charging and discharging operation of the battery. The system parameters are given in Table I.

Test Case 1: Power Quality Improvement with Load-Sharing During Grid-Connected Operation

The first test case describes the ability of the microgrid to improve the power quality of the distribution network. The power quality of the distribution network is improved by eliminating the harmonics from the load current which is done by using MPC algorithm. This algorithm blocks the harmonics. So that during grid-connected operation the harmonics will not propagate to the rest of the distribution network. In this the power generated from DG is greater than that of load requirement. that is $P_{DG}>P_{L..}$

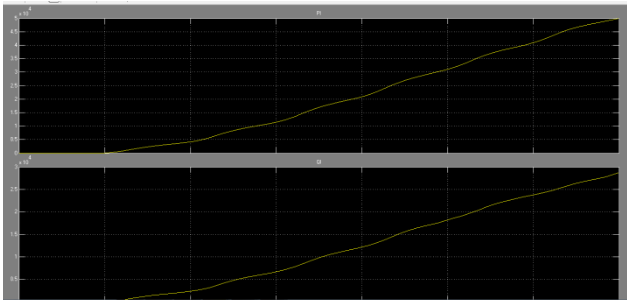

Fig.7. *real and reactive power consumed by load*

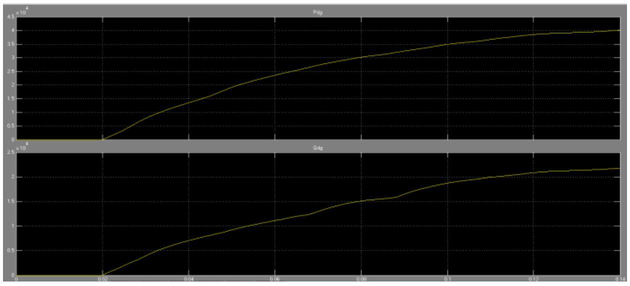

Fig:8.. *Real and reactive power supplied by main DG unit.*

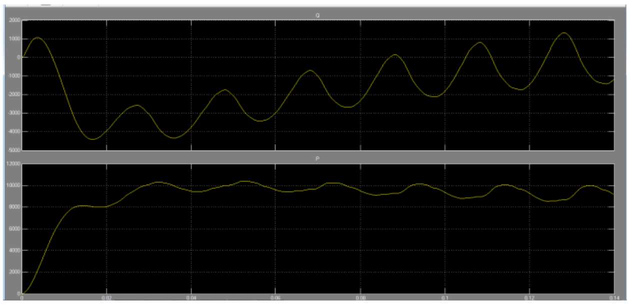

Fig:8. *.real and reactive power supplied by grid*

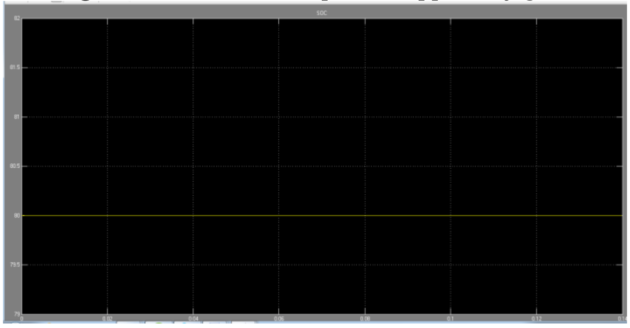

Fig: 9. *SOC of the battery.*

In this case 80% of total load requirement is supplied by main DG unit and 10% is taken from distribution grid.

Test Case 2: Peak Shaving of Loads during Peak Periods

During peak periods the cost of generation from the main utility grid is high. Energy storage devices can be used to reduce the burden of generation of power directly from the distribution grid during peak periods. The second test case explains the operation of the Microgrid to provide peak shaving during peak periods for reducing the cost of generation from the grid.

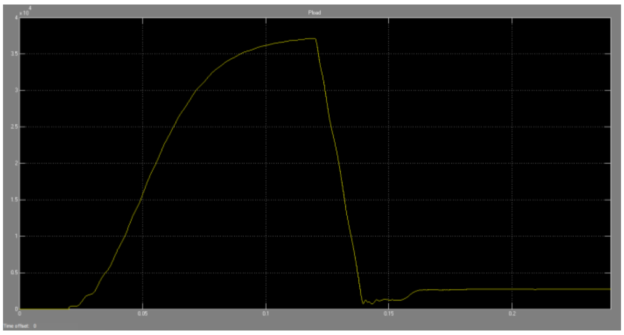

Fig.10. *Hourly demand response curve in a day*

Fig.10. shows a typical hourly demand response curve in a day.Fig:11.Shows the real and reactive power supplied by grid. In this test is PDG$<P_L$ and the battery is controlled to supply 80% of the load demand, remaining 20% of power is supplied by distribution grid. This results in reducing the amount of energy taken from the main utility grid. There by reducing the cost of generation. Fig: 11.real and reactive power delivered by grid. Fig: 12.Shows Power delivered by the battery.

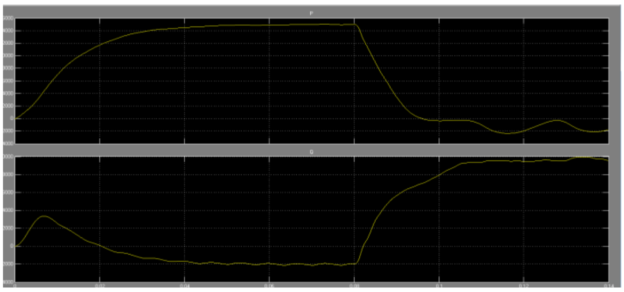

Fig:11 *.real and reactive power delivered by grid.*

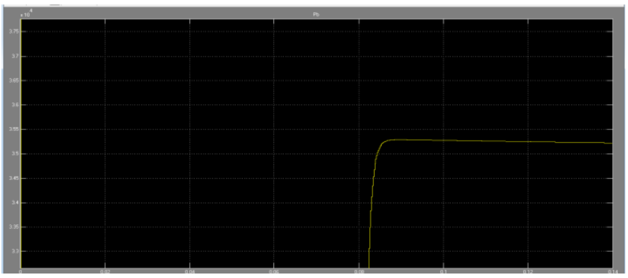

Fig:12. *Power delivered by battery.*

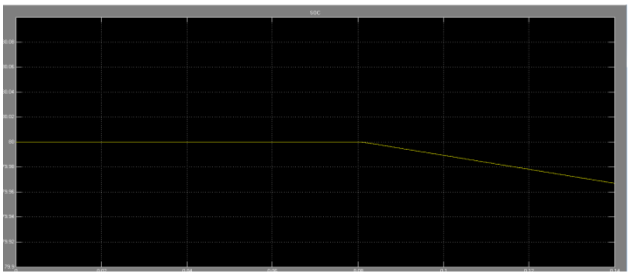

Fig:13. *SOC of thebattery*

Test Case 3: Load Shedding During Islanded Operation:

The third test case explains the operation of the Microgrid when it's disconnected from the distribution grid. The Microgrid will disconnect from the distribution grid when a fault occur on the upstream network of the distribution grid. In this case at t=.02sec the Microgrid is disconnected from the distribution grid. Then the main DG unit and the battery delivering power for satisfying the load demands. Fig: 14. Shows the real and reactive power delivered by the grid. Fig: 15. Shows the real power delivered by SB Fig: 17.Shows the real and reactive power consumed by loads.

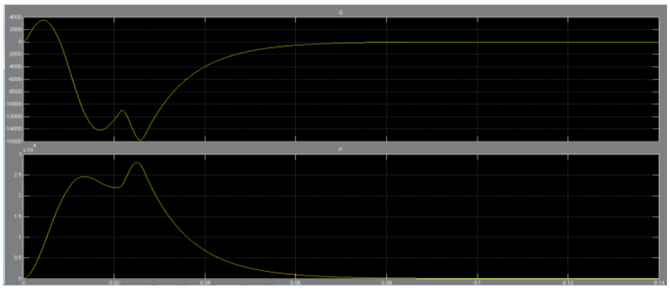

Fig: 14. *Real and reactive power delivered by the grid.*

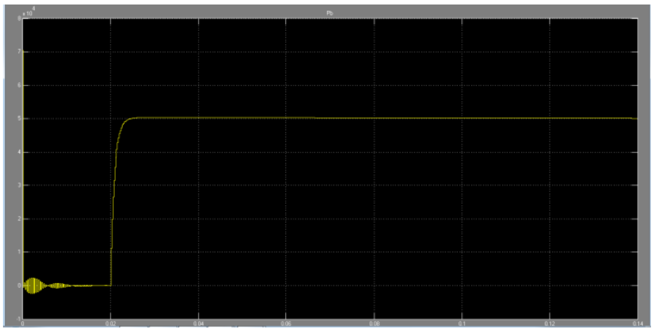

Fig:15: *Real power delivered by battery.*

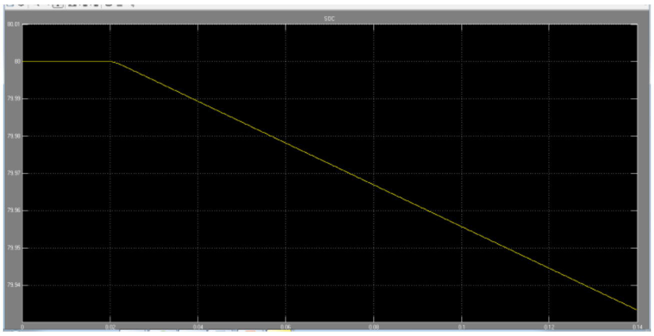

Fig: 16. *SOC of thebattery*

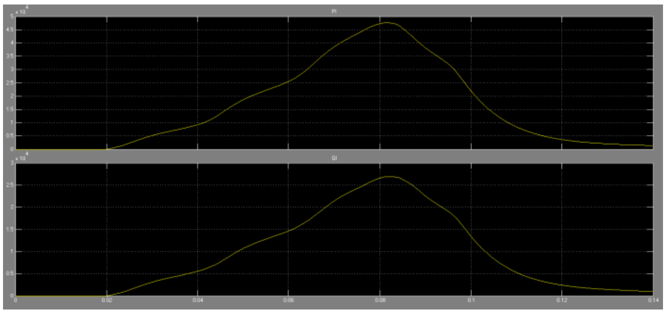

Fig. 17. *Real and reactive power consumed by loads.*

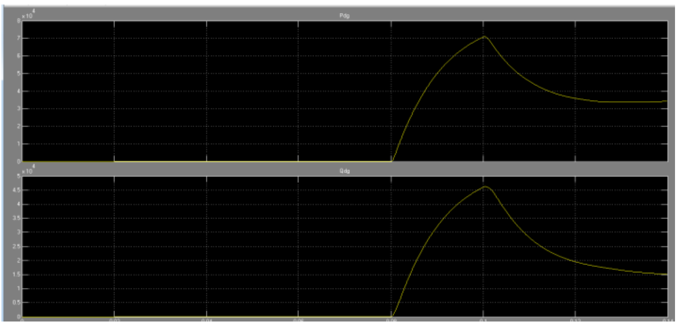

Fig. 18. *Real and reactive power supplied by DG.*

4. CONCLUSION

In this paper, a MPC algorithm controls the operation of multiple DG inverters in the Microgrid for grid connected and islanded mode of operations has been presented. This algorithm enhances the steady-state and transient state control problems separately which reduces the overall computational time. This MPC algorithm consist Kalman filters which are used for eliminating the harmonics. This algorithm also has the ability to eliminating the harmonics from load current in a similar way as conventional compensators, so that no need of additional equipments for increasing the power quality of the distribution system. Here an Energy-management algorithm is implemented to coordinate the operations of the different DG units in the microgrid for grid-connected and islanded operations. As a result of this Microgrid has the ability to handle different operating conditions effectively during grid connected and islanded operation which also helps in improving the overall reliability and stability of the microgrid.

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