Modeling and Control of Parallel Inverters in a Microgrid

VVS Madhuri, Bharath Reddy L.

Abstract— Nowadays, more and more distributed generation and renewable energy sources are connected to the public grid via power electronics, forming a microgrid. The frequency and voltage in a microgrid should be maintained within the predefined limits thereby enabling proper real and reactive power sharing according to load changes. Inverters are frequently employed as interfaces of distributed power sources to loads. The dynamic response of inverter interfaced DGs, such as PVs, fuel cells and batteries are noninertial and are faster compared to inertial DGs. This mismatch in response rate can create power and frequency fluctuations. Therefore, the control and power management strategies are vital for an islanded microgrid with different types of DGs. The most common method of local load sharing is the droop control. This control strategy based on frequency and voltage droop method avoids critical communications among distributed generation units (DGs). The microgrid is modeled in MATLAB/Simulink environment and the voltage and frequency droop control is applied to the model and performance of the droop control strategy is verified. This paper focuses on modeling and control of parallel inverters operating in various conditions.

Index Terms— Distributed Generation , Droop Control, Islanded mode, Micro Grid , Parallel Inverters, PWM , Voltage Source Inverter.

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1 INTRODUCTION

Due to the rapid depletion of fossil fuels and the rising demand for electricity power, the interconnection of distributed generation units (DGs) including wind turbines, photovoltaic (PV) and etc., has raised concern in the last few years. In order to control these DGs more effectively and fulfill power quality requirement, microgrid[1] concept is proposed. A microgrid is a cluster of DGs and loads, which can operate in both grid-connected mode and islanded mode. All the DGs are parallel connected to an ac common bus through inverters or ac-to-ac converters, the common bus is then connected to the utility/grid, as shown in Fig.1.

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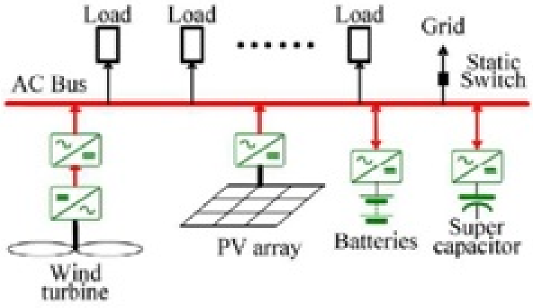

Fig.1. Typical microgrid

The rest of the paper is organized as follows. Proposed control strategy is explained in section 2. Experiment and results are presented in section 3. Concluding remarks are given in section 4.

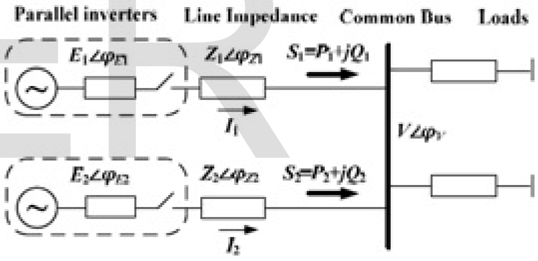

Fig.2. Equivalent circuit of parallel-inverters-based microgrid

2 PROPOSED CONTROL STRATEGY

Fig. 2 shows the equivalent circuit of a parallel-inverters-based microgrid. The active and reactive power flow between DGs and the bus can be expressed as

$$P = \frac{E^2 \cos\varphi_z - EV\cos(\varphi_E - \varphi_V + \varphi_z)}{Z} \qquad (1)$$

$$Q = \frac{E^2 \sin\varphi_z - EV\sin(\varphi_E - \varphi_V + \varphi_z)}{Z} \qquad (2)$$

where E and V are the magnitudes of the inverter output voltage and ac common bus voltage, Z is the line impedance. For a purely inductive line impedance, the line resistance may be neglected, i.e. $\varphi_Z = 90°$, thus (1) and (2) become

$$P = \frac{EV\sin(\varphi_E - \varphi_V)}{X} \tag{3}$$

$$Q = \frac{E^2 - EV\cos(\varphi_E - \varphi_V)}{X} \tag{4}$$

where X is the line reactance. Further, considering that the phase angle difference $\delta = \varphi_E - \varphi_V$ is typically small, we can assume $\sin(\delta) = \delta$ and $\cos(\delta) = 1$, and consequently

$$P = \frac{EV\,\delta)}{X} \tag{5}$$

$$Q = \frac{E(E-V)}{X} \tag{6}$$

As a consequence, the flow of active power is linearly dependent on the phase angle difference (δ) and the flow of reactive power is linearly dependent on the voltage magnitude difference (E-V). At his point, similar to the power system theory where a generator connected to the utility drops its frequency when the power required increases, a voltage and frequency droop control method[3] for microgrid can be defined as

$$\omega = \omega^* - m(P - P^*) \tag{7}$$

$$E = E^* - n(Q - Q^*) \tag{8}$$

where, P^* and Q^* are the desired active and reactive power, ω^* and E^* are the inverter normal output frequency and voltage amplitude, m and n are the slopes of the droop characteristics. Fig. 3 depicts the P- ω droop characteristics. Fig. 4 shows the implementation of Droop control. In droop control method, the changes in load can be taken up by the DGs in a predetermined manner and the wireless control of parallel inverters is achieved with the utilization of system frequency as a communication link within a microgrid[4][5].

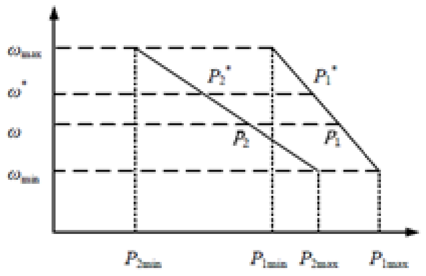

Fig.3. Active power and frequency droop characteristics

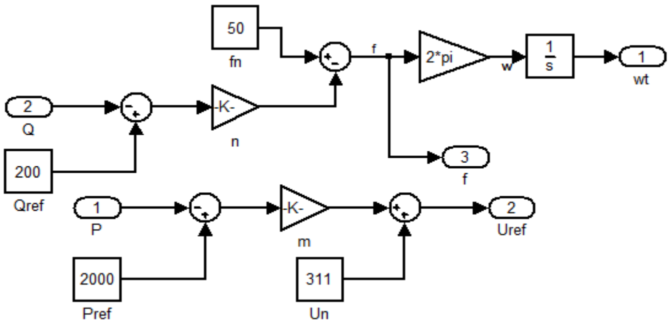

Fig.4. Droop Implementation

3 EXPERIMENT AND RESULT

In the system under study, as shown in Fig.5, the parallel inverters operate in autonomous mode with load1 connected to ac common bus via circuit breaker during simulation. Fig.6 denotes the DG1 and Fig. 7 denotes the subsystem of DG1. After 0.2 s of the operation, the breaker closes and the microgrid connects to the load1 and disconnects after 0.5 s. The performance of the control strategy has been tested in simulation using Matlab/Simulink. In islanded mode, inverters from DG1 and DG2 together supply all the active and reactive power required by the common load according to their frequency and voltage droop characteristics. It can be seen that the power requirement is equally shared by two inverters as the ratings of both are same. At 0.2 s, the power requirement at the ac bus terminal common load will increase. The inverters increase the output power automatically to meet the new power requirement. At 0.5 s, the extra load disconnects from the circuit, it is seen that the output powers and terminal voltage and frequency drop back to their previous values. For evaluating the behaviour of the inverter control algorithm, especially the dynamics of the system power balance and the flow of power, the following load profiles are used.

i. Load is resistive and real power is 1000 W
ii. Load1 is resistive and inductive and real power is 5 kW and reactive power is 14 kVar

The output voltage and current across the common load is shown in the fig. 8 and fig. 9. As the load increases from 0.2 s, the voltage at the output drops with respect to the droop coefficient value and after 0.5 s voltage increases to initial value. The fig 10 and fig. 11 shows the real and reactive power output of inverter 1. For inverter 2 the power sharing is same as the capacity of both the inverters are same and same droop coefficients are used for study.

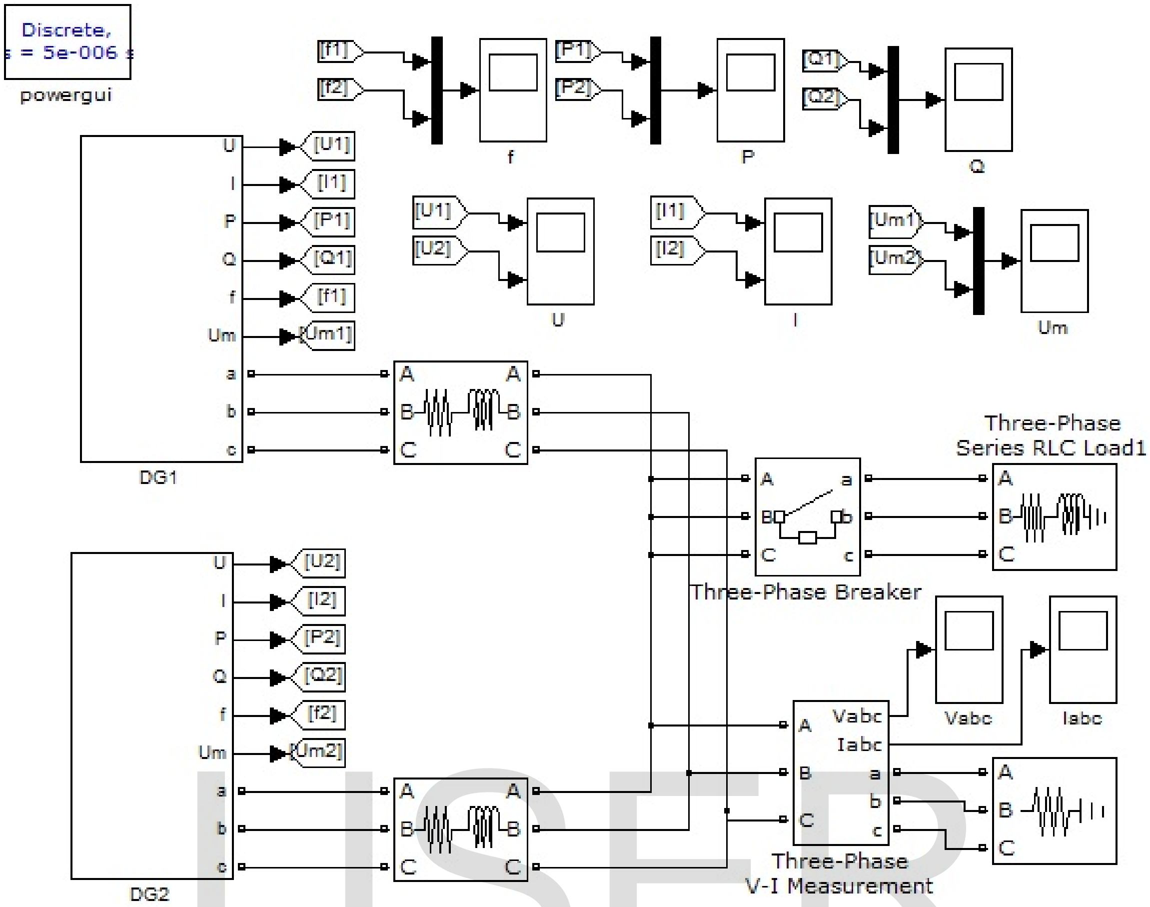

Fig.5. System under study

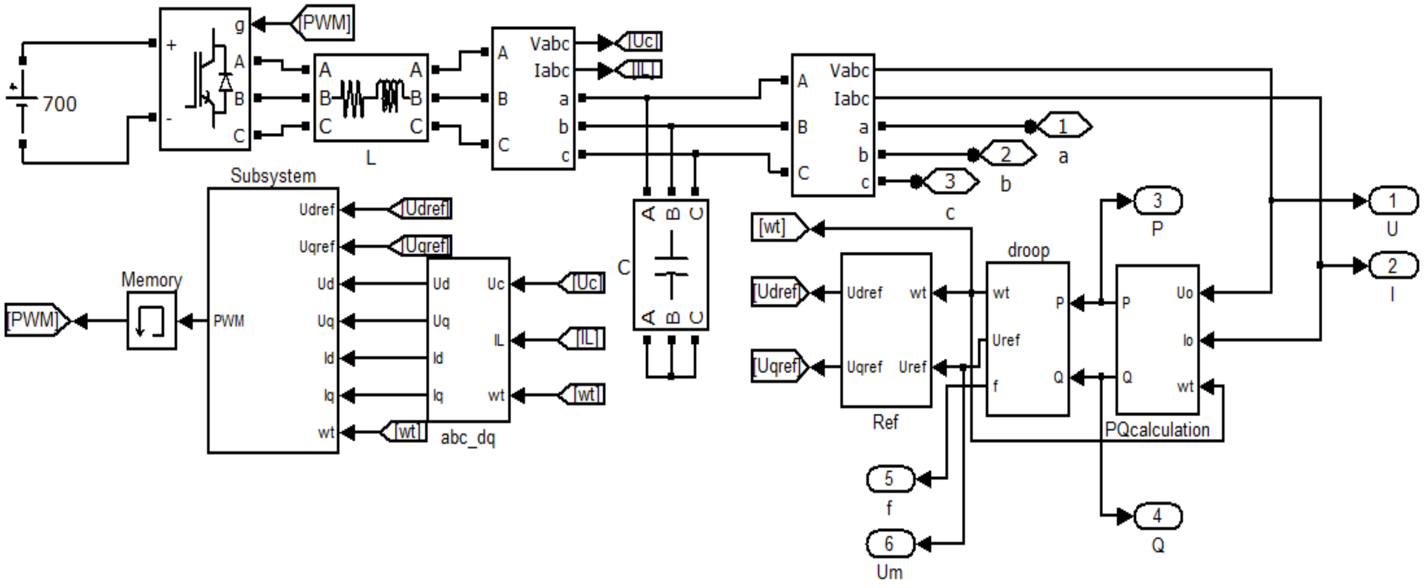

Fig.6. DG1

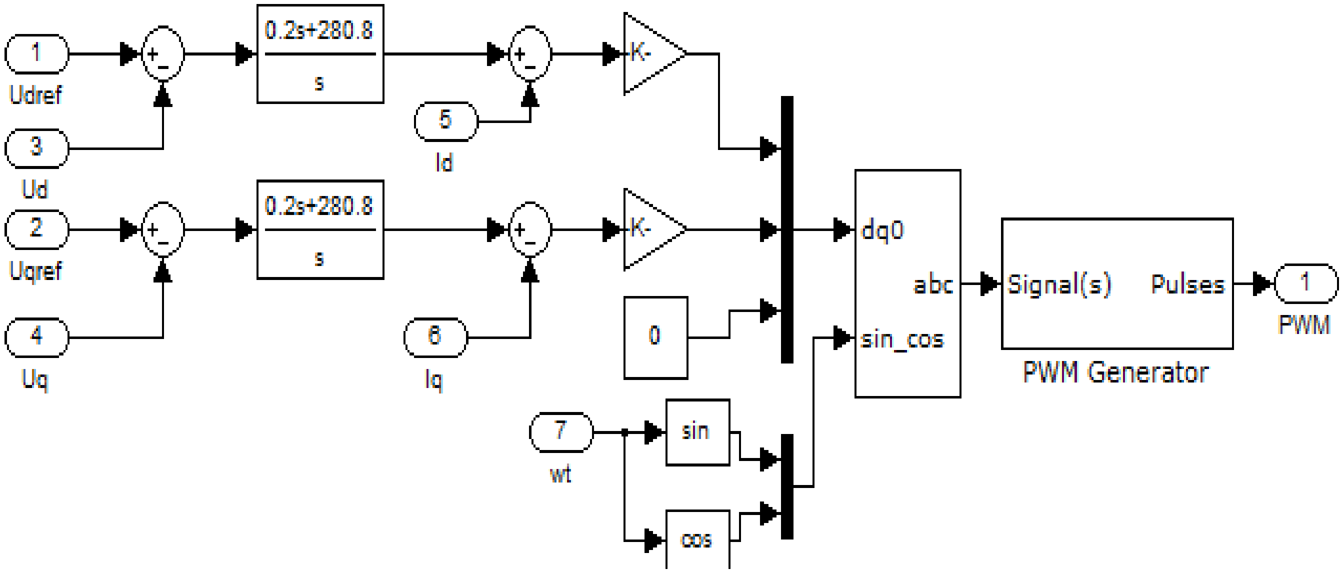

Fig.7. Subsystem of DG1

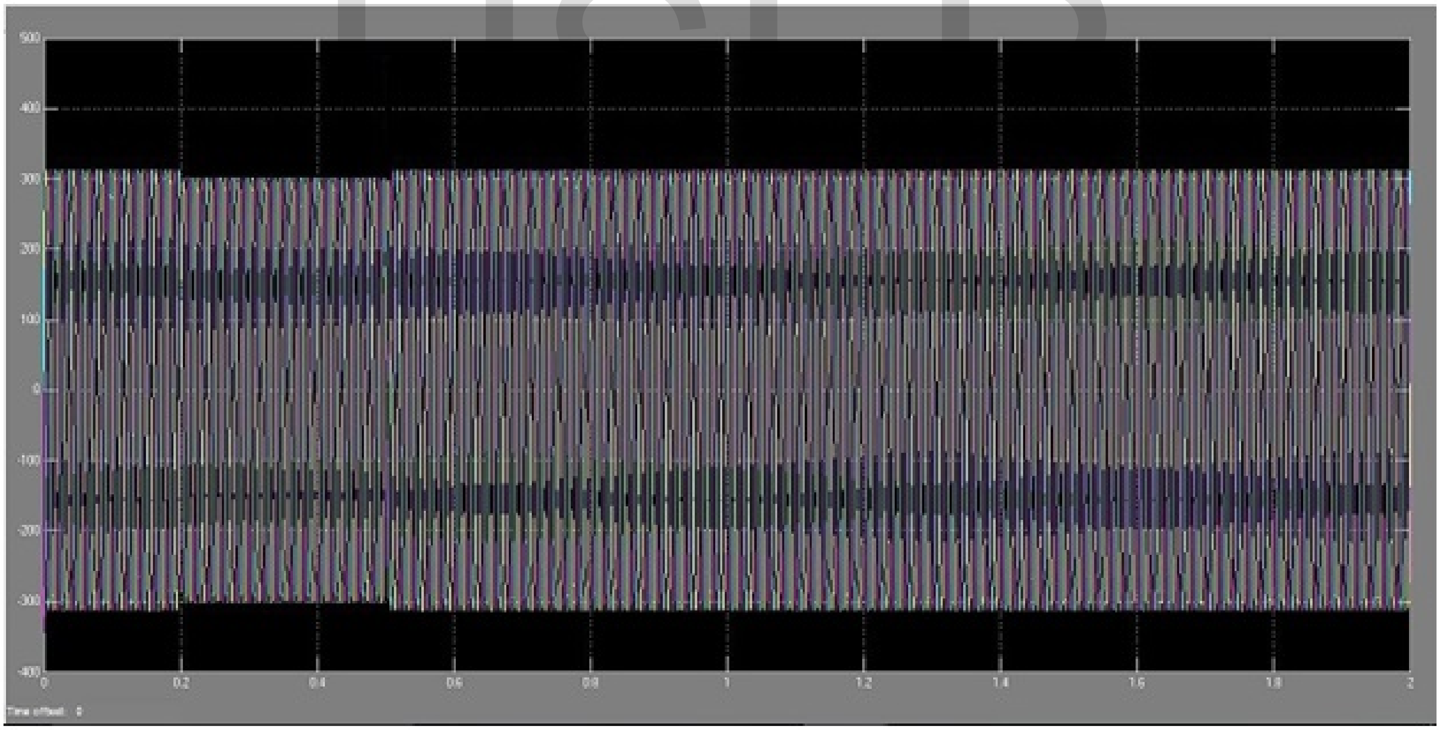

Fig. 8. Output Voltage

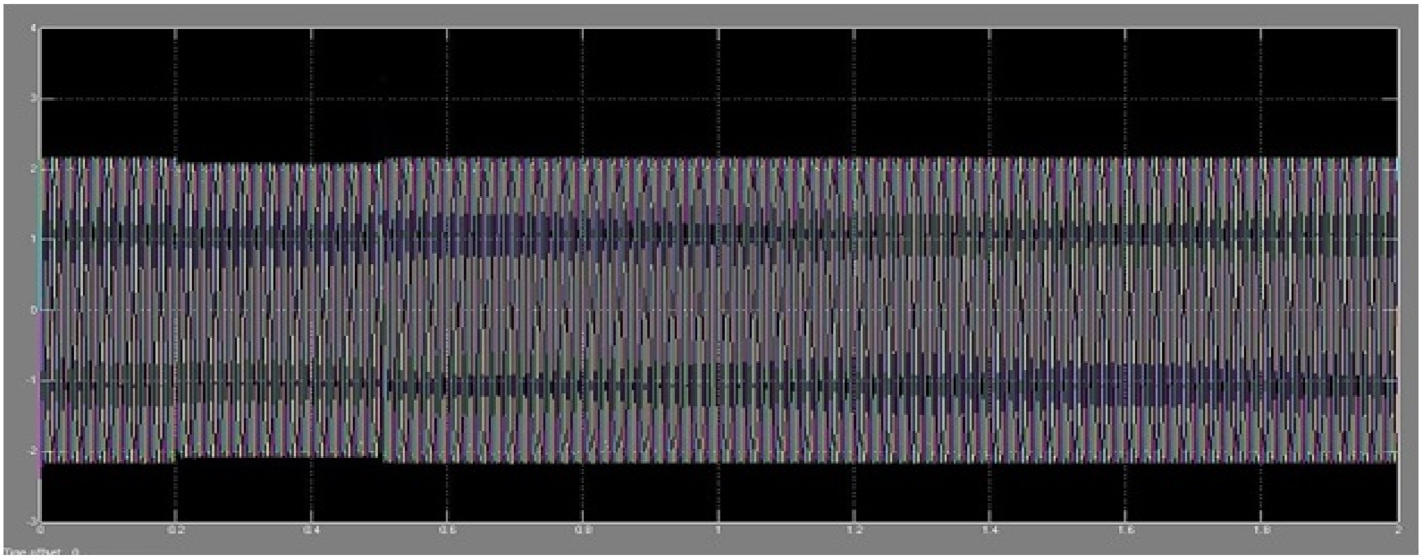

Fig. 9. Output Current

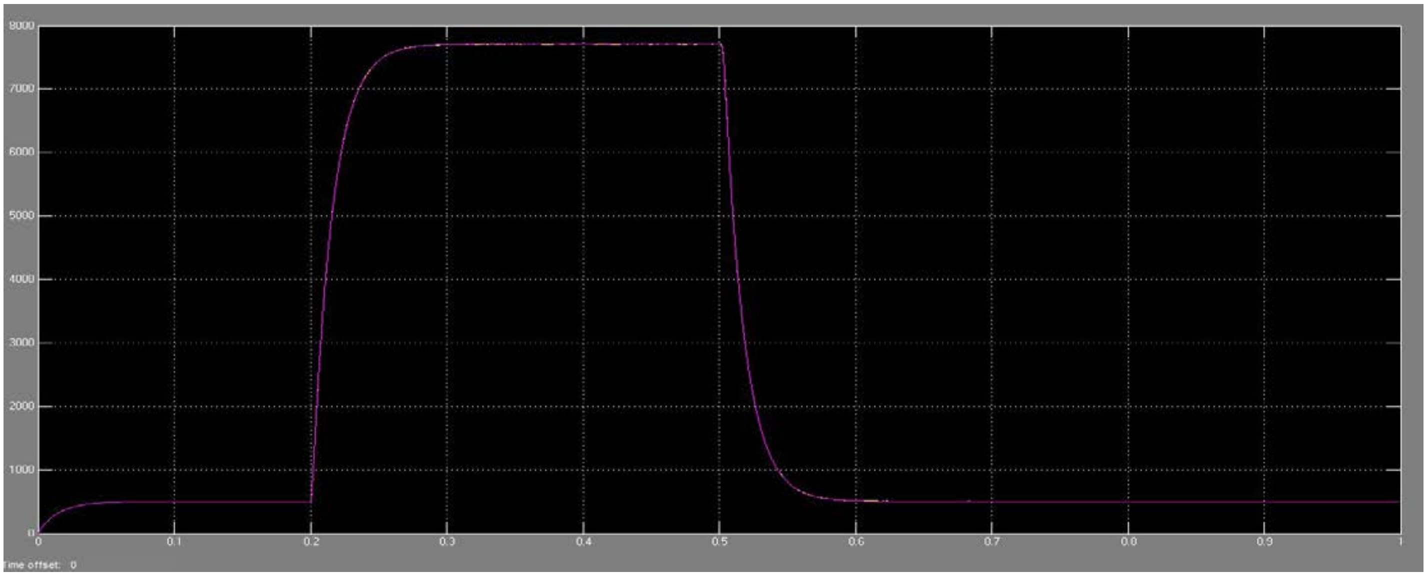

Fig. 10. Active power at Inveter1

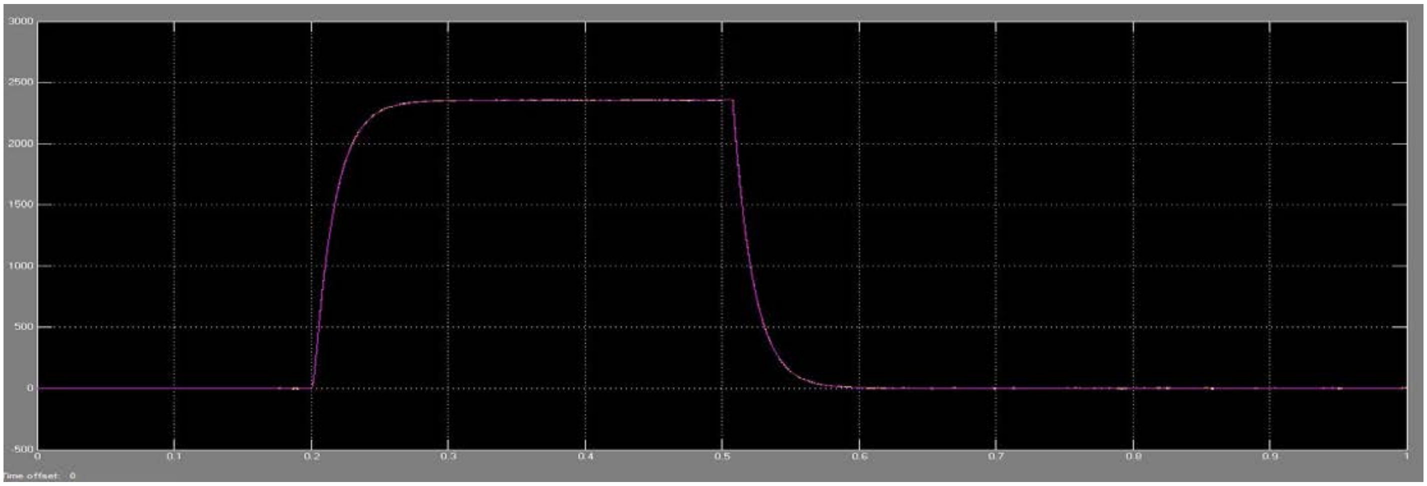

Fig. 11. Reactive power at Inverter1

4 CONCLUSION

Microgrids play a key role in the evolution of smart grids. There are many variations in adopting the microgrid architecture and design. However, they are implemented with common perspectives such as reliability and optimal integration of DGs. With the present experience, identifying the dependable control strategies and utilizing them accordingly to further improve the system reliability is a key requirement. In this paper, a control strategy for parallel-connected DG systems forming a microgrid was presented. The control model of standalone microgrid in which power electronic interfaced distributed generation is simulated in MATLAB/SIMULINK and the converters uses the PWM control method in which the gate pulses generated by the droop control strategy are used. A simplified droop control based voltage and frequency controller was implemented for the voltage source inverters. In this paper droop control methods for an islanded microgrid is summarized. By the results presented in this paper it is believed that all objectives have been fulfilled. A power-sharing method is developed and the output power is regularly maintained according to the power requirement and inverter capacities. In the course of island mode of operation, the load demand has been matched by DGs alone. The simulation results have indicated that all DGs share the proper amount of power especially in islanded mode. This control strategy combines frequency and voltage droop method and inverter voltage regulation control scheme. In the external power control structure, the referenced frequency and magnitude of inverter output voltage are obtained according to the droop characteristics. The load changes can be taken up by the parallel connected DGs. This study examined the MG concept and suggested control strategies that will reliably and efficiently operate on a balanced three phase low voltage MG in islanded mode

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AUTHORS DETAILS

- *VVS Madhuri is Faculty at Department of Electrical and Electronics Engineering in Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, Telangana, India . Email: madhurivvs@gmail.com*

- *Bharath Reddy L is currently pursuing masters degree program in Power Systems in Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, Telangana, India. E-mail: bharathreddyl.91@gmail.com*