ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 11, November 2016

Reactive Power Sharing in Islanded Microgrid using Improved Droop Control

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ABSTRACT: For micro grid in islanded operation, due to the effects of mismatched line impedance, the reactive power could not be shared accurately with the conventional droop method. To improve the reactive power sharing accuracy, this paper provides an improved droop control method which mainly includes two important operations error reduction operation and voltage recovery operation. The sharing accuracy is improved by the sharing error reduction operation, which is activated by the low-bandwidth synchronization signals. The error reduction operation will result in a decrease in output voltage amplitude. Therefore, the voltage recovery operation is proposed to compensate the decrease. The needed communication in this method is simple. Simulations results show that the improved droop controller can share load active and reactive power, enhance the power quality of the micro grid, and also have good dynamic performance.

KEYWORDS: microgrid, reactive power sharing, low-bandwidth synchronization signals, voltage recovery operation, Droop control.

I.INTRODUCTION

In an islanded mode, the load power in the microgrid should be properly shared by multiple DG units. Usually, the droop control method which mimics the behaviour of a synchronous generator in traditional power system is adopted, which does not need the use of critical communications. The active power sharing is always achieved by the droop control method easily. However, due to effects of mismatched feeder impedance between the DGs and loads, the reactive power will not be shared accurately. In extreme situations, it can even result in severe circulating reactive power and stability problems.To overcome the reactive power sharing issue, a few improved methods have been proposed. Specifically, there are mainly three approaches to address the effect of the interconnecting line impedance on droop-based control. The first approach is to introduce the virtual output impedance by modifying the output voltage reference based on output current feedback. This method can reduce the reactive power sharing error by reducing the relative error of the output impedances.However, the introduction of the virtual impedance may lead to degradation of the system voltage quality.

The second approach is based on a signal injection technique. In, a certain harmonic signal containing reactive power information is injected into the output voltage reference of each DG unit, and the output reactive power is regulated to improve the accuracy of the reactive power sharing according to the harmonic power. However, this method results in output voltage distortion.

II. MICROGRID AND ISLANDING TECHNIQUE

The popularity of distributed generation systems is growing faster from last few years because of their higher operating efficiency and low emission levels. Distributed generators make use of several microsources for their operation like photovoltaic cells, batteries, micro turbines and fuel cells. During peak load hours DGs provide peak generation when the energy cost is high and stand by generation during system outages. Microgrid is built up by combining cluster of loads and parallel distributed generation systems in a certain local area. Microgrids have large power capacity and more control flexibility which accomplishes the reliability of the system as well as the requirement of power quality. Operation of microgrid needs implementation of high performance power control and voltage regulation algorithm. To realize the emerging potential of distributed generation, a system approach i.e. microgrid is proposed which considers generation and associated loads as a subsystem. This approach involves local control of distributed generation and hence reduces the need for central dispatch.

During disturbances by islanding generation and loads, local reliability can be higher in microgrid than the

DOI:10.15662/IJAREEIE.2016.0511060

whole power system. This application makes the system efficiency double. The current implementation of microgrid incorporates sources with loads, permits for intentional islanding and use available waste heat of power generation systems. The microgrid concept lowers the cost and improves the reliability of small scale distributed generators. The main purpose of this concept is to accelerate the recognition of the advantage offered by small scale distributed generators like ability to supply waste heat during the time of need. From a grid point of view, microgrid is an attractive option as it recognizes that the nation's distribution system is extensive, old and will change very slowly. This concept permits high penetration of distribution generation without requiring redesign of the distribution system itself . The microgrid concept acts as solution to the problem of integrating large amount of micro generation without interrupting the utility network's operation. The microgrid or distribution network subsystem will create less trouble to the utility network than the conventional micro generation if there is proper and intelligent coordination of micro generation and loads. In case of disturbances on the main network, microgrid could potentially disconnect and continue to operate individually, which helps in improving power quality to the consumer . With advancement in DGs and microgrids there is development of various essential power conditioning interfaces and their associated control for tying multiple micro sources to the microgrid, and then tying the microgrids to the traditional power systems. Microgrid operation becomes highly flexible, with such interconnection and can be operated freely in the grid connected or islanded mode of operation. Each micro source can be operated like a current source with maximum power transferred to the grid for the former case. The islanded mode of operation with more balancing requirements of supply-demand would be triggered when the main grid is not comparatively larger or is simply disconnected due to the occurrence of a fault. Without a strong grid and a firm system voltage, each micro source must now regulate its own terminal voltage within an allowed range, determined by its internally generated reference.

Islanding Detection Techniques : The main philosophy of detecting an islanding situation is to monitor the DG output parameters and system parameters and decide whether or not an islanding situation has occurred from change in these parameters. Islanding detection techniques can be divided into remote and local techniques and local techniques can further be divided into passive, active and hybrid techniques as shown in Figure 1

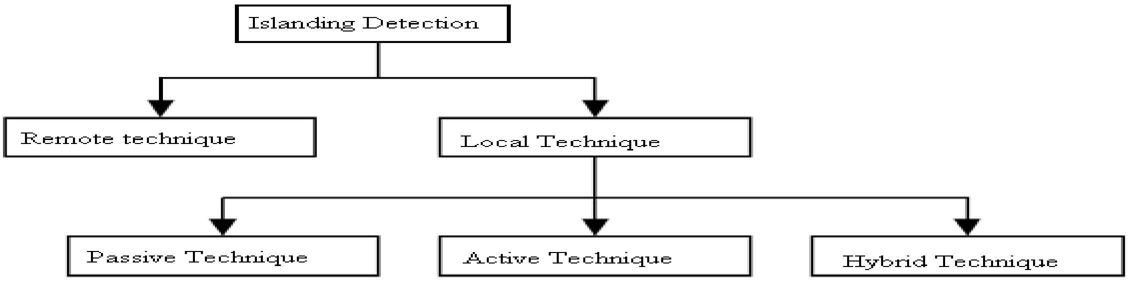

Figure: 1 Islanding detection techniques

Remote Islanding Detection Techniques: Remote islanding detection techniques are based on communication between utilities and DGs. Although these techniques may have better reliability than local techniques, they are expensive to implement and hence uneconomical .Some of the remote islanding detection techniques are as follows:

(A) Power Line Signaling Scheme: These methods use the power line as a carrier of signals to transmit islanded or non-islanded information on the power lines. The apparatus includes a signal generator at the substation (25+ kV) that is coupled into the network where it continually broadcasts a signal as shown in figure. 2 Due to the low-pass filter nature of a power system, the signals need to be transmitted near or below the fundamental frequency and not interfere with other carrier technologies such as automatic meter reading. Each DG is then equipped with a signal detector to receive this transmitted signal. Under normal operating conditions, the signal is received by the DG and the system remains connected. However, if an island state occurs, the transmitted signal is cut off because of the substation breaker opening and the signal cannot be received by the DG, hence indicating an island condition.

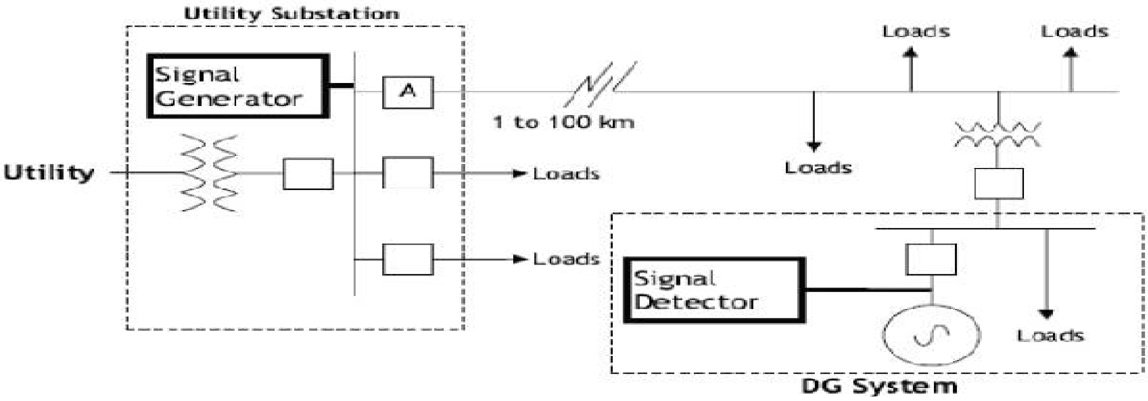

Fig 2 Distributed Generation power line Signaling Islanding Detection

This method has the advantages of its simplicity of control and its reliability. In a radial system there is only one transmitting generator needed that can continuously relay a message to many DGs in the network. The only times the message is not received is if the interconnecting breaker has been opened, or if there is a line fault that corrupts the transmitted signal. There are also several significant disadvantages to this method, the fist being the practical implementation. To connect the device to a substation, a high voltage to low voltage coupling transformer is required. A transformer of this voltage capacity can have prohibitive cost barriers associated with it that may be especially undesirable for the first DG system installed in the local network. Another disadvantage is if the signaling method is applied in a non radial system, resulting in the use of multiple signal generators. This scenario can be seen in Figure where the three feeder busses connect to one island bus. The implementation of this system, opposed to a simple radial system, will be up to three times the cost.

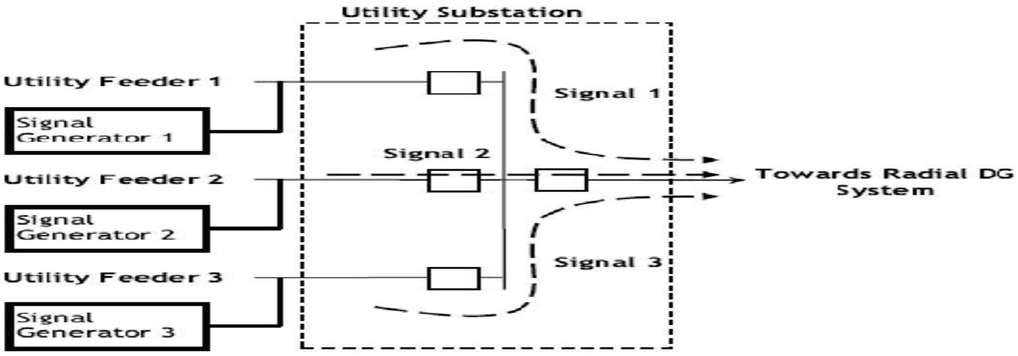

Fig.3 Distributed Generation Multi Power Line Signaling Islanding Detection

Another problem for power line communication is the complexity of the network and the affected networks. A perfectly radial network with one connecting breaker is a simple example of island signalling; however, more complex systems with multiple utility feeders may find that differentiation between upstream breakers difficult.

(B) Transfer Trip Scheme: The basic idea of transfer trip scheme is to monitor the status of all the circuit breakers and reclosers that could island a distribution system as shown in fig 4. Supervisory Control and Data Acquisition (SCADA) systems can be used for that. When a disconnection is detected at the substation, the transfer trip system determines which areas are islanded and sends the appropriate signal to the DGs, to either remain in operation, or to discontinue operation. Transfer tip has the distinct advantage similar to Power Line Carrier Signal that it is a very simple concept. With a radial topology that has few DG sources and a limited number of breakers, the system state can be sent to the DG directly from each monitoring point. This is one of the most common schemes used for islanding detection.

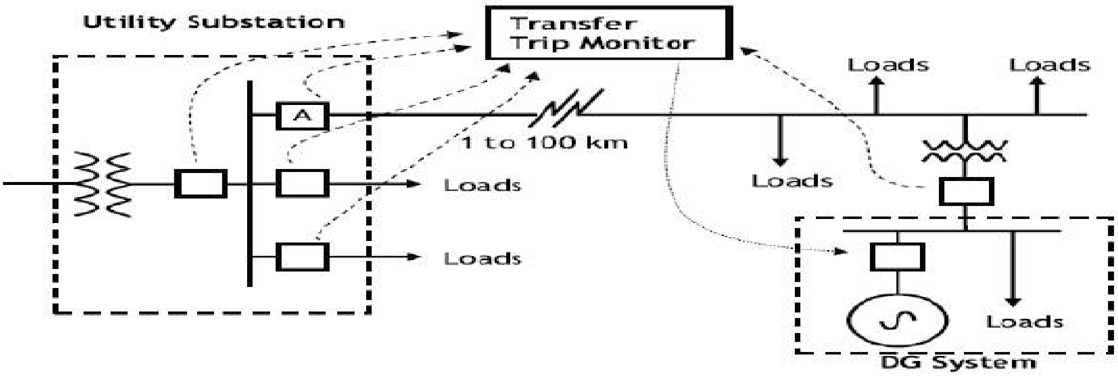

Fig.4 Distributed Generation Transfer Trip Islanding Detection

The weaknesses of the transfer trip system are better related to larger system complexity cost and control. As a system grows in complexity, the transfer trip scheme may also become obsolete, and need relocation or updating. Reconfiguration of this device in the planning stages of DG network is necessary in order to consider if the network is expected to grow or if many DG installations are planned. The other weakness of this system is control. As the substation gains control of the DG, the DG may lose control over power producing capability and special agreements may be necessary with the utility. If the transfer trip method is implemented correctly in a simple network, there are no non-detection zones of operation.

A. LOCAL DETECTION TECHNIQUES

It is based on the measurement of system parameters at the DG site, like voltage, frequency, etc. It is further classified as:

(A) Passive Detection Techniques:

Passive methods work on measuring system parameters such as variations in voltage, frequency, harmonic distortion, etc. These parameters vary greatly when the system is islanded. Differentiation between an islanding and grid connected condition is based upon the thresholds set for these parameters. Special care should be taken while setting the threshold value so as to differentiate islanding from other disturbances in the system. Passive techniques are fast and they don’t introduce disturbance in the system but they have a large non detectable zone (NDZ) where they fail to detect the islanding condition.

There are various passive islanding detection techniques and some of them are as follows:

Rate of Change of Output Power: The rate of change of output power, dp/dt , at the DG side, once it is islanded, will be much greater than that of the rate of change of output power before the DG is islanded for the same rate of load change[30]. It has been found that this method is much more effective when the distribution system with DG has unbalanced load rather than balanced load.

Rate of Change of Frequency: The rate of change of frequency, df /dt, will be very high when the DG is islanded. The rate of change of frequency (ROCOF)

$$\text{ROCOF, } \frac{df}{dt} = \frac{\Delta p}{2HG} \times f$$

Where, ΔP is power mismatch at the DG side ,H is the moment of inertia for DG/system , G is the rated generation capacity of the DG/system

Large systems have large H and G where as small systems have small H and G giving larger value for *df/dt* ROCOF relay monitors the voltage waveform and will operate if ROCOF is higher than setting for certain duration of time. The setting has to be chosen in such a way that the relay will trigger for island condition but not for load changes.

This method is highly reliable when there is large mismatch in power but it fails to operate if DG's capacity matches with its local loads. However, an advantage of this method along with he rate of change of power algorithm is that, even they fail to operate when load matches DG's generation, any subsequent local load change would generally lead to islanding being detected as a result of load and generation mismatch in the islanded system.

Rate of Change of Frequency over Power: df/dt in a small generation system is larger than that of the power system with larger capacity. Rate of change of frequency over power utilize this concept to determine islanding condition .Furthermore, test results have shown that for a small power mismatch between the DG and local loads, rate of change of frequency over power is much more sensitive than rate of frequency over time.

Voltage Unbalance: Once the islanding occurs, DG has to take change of the loads in the island. If the change in loading is large, then islanding conditions are easily detected by monitoring several parameters: voltage magnitude, phase displacement, and frequency change. However, these methods may not be effective if the changes are small. As the distribution networks generally include single-phase loads, it is highly possible that the islanding will change the load balance of DG. Furthermore, even though the change in DG loads is small, voltage unbalance will occur due to the change in network condition.

Harmonic Distortion: Change in the amount and configuration of load might result in different harmonic currents in the network, especially when the system has inverter based DGs. One approach to detect islanding is to monitor the change of total harmonic distortion (THD) of the terminal voltage at the DG before and after the island is formed**.** The change in the third harmonic of the DG's voltage also gives a good picture of when the DG is islanded.

(B) Active Detection Techniques: With active methods, islanding can be detected even under the perfect match of generation and load, which is not possible in case of the passive detection schemes. Active methods directly interact with the power system operation by introducing perturbations. The idea of an active detection method is that this small perturbation will result in a significant change in system parameters when the DG is islanded, whereas the change will be negligible when the DG is connected to the grid.

Reactive Power Export Error Detection: In this scheme, DG generates a level of reactive power flow at the point of common coupling (PCC) between the DG site and grid or at the point where the Reed relay is connected. This power flow can only be maintained when the grid is connected. Islanding can be detected if the level of reactive power flow is not maintained at the set value. For the synchronous generator based DG, islanding can be detected by increasing the internal induced voltage of DG by a small amount from time to time and monitoring the change in voltage and reactive power at the terminal where DG is connected to the distribution system. A large change in the terminal voltage, with the reactive power remaining almost unchanged, indicates islanding. The major drawbacks of this method are it is slow and it cannot be used in the system where DG has to generate power at unity power factor.

Phase (or Frequency) Shift Methods: Measurement of the relative phase shift can give a good idea of when the inverter based DG is islanded. A small perturbation is introduced in form of phase shift. When the DG is grid connected, the frequency will be stabilized. When the system is islanded, the perturbation will result in significant change in frequency. The Slip-Mode Frequency Shift Algorithm (SMS) uses positive feedback which changes phase angle of the current of the inverter with respect to the deviation of frequency at the PCC.

III. MODELLING OF PROPOSED METHOD

Fig 5 Shows the block diagram of the proposed system

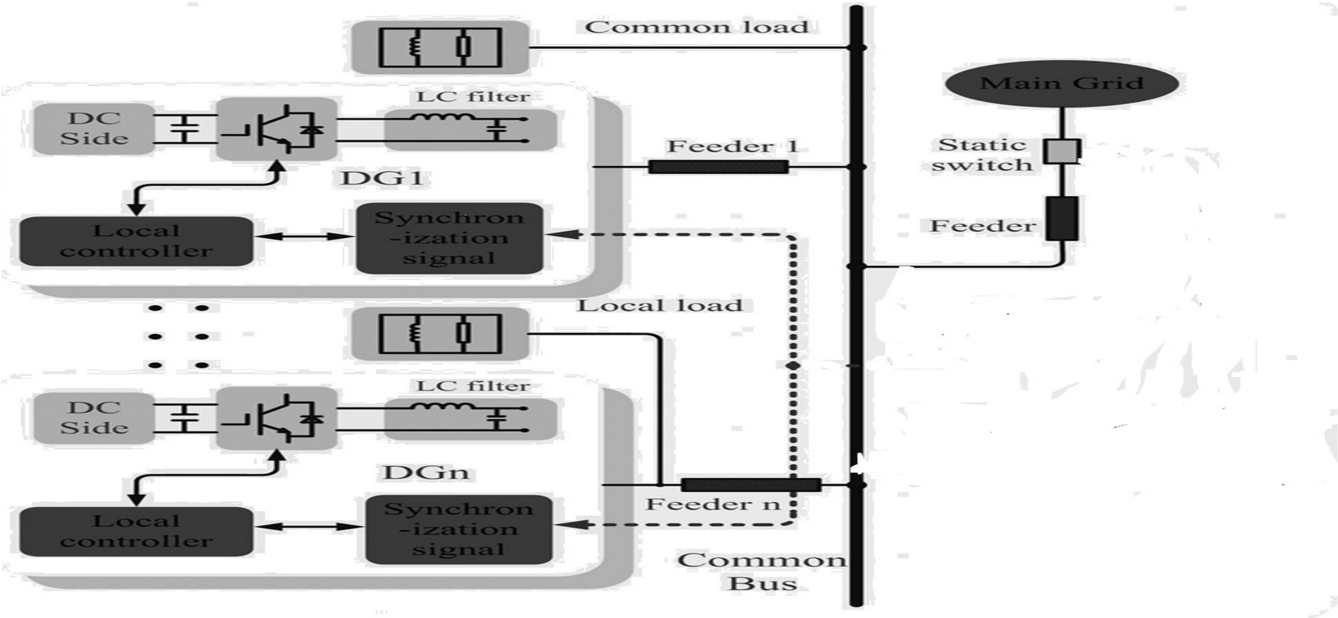

Fig.5 Illustration of the Ac Microgrid Configuration.

A configuration of a microgrid that consists of multiple DG units and dispersed loads is shown in Fig. 5. The microgrid is connected to the utility through a static transfer switch at the point of common coupling (PCC). Each DG unit is connected to the microgrid through power electronic converter and its respective feeder.

Model of DG Unit:

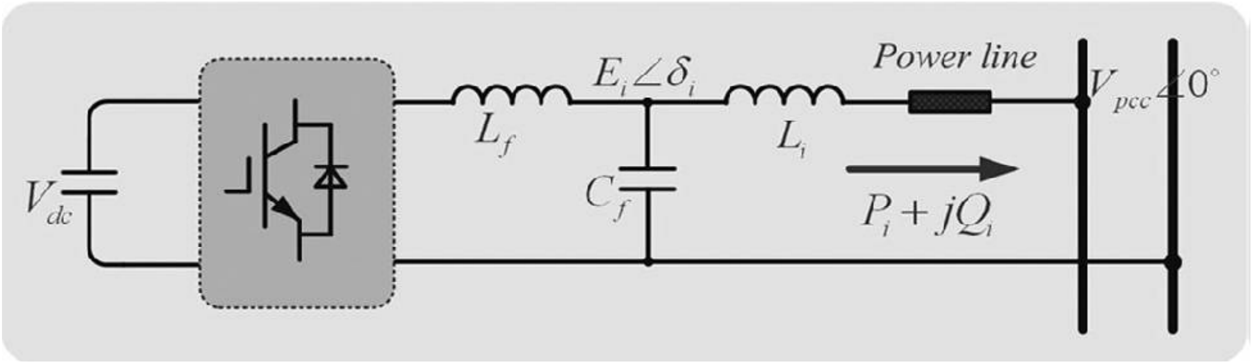

Fig 6 Block Diagram of DG Unit

Fig.6 shows the equivalent model of a DG unit, which is interfaced to the common bus of the ac microgrid through a power inverter with an output *LCL* filter.

DOI:10.15662/IJAREEIE.2016.0511060

Configuration of one Single Phase DG Unit

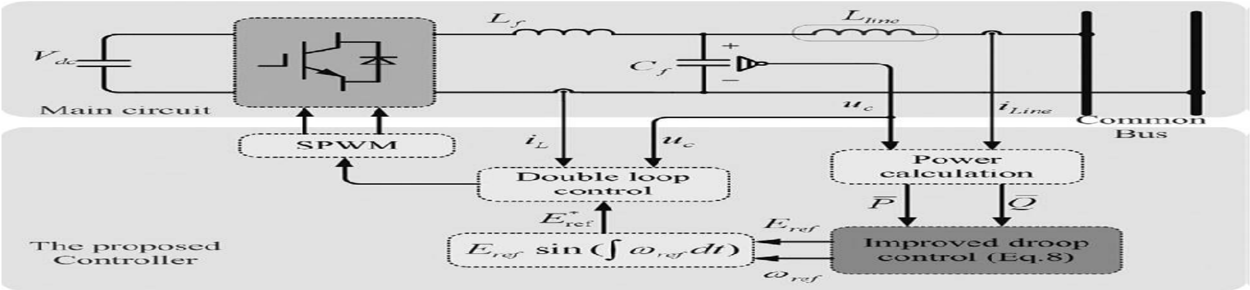

Fig.7 Configuration of one Single Phase DG Unit

The detailed configuration of the single DG unit is depicted in Fig. 7, where a *LCL* filter is placed between the insulated-gate bipolar transistor bridge output and the DG feeder. The DG line current and filter capacitor voltage are measured to calculate the real and reactive powers.

Performance Evaluation of Proposed System The proposed improved reactive power sharing strategy is verified with simulation results. In the simulation a microgrid with two DG systems, as shown in Fig.5, is employed. The associated parameters for power stage and control of the DG unit. Also, in order to facilitate the observation of the reactive power sharing, the two DG units are designed with same power rating and different line impedances. The detailed configuration of the single DG unit is depicted in Fig. 7, where a *LCL* filter is placed between the insulated-gate bipolar transistor bridge output and the DG feeder. The DG line current and filter capacitor voltage are measured to calculate the real and reactive power .In addition, the commonly used double closed-loop control is employed to track the reference voltage.

IV. RESULTS AND DISCUSSION

A. DESIGN OF PROPOSED SYSTEM MODEL:

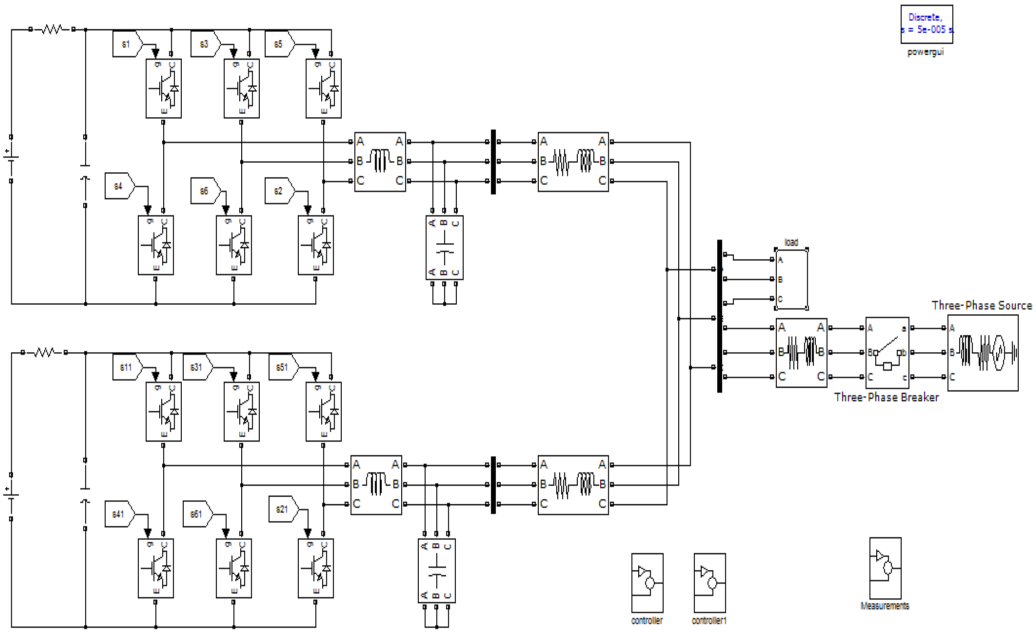

Fig.8 Proposed system simulink circuit configuration

Controlling unit of the design model:

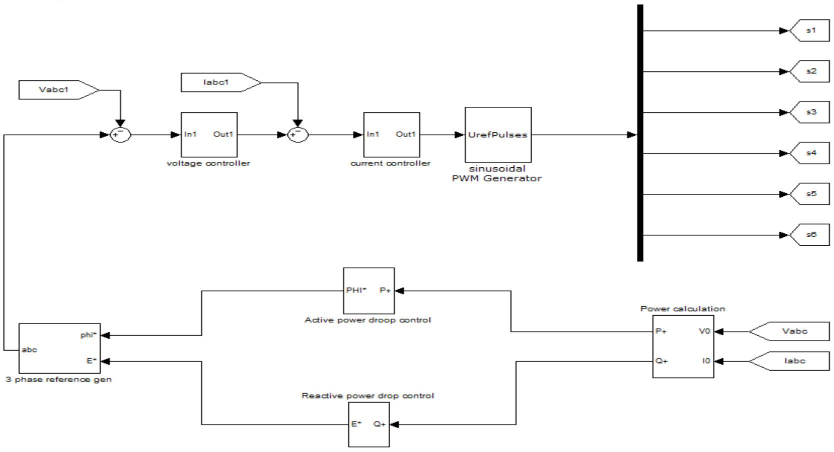

Fig.9 Matlab/Simlink controller unit

Measurement block of the design model:

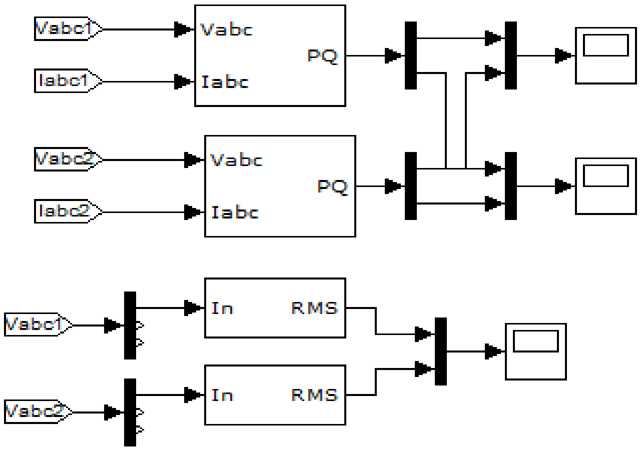

Fig.10 Matlab/Simlink measurement design model

B. WAVEFORMS

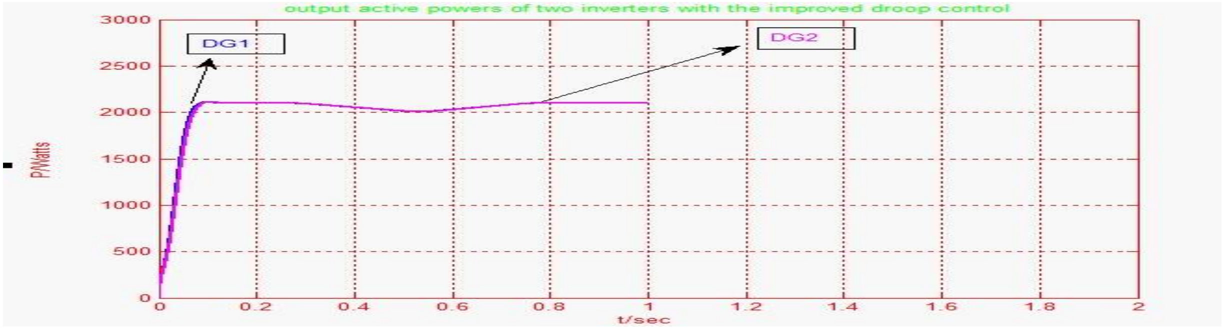

Fig.11 Output active powers of two inverters

Fig. 11 shows active power sharing performance of the two DG units. It is obvious that the proposed improved reactive power sharing strategy does not affect active power sharing performance

Fig.12 Output reactive powers of two inverters

Fig. 12 shows the reactive power sharing performance of the two DGs before *t* = 0.5 s, the sharing error reduction operation and voltage recovery operation are disabled, which is equivalent to the conventional droop control being in effect. There exists an obvious reactive power sharing error due to the unequal voltage drops on the feeders. After *t* = 0.5 s, the reactive power sharing error reduction operation is performed, and it is clear that the reactive power sharing error converges to zero gradually. After *t* = 1 s, the voltage recovery operation is performed. It can be observed that the output reactive power increases but the reactive power sharing performance does not degrade.

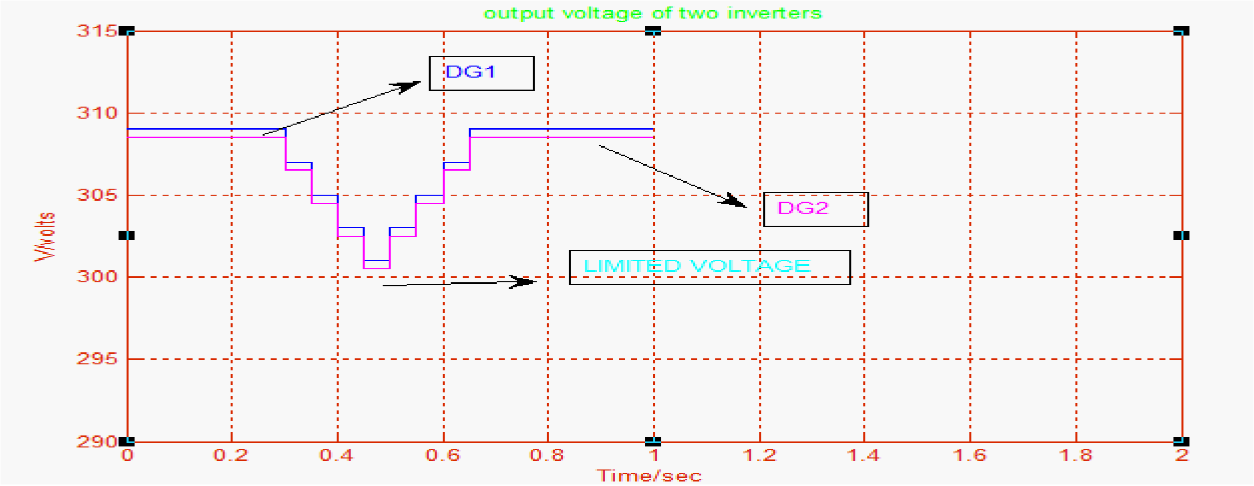

Fig.13Output voltages of two inverters with improved droop controller

Fig. 13 shows the corresponding output voltages of two inverters with improved droop controller. It can be observed that the output voltages decrease during the sharing error reduction operation, while the voltage recovery operation ensures that DG output voltage amplitudes can restore back nearby to the rated value.

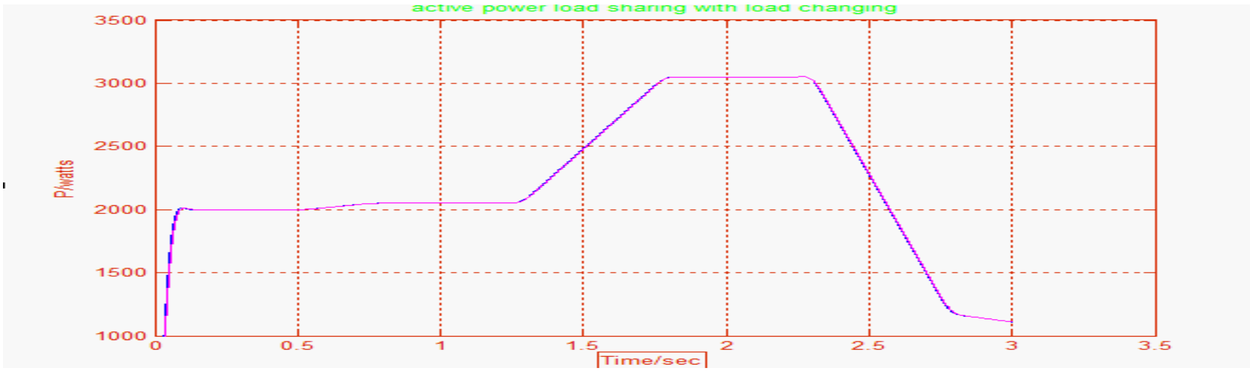

Fig.14Active power sharing performance of improved droop controller (with load changing)

Fig 14 shows simulated waveforms of active power sharing performance of improved droop controller with load change, the active load increases to 3.1 kW at t = 1.8s, and at t = 3s the active load decreases about 1.2 kW large active power sharing deviation appears at t = 1.2 s and t = 2.2 s. However, the deviation becomes almost zero after a while.

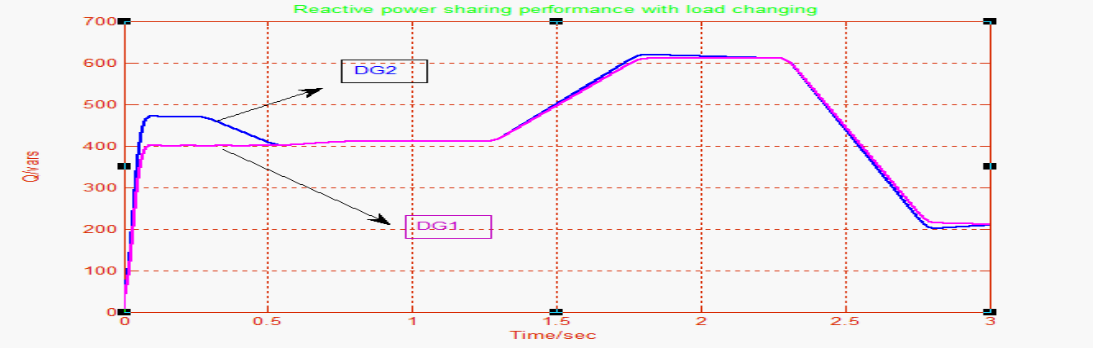

Fig.15 Reactive power sharing performance of improved droop controller with load changing

Fig 15shows simulated waveforms of reactive power sharing performance of improved droop controller with load change, the reactive load increases to 0.6 kvar at t = 1.8s, and at t = 3s the reactive load decreases about 0.2 kvar and large reactive power sharing deviation appears at t = 1.2 s and t = 2.2 s. However, the deviation becomes almost zero after a while.

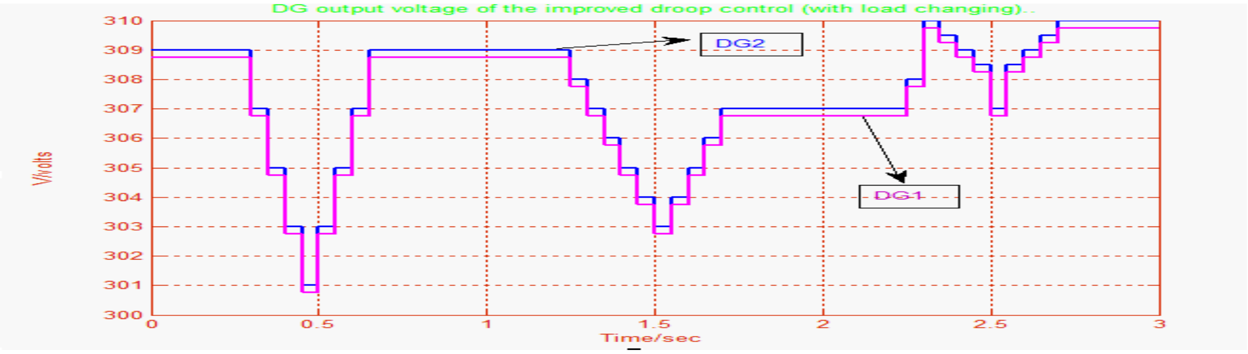

Fig. 16 DG output voltage of the improved droop control (with load changing)

Fig.16 shows the simulated waveforms of DG output voltage of the improved droop control with load changing. It is seen that output voltage decrease and output voltage increase processes during each reactive power sharing error reduction process.

V. CONCLUSION

In this paper, a new reactive power control for improving the reactive sharing is proposed for power electronics interfaced DG units in ac microgrid. The proposed control strategy is realized through the following two operations: sharing error reduction operation and voltage recovery operation.

The first operation changes the voltage bias of the conventional droop characteristic curve periodically, which is activated by the low-bandwidth synchronization signals. The second operation is performed to restore the output voltage to its rated value. The improved power sharing can be achieved with very simple communications among DG units.The plug-and-play feature of each DG unit will not be affected. Simulations results are provided to verify the effectiveness of the proposed control strategy.

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