

Control Strategy of Reactive Power Sharing in an Islanded Microgrids

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Abstract

Precise power sharing considered is necessary for the effective operation of an Autonomous microgrid with droop controller especially when the total loads change periodically. In this paper, reactive power sharing control strategy that employs central controller is proposed to enhance the accuracy of fundamental reactive power sharing in an islanded microgrid. Microgrid central controller is used as external loop requiring communications to facilitate the tuning of the output voltage of the inverter to achieve equal reactive power sharing dependent on reactive power load to control when the mismatch in voltage drops through the feeders. Even if central controller is disrupted the control strategy will still operate with conventional droop control method. additionally, based on the proposed strategy the reactive power sharing accuracy is immune to the time delay in the central controller. The developed of the proposed strategy are validated using simulation with detailed switching models in PSCAD/EMTDC.

KEYWORDS: Microgrid, reactive power control, Droop control, voltage control, central controller.

I. INTRODUCTION

With the expanded penetration of distributed generation (DG) units on the electrical grid systems, the renewable energy sources (RESs) including photovoltaic (PV) systems, fuel cells, microturbines, and wind energy systems have been widely used in the distributed power systems in the past decades [1]. The DG units play an important role in decreasing power transmission losses, reducing pollution, and improving local operation of RESs.

A Microgrid (MG) consists of a collection of the distributed interconnection energy resource (DER) and many loads controlled intelligently by using a central controller. Most the DG, such as energy storage systems and RES, require interfaced by a power electronics such as inverter, rectifier to be linked to the MG, which permits them to be further adaptable in their control and operation [2].

DG also get difficulties to the distribution network system for example: voltage fluctuations, voltage profile, and inverse power flow. if an among of DG units are tied close proximity, this connection can make a MG have ability to solve the difficulties occurs by high penetration of DG effectively and makes the application of large-scale for DG systems possible [3]. Actually, the DG placed in various geographic sites therefore this methodology considered ineffective.

MG can operate in two basic modes: islanded mode (autonomous) and grid connected mode. When the MG working in autonomous mode, the MG must share loads and each DG unit must be it has the ability to deliver the power proportion to its rating in order to share the total load [4]. Also, DG unit must adjust its own voltage and frequency separately dependent on the local information comes from the same DG and any DG activity mode exchanging must not influence the MG steady state operation. Many papers, focus on the load sharing specially with reactive power, what's more, how to control the voltage and frequency of an autonomous droop-controlled MG.

In operation of MG, to guarantee stability should be the active and reactive power of DG units shared instantaneously. The droop control method provides a decentralized control and the preferred favored strategy to control an enormous number of DG since does not required any type from communication lines between inverters and this enhances the reliability of the system, enables "plug-and-play" interfacing [5], and also can be utilized to accomplish each of the real and reactive power sharing by mimic the steady state features of the synchronous generator in autonomous MG.

Several configurations and control schemes of droop control exist so as to permit great quality load sharing for nonlinear and fixed loads. The traditional droop control utilizes the reactive power-voltage (Q-V) control and the real



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power-frequency (P-w) control to understand decoupling control for each real and reactive power [6].

Under extreme situation, the frequency droop control can achieve accurate real power sharing because the frequency of the microgrid is not affected and remains constant during the whole microgrid. therefore, the active power provided by the DG units is shared accurately between the DG unit in any even when mismatches are existing. also, the local load demand should be not exceeding the maximum power rating of the inverters connected to the whole MG.

The voltage droop control commonly results in poor reactive which cause circulating current between the inverter units and make microgrid network instability because the various ratings of the DG units and the various values in the impedances of the DG unit feeders. Communication lines can be used, however, in addition to the droop control method to improve the system performance without reducing reliability and achieve accurate reactive power sharing [7].

various control techniques have been proposed in the literature recently to address the reactive power sharing issue.

in [8] islanded microgrid could operate with two operation modes, the first mode with single master operation which has one master inverter entrusted with voltage/frequency control and real-time load balancing thereby offering a more straightforward control. The multi-master operation used as the second mode, this mode have more than one master inverter entrusted with supporting coordinated voltage/frequency control and real-time load sharing.

The virtual impedance idea presented in [9] to reduce errors focus on reactive power sharing with the different values in the output impedances for closed-loop controlled inverters that are utilized to connect between PCC and the DG units. using suitable strategy of the voltage controller, for the closed-loop the output impedances should be negligible especially at steady state about the reference operating frequency. So, the virtual impedance is prevailing under this condition, which yields precise reactive power sharing. the study, However, the mismatch in the feeder's impedance did not consider, including links, transformers, and the interface inductors related with every DG unit.

in [10] is proposed a unique approach to realize precise reactive power sharing. The technique dependents injection in the system a small AC voltage signal, but the quality of line current and the result voltage may be reduced when injection small voltage signal. Also, processing and generating this signal may result in a difficult achievement.

A control technique utilizing only inductive virtual impedance is used in [11] to guarantee precise reactive power sharing. Design method and analysis in [11] are depend on the virtual impedance which is a known parameter is dominate when assumption that the impedance of feeder is small. furthermore, to enhance the precision should be the feeder physical impedance is estimated, and to contain the impact of the impedance resistive part. The problem in this method, the estimation method needs the MG it works first

in grid connected before islanded mode and simulated the system with identical feeder physical impedances.

in [12] the analysis and control strategy require that the impedances of feeder are resistive. Therefore, the control method and the analysis yields in perfect power sharing if used only the resistive. Actually, the feeders may have resistive and inductive components and both cannot negligible.

Communication is used in [13] to set the virtual impedances to guarantee precise reactive power sharing after estimation the impedances of feeders. using the point of common coupling (PCC) voltage information transferred through a communication link in order to estimate the feeder impedance at each the local DG controller. This study established on the hypothesis that the power angle variance between the inverter output and the voltages at the PCC is negligible. This assumption considered not appropriate for higher power levels or for long feeders.

The distributed strategy presented in [14] coordinates the voltage control mode (VCM) and power control mode (PCM) units to share the real and reactive power. The droop control and opposite droop control are added to the VCM and PCM compensators to adjust the reactive power adaptively.

graph theory is presented in [15] utilizing optimized algorithm to realize the sharing in reactive power when the different values feeder impedance situation.

A secondary control technique is developed in [16] to ensure precise reactive power sharing. Also, to restore the voltage and the frequency. the controller is applied in every DG unit for this technique instead of executing it in the MG central controller unit. the state of a whole communication when failure, however, is not studied.

in [17] a control strategy which combines droop control and the MG central controller (MGCC) in order to share the reactive power. In this paper, The MGCC is utilized to regulate reactive power references to the corresponding inverter units and compute the averaged reactive power. basically, the physical modes of the MG are complex and the reactive power can be seriously influenced by the communication delay.

in [18] used only MGCC as a control method to share both the active and reactive power. Also, The MGCC is used to regulate active and reactive power references to the corresponding DG units dependent on two paradigms derived, quantity of real power bound and the quantity of optimized reference active power. basically, the analysis and control strategy in this proposed assuming that the feeder impedances are inductance only. Also, if the MGCC is disrupted the control strategy will not operate the droop control.

In this paper, a central controller strategy is developed to improve reactive power sharing precision. central controller is used to tuning of the output voltage of the inverter to achieve equal reactive power sharing dependent on reactive power load to avoid time delay unlike [19] which be used reactive power from all DG to compensate for the different values in voltage drops across each feeder.

The layout of the remainder of the paper is as per the following. In section II, explain the proposed structure and control of an islanded microgrid, control of inverter unit with explain the outer and inner control loop. Section III, power sharing strategy discussed for the reactive power sharing and explain the function of MGCC and how to operating in system. Sections IV and V consist of simulation results and conclusion respectively.

II. ISLANDED MICROGRID STRUCTURE AND CONTROL

A. Structure of the proposed Microgrid

The structure of the IEEE 4-bus test feeder [20] with one-line diagram as appeared in Fig. 1 used to confirm the reactive power sharing capability. The system is modified by adding two cumulative loads, it is indicated L1 and L2, additionally, switch will be used with each load. the loads in this paper, are modeled as linear loads. Also, in the system used, three DGs the MG contain: DG1, DG2, and DG3. Every unit is demonstrated as a droop-controlled inverter linked DG. PSCAD/EMTDC is used to develop the droop control inverter model.

In this paper, the microgrid considered runs with low voltage distribution level (480 V_{ll}). LC output filters (not appear in Fig.1) connected to output three phase inverters, the feeder and then the isolation transformer connected each inverter unit to the point of common connection (PCC). the voltage converted by the transformer to the distribution network close of (4.16 kV_{ll}). The focus in this work is on the basic active and reactive power sharing. All quantities are in per unit with base voltage used in the inverter side is 0.48 kV_{ll} and base power is 1 MVA.

The switch (s) is open when operating in islanding mode, and each inverter work alone to regulate the frequency. local grid voltage regulated by MGCC for accurate load sharing.

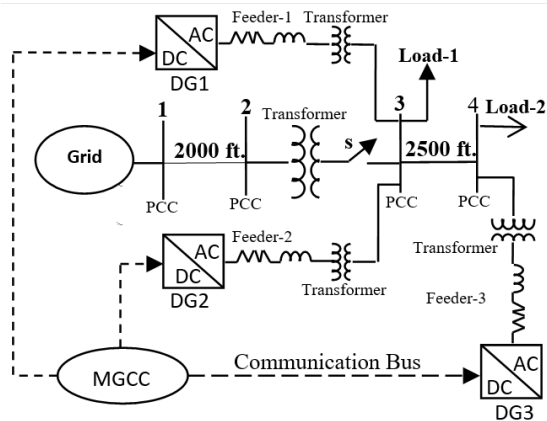


Fig. 1 Structure of proposed Microgrid

B. inverter unit control

The basic control structure in islanded microgrid, outer droop control loop which is also called primary loop used to control on the real power and reactive power for the microgrid, and Inner control loop to regulate the voltage and current in three phase inverter voltage.

The (P-w) and (Q-V) droop control considered a straight technique utilized to solve active and reactive load sharing problem in MG. to developed the droop control method, using Fig.2 to explain the power flow between two nodes can expressions as (1) and (2) [11].

$$p = \frac{V^*}{R^2 + X^2} (V^* R - V_{PCC} R \cos \delta + V_{PCC} X \sin \delta) \quad (1)$$

$$Q = \frac{V^*}{R^2 + X^2} (V^* X - V_{PCC} X \cos \delta - V_{PCC} R \sin \delta) \quad (2)$$

Where V_{PCC} and V^* are the terminal node voltage and magnitudes of the power output node, R represent the resistance of the feeder impedance while X represent the reactance, the phase angle variance between the two nodes represented as δ . For high power flow the value of inductive larger than resistance, may be neglect the resistance. additional, when the δ is typically small, the (1) and (2) can be simplified as:

$$p = \frac{V^* V_{PCC} \sin \delta}{X} \quad (3)$$

$$Q = \frac{V^*}{X} (V^* - V_{PCC}) = \frac{V^*}{X} \Delta V \quad (4)$$

Therefore, the output active power is relative to δ and the active power from every inverter can be controlled by adjusting the inverter output frequency. Also, the reactive power is proportional to ΔV and the inverter reactive power can be adjusted by varying the inverter output voltage value.

The straightforward idea of droop control, if the power output of a inverter exceeds the set point value, the power output will be reduced by the droop control characteristics (P-w) and (Q-V), which can be statement as:

$$w = w^* - m (p_m - p^*) \quad (5)$$

$$V = V^* - n (Q_m - Q^*) \quad (6)$$

Where p^* and Q^* are the set point real and reactive power outputs that the DG can supply; w^* and V^* represented frequency and the root mean square value of the nominal voltage, respectively; p_m and Q_m represented the output measurement for real and reactive power of the DG, respectively; w and V represented the output reference frequency and voltage value, respectively; m and n represented the relative angular frequency and the voltage drooping coefficients, respectively. These coefficients are selected as a deviation in frequency and voltage divided by set point active and reactive power, respectively.

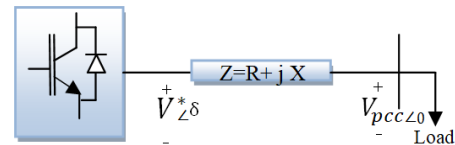


Fig. 2 Equivalent Circuit MG in Islanded Mode

In this paper, the structure of each DG shown in Fig.3, V_{DC} represented the DC prime mover operating as input for three

phase voltage source inverter, where L_f and C_f represented the filter inductor and filter capacitor, respectively. v represented the capacitor voltage while i is the inductor current.

Inner control loop identified as low-level current and voltage compensators. This loop consists of a filter inductor current control loop, a filter capacitor voltage control loop also used, and maintains feed-forward compensators and the feedback together with the linear control loop. The Clark and park transformation (ABC-dq0) which be used in this loop.

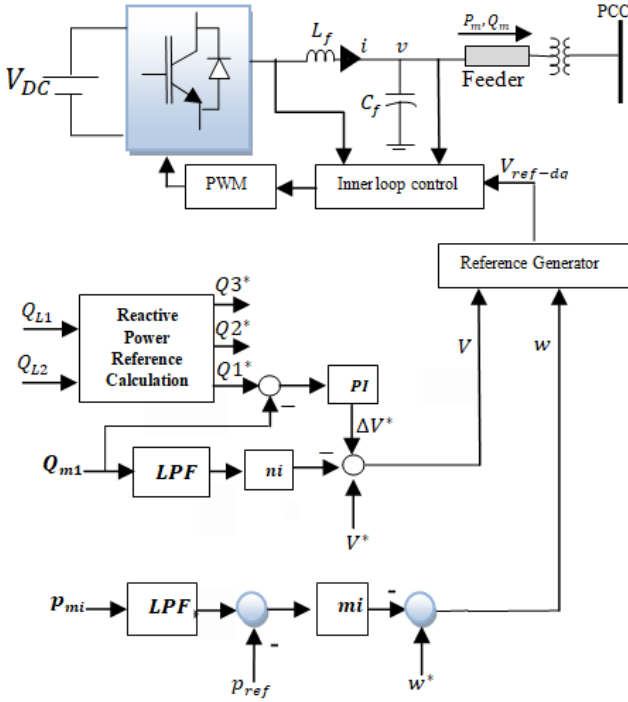


Fig. 3 local controls and structure of a DG unit

III. POWER SHARING STRATEGY

Completing equivalent reactive power sharing for islanded system among the DG that are linked to the MG is a difficult job. When dependent on only local voltage and current information the inverters cannot compensate for mismatches in their reactive power productions, since the working parameters of the other DG are unidentified. To improve the work of the DG and complete equivalent sharing of the reactive power request, must be made the MGCC to adjust the reactive power provided by every DG connected to the MG.

Every of the loads delivers information to the MGCC related of the reactive power distributed to the microgrid (Q_{L1} and Q_{L2}). The MGCC then determines the quantity of reactive power that every DG must be provide and adjusts the reactive power of every DG through an external loop as illustrate in Fig.3.

To allow good sharing of the reactive power, each inverter should send the droop gain (n) to the MGCC. This operation achieved through the setup time only i.e. when the DG is

linked to the MG for the first time. The reactive power request for each DG can be determined by:

$$Q_x^* = \frac{Q_{load}}{n_x \sum_{i=1}^3 \frac{1}{n_i}} \quad (7)$$

where Q_{load} is the reactive power consumed by all the loads, the droop gain of inverter x represented by n_x , $\sum_{i=1}^3 \frac{1}{n_i}$ is the summation for all droop gains of the DG connected with MG, and Q_x^* is the reactive power request namely required to be provided by inverter x .

The MGCC adjusts the reactive power of each inverter by using PI controllers. PI controllers in this paper, deliver an extra modification in voltage production which additional to the droop control output (ΔV^*).

IV. SIMULATION RESULTS

In this paper, the case study simulated with program PSCAD/EMTDC, there are three sequence of actions with each lasting 4 seconds. Also, The MGCC was assumed to adjust the voltage reference starting from the beginning of the simulation. In this paper, two case study discussed: the first case, the rating of the three DG units have same rating with different feeder impedance, while another case discussed the rating of the three DG units with different ratings.

A. First Case

At beginning, the three DGs were operated together with load 1, while the load 2 were off. Loads were shared between the inverter's unit for both real and reactive power load sharing according to the droop control and the equation (7). Reactive power when the DG in the same rating was shared in the same ratio. Additionally, reference points for voltage inverter output for the droop controllers were determined as previous discussed and transmitted to the every DGs by the MGCC.

The rating of each DG in this case (0.2 MVA) while the load 1 represented the fixed load with (0.27 MW, 0.135 MVAR). At 4 seconds simulation time, the load 2 was turned on with (0.135 MW, 0.045 MVAR). Also, the real and reactive power was shared according to droop control and the equation (7). At 8 seconds, load 2 increased to (0.27 MW, 0.09 MVAR). Table 1 explained the parameters used for both MG and DG while the results for real and reactive powers, frequency, and voltage inverter output are shown in Fig. 4 and Fig. 5. Examining the plots in Figs. 4 (a) and (b), notice that the active and the reactive power was shared accurately.

TABLE. 1
MG and DG parameters

Description	parameter	value
Rating of each DG system	MVA	0.2
Nominal voltage	V_o	480 V (L-L)
Nominal Frequency	w_o	377 rad/s
Input DC voltage	V_{DC}	850 V
Feeder 1 impedance	$R + j X (\Omega)$	$1.1 + j 0.434$
Feeder 2 impedance	$R + j X (\Omega)$	$1.0 + j 0.563$
Feeder 3 impedance	$R + j X (\Omega)$	$1.2 + j 0.372$

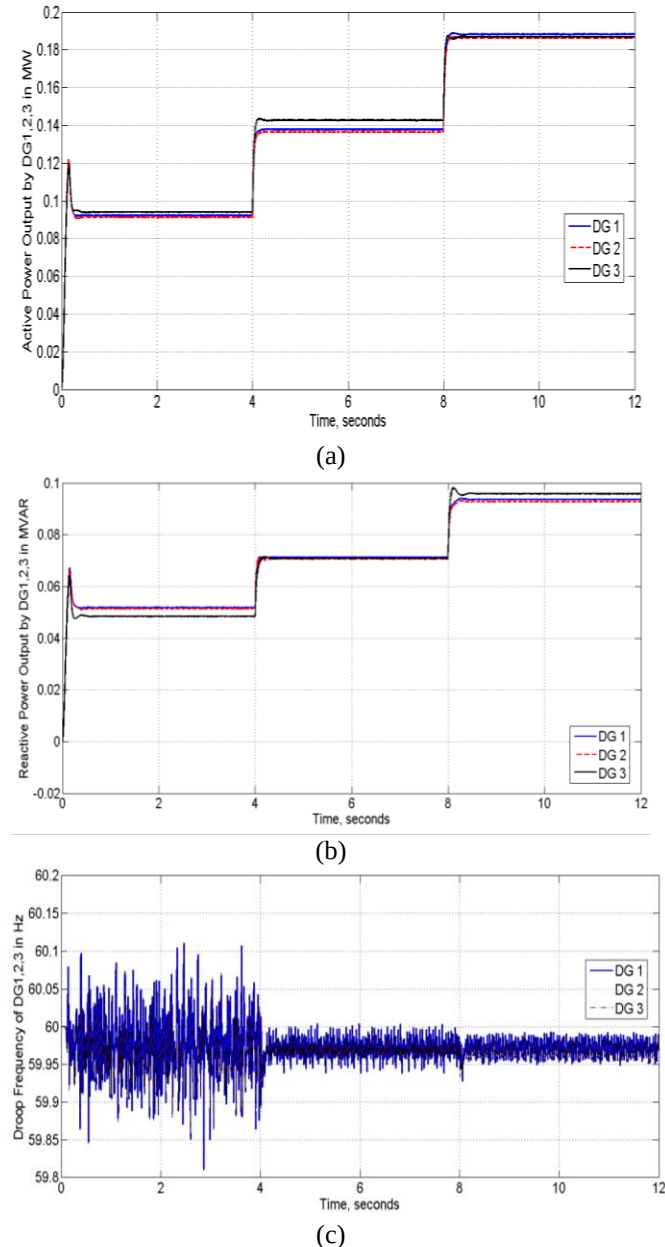


Fig. 4 Output of (a) Real power (b) The reactive power (c) drop frequency for three DG

We note that at the beginning of the simulation, the transient will be occurring but quickly removed with less than (0.03 sec.) by controlling ability for each of the real and

reactive power. In this paper, the droop frequency selected as 0.25 Hz and the result as shown in Fig. 4 (c). Also, it can be seen that the DG3 differs slightly from the DG1 and DG2 because the distance between them.

Fig. (5) shown that the minimum drop voltage occurs when any new load appears in the MG and then this drop quickly removed.

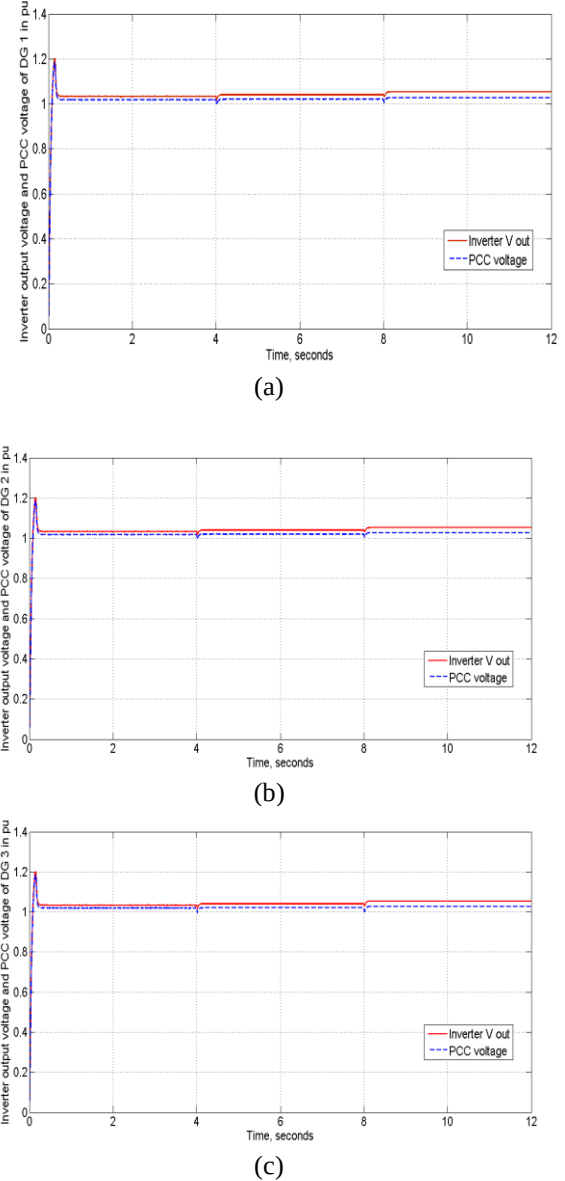


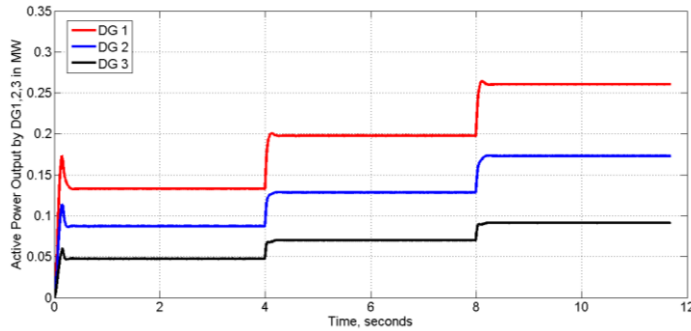
Fig. 5 Inverter output voltage for (a) DG1 (b) DG2 (c) DG3

B. Second Case

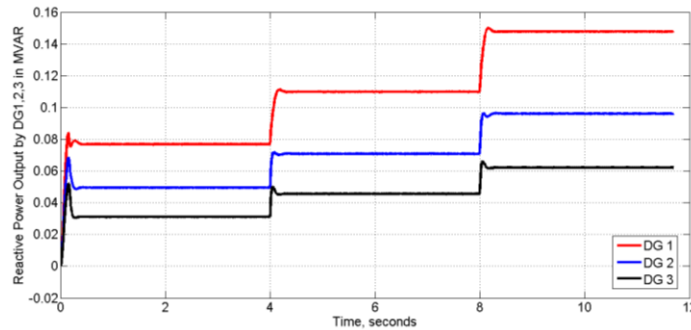
In this case, the DG operating with different rating (0.3 MVA for DG1, 0.2 MVA for DG2, and 0.1 MVA for DG3). The active and reactive power sharing the load according to rating of each DG with ratio (3:2:1).

At beginning, the three DGs were operated together with load 1, while the load 2 were off. Loads were shared between the inverter's unit for both real and reactive power load sharing according to the droop control and the equation (7).

Reactive power was shared according to ratio. The reference points for voltage inverter output for the droop controllers were determined as previous discussed and transmitted to the DGs by the MGCC. Remaining parameters used the same parameters in Table 1. The results for real and reactive powers, frequency, voltage inverter output, and current inverter output are shown in Fig. 6, Fig. 7, Fig. 8, and Fig. 9.

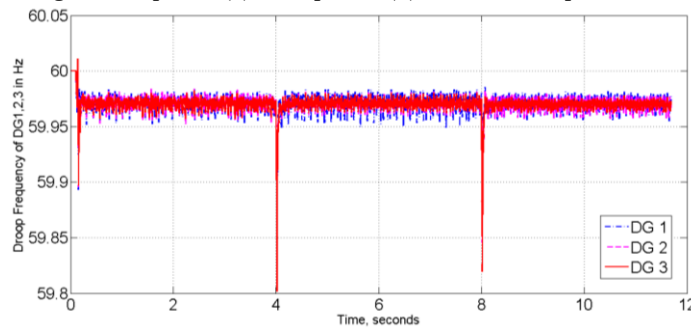


(a)

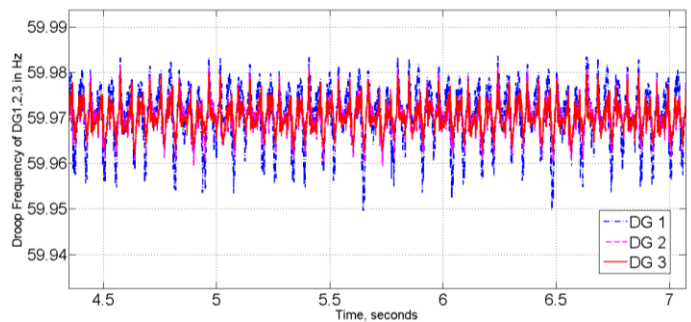


(b)

Fig. 6 Output of (a) Real power (b) The reactive power



(a)



(b)

Fig. 7 Output of (a) drop frequency for three DG (b) Zoom the droop frequency

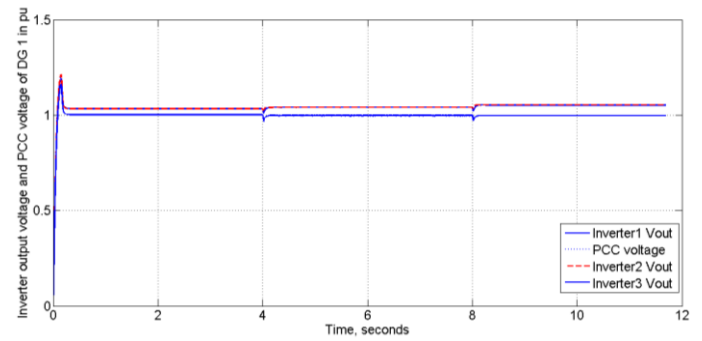


Fig. 8 Inverter output voltage for DG1, DG2, and DG3

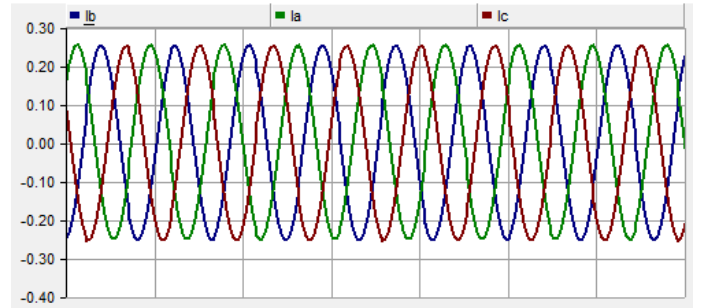


Fig. 9 Inverter output current for DG1

V. CONCLUSION

In this work, an enhanced MG reactive power load sharing strategy was proposed for parallel DGs in an islanded microgrid. This strategy uses reactive power load information to help calculated power sharing according to power rating for each DG then compared with reactive measurement, the error of reactive power load sharing is compensated by utilizing PI controller. The output of PI controller used to adjust the voltage reference output from each inverter.

Modelling of MG has been established by using PSCAD/EMTDC. The simulated MG consist of three DG units with two linear loads. DG operating with the equal power rating and in this case DG units segment the load equally. Also, DG operating with the different power rating and in this case DG units share the load according to rating for each DG. In two case, the feeder impedance different from each DG to PCC.

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