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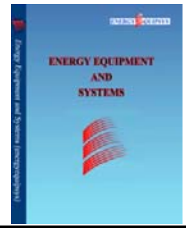

Simultaneous power sharing and protection against faults for DGs in microgrid with different loads

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ABSTRACT

The LVRT (Low Voltage Ride Through) is the main characteristic of every power system in faulty conditions. When fault occurs, it is essential for power system such as microgrid to control the voltage and frequency normally. Naturally in fault status, the unbalanced voltage and current are inevitable, but with the aid of LVRT technique, microgrid can keep stability in main system parameters such as voltage and current of each phase. In this paper, the microgrid is proposed in islanded state and using the reactive power injection in faulty conditions, and the LVRT technique is applied. When reactive power is inserted, simultaneously the active power must be reduced, and so the current is limited, and overcurrent is controlled. Simulation results indicate that this strategy enhances the presentation of the structure in symmetric and asymmetric faults. That is noticeable declaring that the suggested approach has not degraded the power sharing among DGs both in faulty and faultless status and also plug and play property is kept using this suggested LVRT strategy.

Keywords: Protection Method, Faulty Conditions, Symmetric Fault, Asymmetric Fault, Power Sharing.

1. Introduction

LVRT is the main property of any power system such as microgrid, especially in faulty status. In faulty conditions, Voltage unbalance, and current overflow is created. Thus LVRT strategies must be applied to keep the system stable leading to control of voltage and current and avoiding damages of devices.

Some LVRT strategies have been discussed in [1, 2]. The faults are the reasons for overvoltage and overcurrents in PCC, and thus the sinusoidal voltage is degraded. Voltage harmonics are created in this status, and method of undistorted reference current delivery power has been distorted. Therefore, some papers investigated the generation for LVRT purposes [4, 6, 7]. [6, 7] have worked on removing power distortions and yielding balanced power sharing even in faulty conditions. In [4], the current controller for reference current generation is applied to keep the stable current injection. Power harmonic rejection by notch filter is proposed in [3]. In [5, 6] some new LVRT techniques based on reference current generation combining with the current controller are described. In grid-connected mode of microgrid, by analysis the voltage sequences and improving them leads to a modified LVRT scheme [7]. Also in [8], these voltage sequences are

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controlled, and so the desired controllable power is injected into the network when network voltage is degraded.

In [9], the negative and zero sequences are used to protect microgrid from asymmetric faults. In [10] a protection structure using communication relations has been suggested. Some other protection plans for islanded microgrid are presented in [11-13].

In microgrid with multiple DGs, the power sharing among DGs must be balanced related to the droop coefficients. Therefore, power sharing due to droop gains and other parameters is focused in some papers [14]. When there exists impedance difference in the feeder of three inverter-based DGs, the smaller-impedance DG picks the load faster and results different transient power sharing. To overcome this defect of droop control, some modifications are needed and discussed in previous papers. Feedback control in [15, 16], dynamic droop coefficients [17, 18] and phase droop instead of frequency droop in [19], virtual impedance strategy [20-22] are some well-known strategies proposed.

Here, a new LVRT scheme is proposed to balance voltage distortion in faulty conditions. In this method, in faulty status, reactive power injection is applied due to the sense of fault by controllers of the system. Simultaneously, real power is decreased when the fault occurs. When fault passed, the active power is again increased, and reactive power is decreased by the current controllers. This method also preserves the load sharing balance among the parallel DGs in both active and reactive mode. The proposed method includes control system of virtual impedance, compensating voltage and load sharing is shown for 5 and 6 inverters. It has been shown that significant improvement has been obtained using the proposed strategy in faulty and faultless conditions and both three-phase and one-phase faults.

The remainder of the paper is as shown: Part 2 discusses the microgrid model while suggested strategy is presented in part 3. The consequences are stated in part 4 and conclusions are strained in part 5.

2. Structure Model

A simple microgrid model including three inverter-based DGs is shown in Fig.1. Different feeder impedances are considered, and reference signals from the control unit are used for PWM triggering to set DGs voltage and current. A low pass filter is also applied to remove undesired frequencies. Droop method is used for control of frequency and voltage [23] as

$$\omega = \omega_s - mp \quad (1)$$

$$v = v_{ref} - nq \quad (2)$$

m and n represent the droop coefficients. ω_s resembles the system frequency, v_{ref} is the inverter reference voltage amplitude and ω is voltage frequency. Active and reactive powers of inverters are presented by p and q, respectively. This model supports various loads as shown in the figure. Obviously with equal feeder impedances, i_{inv1}, i_{inv2} and $i_{inv3}$are equal, and consequently power sharing are also equal. However, feeder impedances are not the same practically which affects the power sharing among DGs. Multi-bus model can also be applied in the simulated system as Fig.2. In this case, the three-bus model is assumed and can be generalized simply for more complex system.

3. Proposed Method

The suggested method is focused on limiting the current overflow during the voltage dip and other faults in the islanded microgrid. Also applying the suggested strategy, the voltage of faultless phases must not be corrupted in asymmetric fault.

The suggested strategy is founded on injecting the active power from DGs to the loads in normal condition. During the fault, the overcurrent is created, and the reactive power is injected instead of active power. Using this scheme, the current is restricted to the nominal value. This reactive power insertion results in the enhancement of faulty voltages in phases.

In addition to the proposed LVRT, the well-adjusted power sharing among

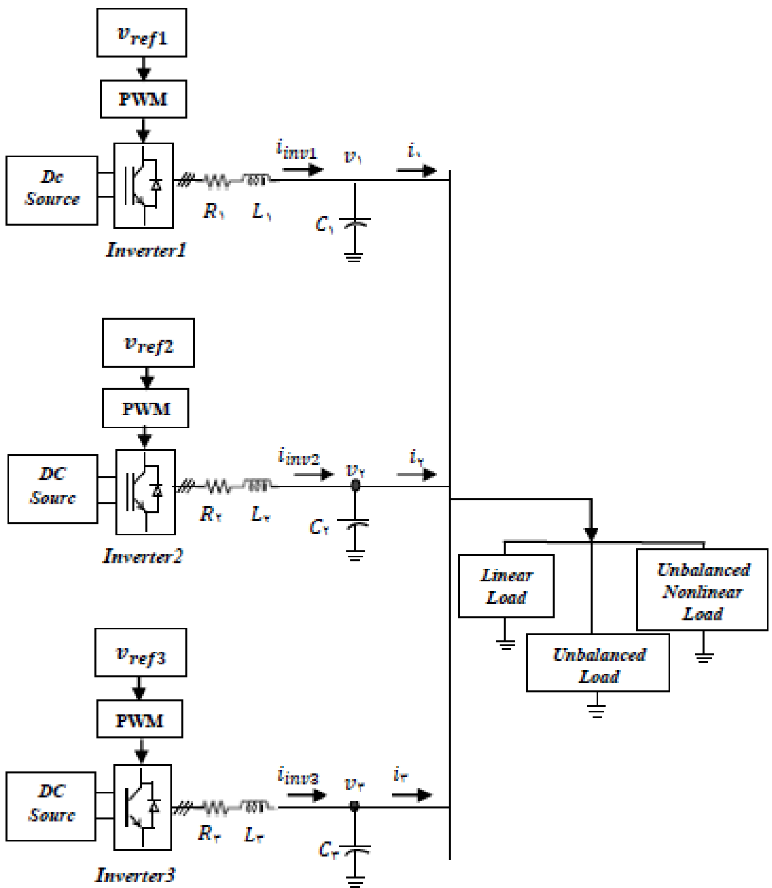


Fig.1. Microgrid model

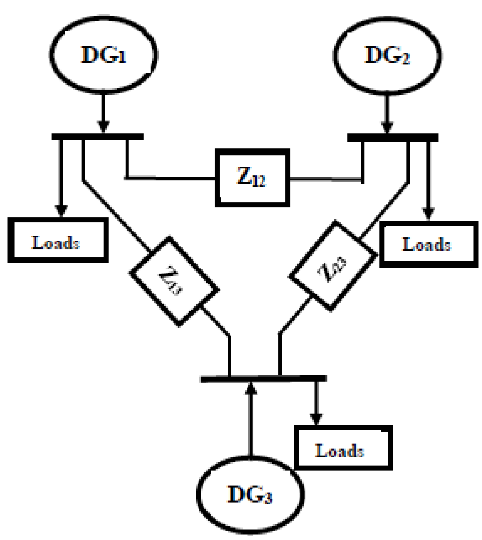


Fig.2. Multi-bus model of the proposed microgrid

DGs both in abnormal and normal situations is another primary concern of this paper. The suggested method performance in both applications must be acceptable. In the sequel, first, the load sharing scheme is mentioned and in the second part, proposed LVRT method is presented.

Power sharing must be balanced both in transient and stable mode.

3.1 Virtual impedance

Firstly, the difference in voltage drops due to the difference in feeder impedances of DGs must be corrected. Thus virtual impedance is used for this step as [24, 25]

$$\Delta Z_{VI} = \Delta R_{VI} + j\Delta X_{VI} \tag{3}$$

$$V_{d,VI} = \Delta R_{VI} i_d - \Delta X_{VI} i_q \tag{4}$$

$$V_{q,VI} = \Delta R_{VI} i_q + \Delta X_{VI} i_d \tag{5}$$

The virtual impedance is used in the mechanism part of DG with smaller impedance with a smaller voltage drop.

For stability of this virtual impedance, the control loop using the difference of reactive power of two DGs is used because of depending voltage to reactive power. It is stated as

$$\Delta Q = Q_1 - Q_2 \tag{6}$$

Due to using dq-axis and PI controller, we have

$$V_{qVI}^{*} = \left(C_1(\Delta Q) + \int (\Delta Q)\right) C_2 V_{q,VI} \tag{7}$$

$$V_{dVI}^{*} = \left(C_3(\Delta Q) + \int (\Delta Q)\right) C_4 V_{d,VI} \tag{8}$$

These voltages are applied in the control unit, and it is expected the load sharing in transient mode is balanced better via two DGs.

3.2 Compensating Voltage

In the second step, the steady-state power sharing is focused. As known, we have

$$V_d + jV_q = \frac{P + jQ}{i_d + ji_q} \tag{9}$$

For defining the compensation voltage, we have (see Appendix for details)

$$\begin{cases} \Delta V_d = \dfrac{\Delta RP + \Delta XQ}{P + Q}\left(i_q + i_d\right) \\ \Delta V_d = \dfrac{\Delta RP + \Delta XQ}{P + Q}\left(i_q - i_d\right) \end{cases} \tag{10}$$

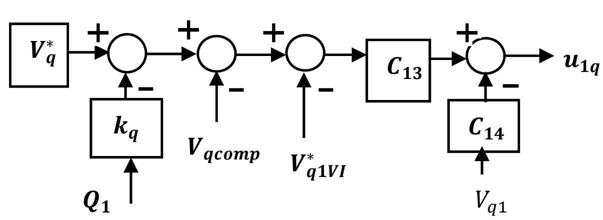
It is noticeable that the feeder' exact values are not needed and it is not, in fact, available [26]. The initial values can be applied, and considering the control loop, the convergence is accessible. Compensation voltage is suggested as below:

$$\begin{cases} V_{qcomp} = \alpha\left[[\int C_7(\Delta V_q)] + C_8(\Delta V_q) \right] \\ \alpha = \left[[\int C_5(\Delta Q)] + C_6(\Delta Q) \right] \end{cases} \tag{11}$$

$$\begin{cases} V_{dcomp} = \beta\left[[\int C_{11}(\Delta V_d)] + C_{12}(\Delta V_d) \right] \\ \beta = \left[[\int C_9(\Delta Q)] + C_{10}(\Delta Q) \right] \end{cases} \tag{12}$$

where α and β are PI-control gains.

The general control unit is presented in Fig.3. m_q and m_d are the droop coefficients of reactive and active power, respectively.



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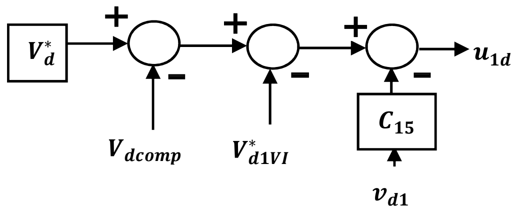

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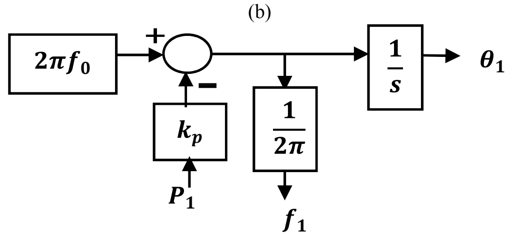


(c)

Fig.3. Control unit: a) q-axis voltage control, b) d-axis voltage control, c) frequency control

Next, to the load sharing challenge, LVRT strategy is applied. The proposed block diagram to restrict the overcurrent during faulty conditions is shown in Fig.4.
From Fig.4, two control switches are used for checking the voltage dip of each phase. If the rms value of PCC voltage is under 0.9 p.u., the LVRT is started, and reactive power is injected while active power is fixed. If the voltage dip is significant and PCC voltage is critically being less than 0.5 p.u., the active power must be discarded, and maximum reactive power is inserted for limiting the overcurrent.

4. Results Discussion

Proposed LVRT performance is verified with various faults and loads in this part of the paper. Table 1 shows the simulation parameters.

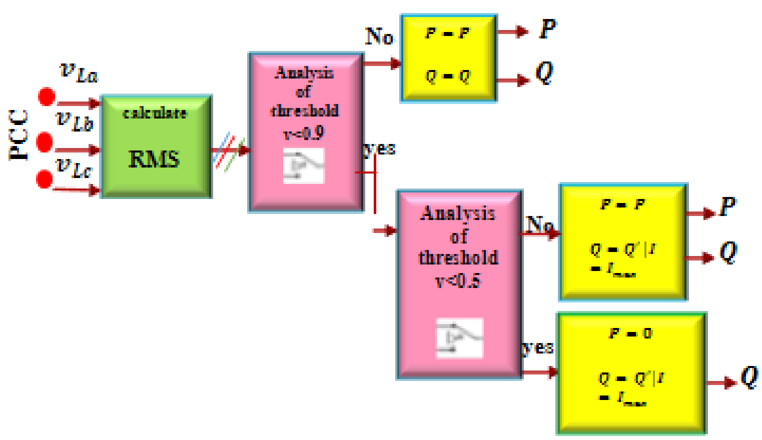


Fig.4. Flow chart of suggested LVRT strategy by reactive power insertion

Table 1: Model factors

Factors	Worth
k_p	4*pi
k_q	0.07
$C_1=C_3$	10
C_2	0.5
C_4	0.07
$C_5=C_9$	20
$C_6=C_8$	4
$C_7=C_{11}$	400
$C_{10}=C_{12}$	4
C_{13}	1
$C_{14}=C_{15}$	0.5
R_1+jX_1	1.2+j1.6
R_2+jX_2	1.7+j2.55
R_3+jX_3	1.7+j2.55

4.1 Real and reactive power insertion

In this section, the reactive and active power insertion is discussed when fault happens. In Fig.5-phase fault is applied in 0.3(s), 2-phase fault in 0.9 and 1-phase fault in 1.5. As can be seen in different fault states, reactive power is increased, and in turn, active power is decreased due to the proposed LVRT method to limit the overcurrent noticeably.
In the sequel, the current and PCC voltage status with and without LVRT are described. As obviously shown, when the proposed LVRT method is used, over current is limited and PCC voltage is significantly balanced and improved. These effects are shown in Fig.6. Figure 6.a and 6.b show the performance without using LVRT, but in Figs. 6.c and 6.d, the improvement in current and voltage have been depicted.

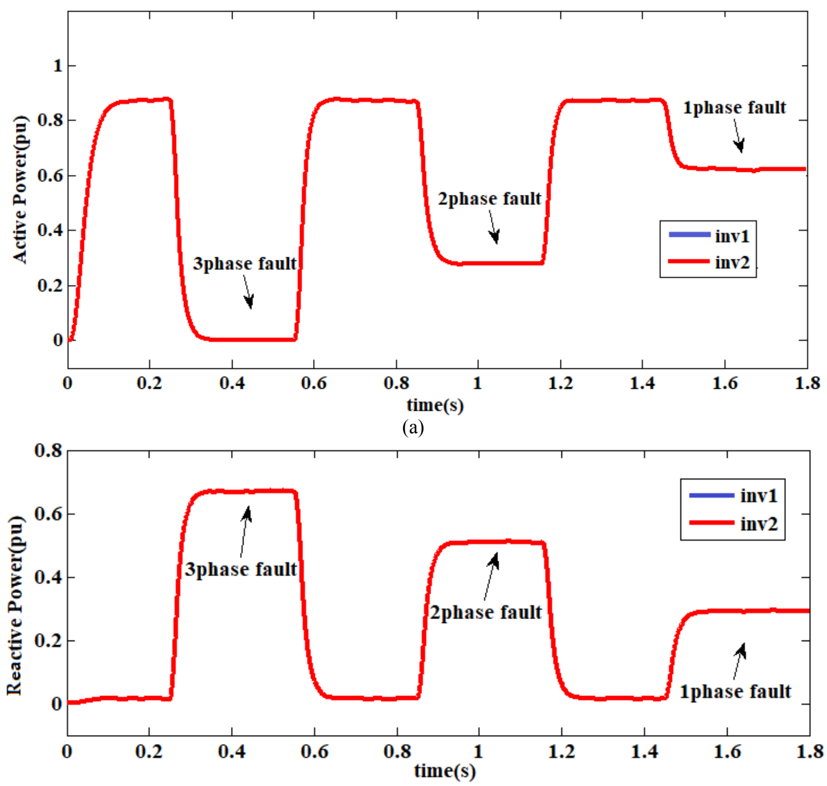
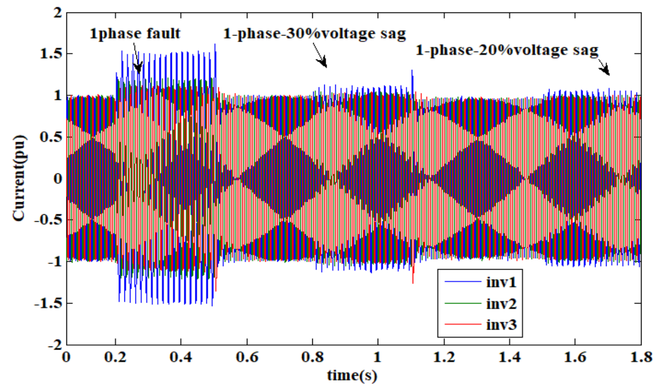


Fig.5. Inverter powers injection, Faulty and faultless conditions



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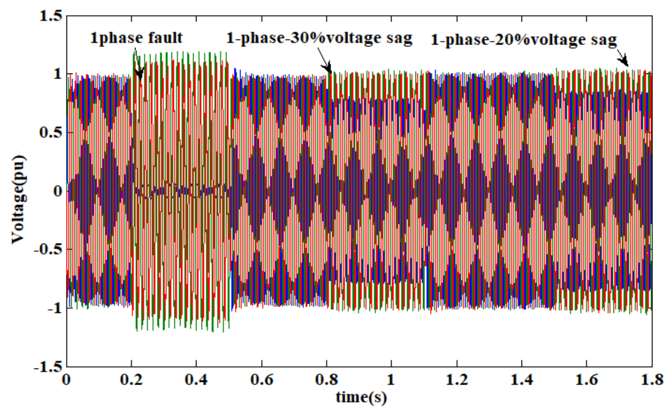

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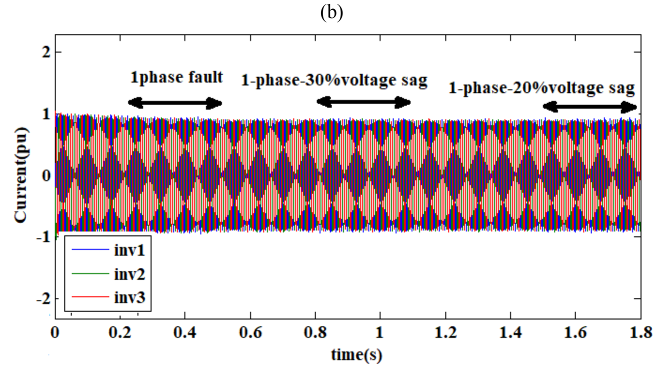

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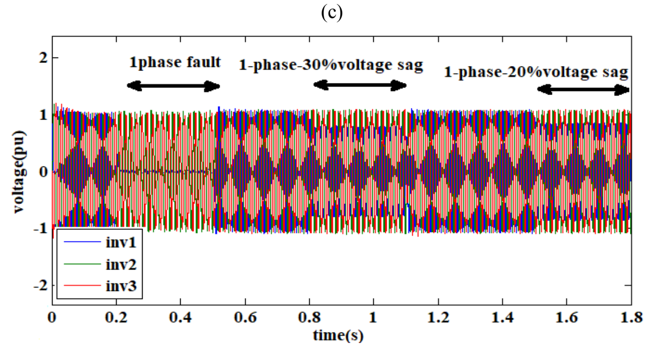


(d)

Fig.6. a) DG current (no LVRT), b) Point Common Coupling voltage (no LVRT), c) DG current (LVRT), d) Point Common Coupling voltage (LVRT).

4.2 Discussion of one-phase and three-phase Faults

The suggested strategy performance for Asymmetric fault is discussed in follow. Figure 7 depicts the voltages and currents of the system without using the suggested method. From this figure, when fault occurs, the overvoltages and overcurrents are inevitable.

In Fig.8, the consequence of using this strategy is depicted. Obviously, the methods prevent the overcurrents in faulty phases and balance the voltage of faultless phases.

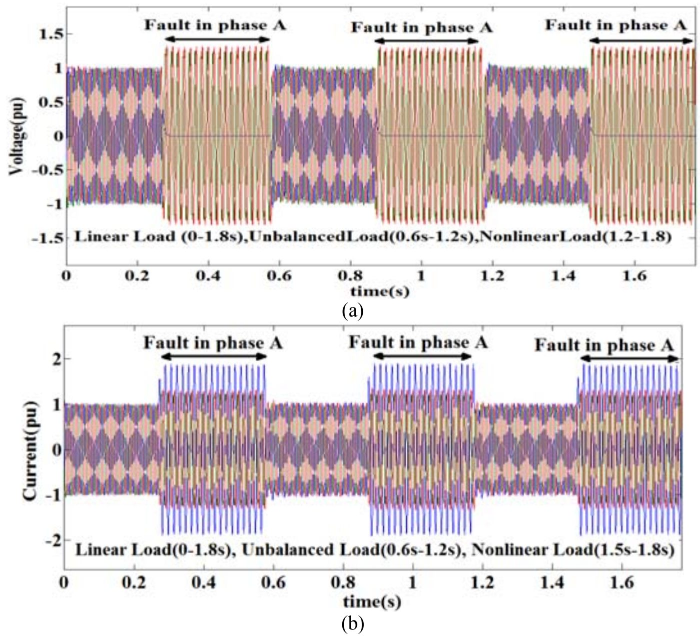


Fig.7. a) Point Common Coupling voltage in one-phase fault (no LVRT), b) the current of DG 1 (no LVRT)

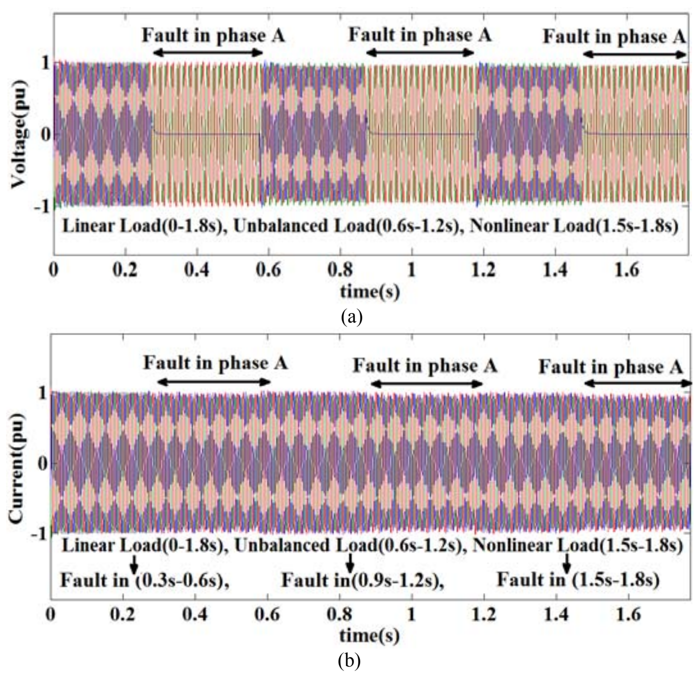


Fig.8. a) Point Common coupling voltage in one-phase fault (LVRT), b) current of DG 1 (LVRT)

In Fig.9, the symmetric fault is considered, and the performance of the system is shown without using the suggested method. Figure 10 depicts this performance implementing the suggested strategy.

4.3. Plug and play

In this section, we have investigated the plug and play property of proposed method. If one of inverters will be out of service from the system, the system has capability of sharing power on other active DGs without any degradation in system performance as shown in Fig.11. As can be seen, inverter 3 is inactive, and the load is shared between two other DGs in active and reactive mode based on their droop gains.

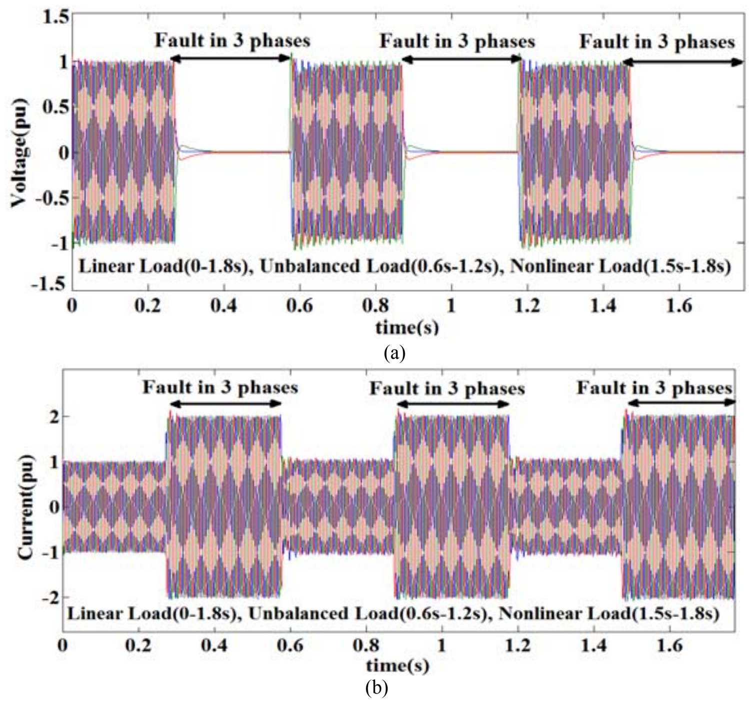


Fig.9. a) Point Common Coupling voltage in symmetric fault (no LVRT), b) the current of DG 1 (no LVRT).

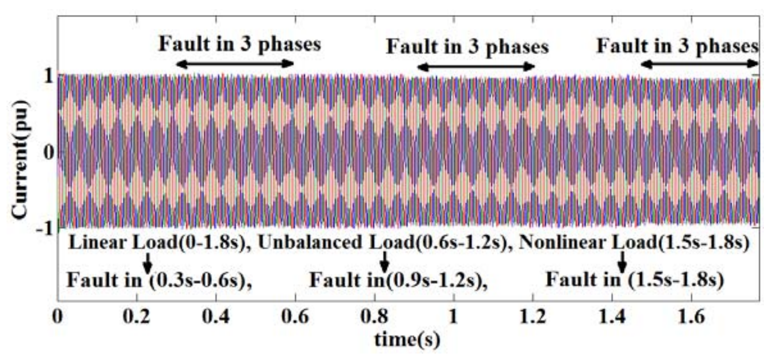
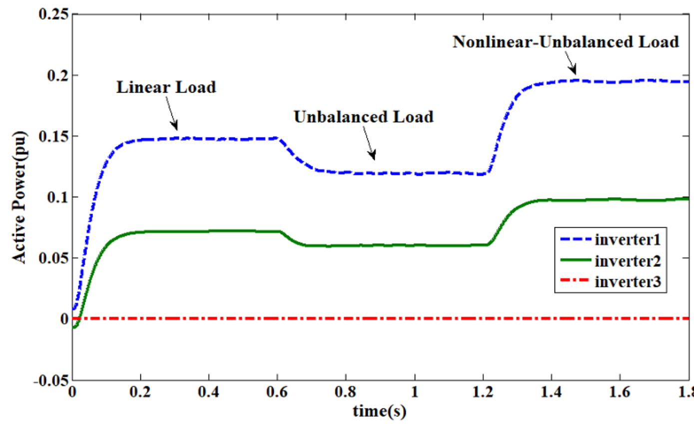


Fig.10. Inverter 1 current using protection



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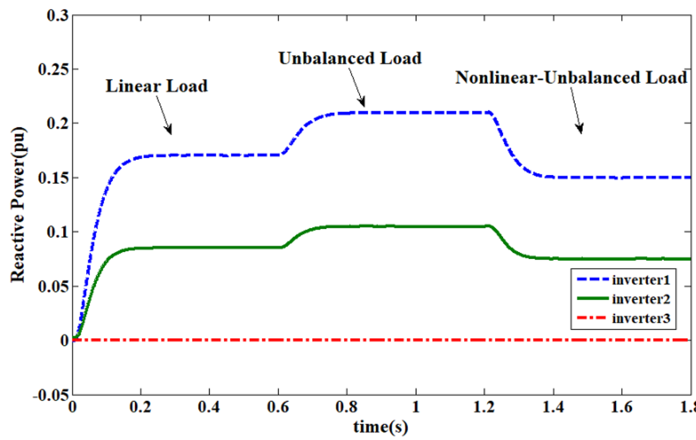

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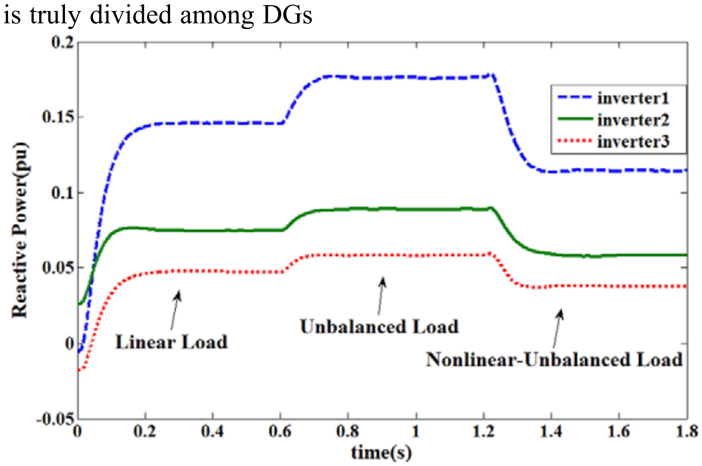
Fig.11. Inverter powers, Plug and Play

4.4 Load sharing with different and equal droop gains

In consequence, load sharing for 3 DGs with dissimilar droop gains is analyzed. As observed from figure 12, active and reactive power is truly divided among DGs due to their droop coefficients. The gains are selected as 1:2:3 for three inverters respectively.

In continue the load sharing is depicted for 4 DGs, including droop coefficients of 1:2:3:4.



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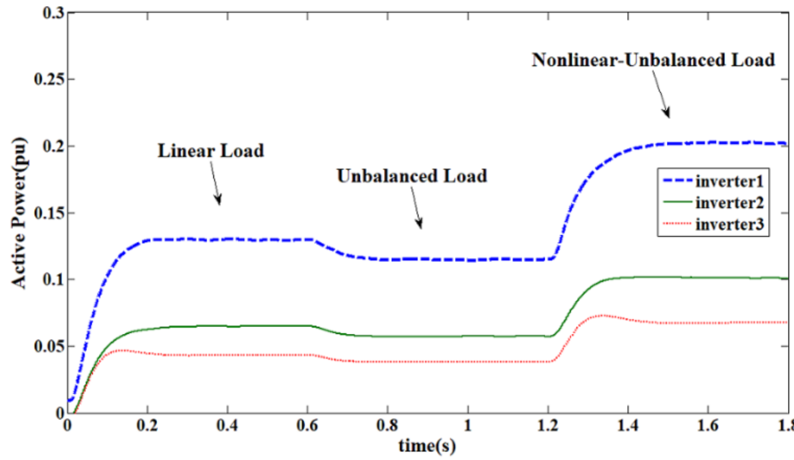

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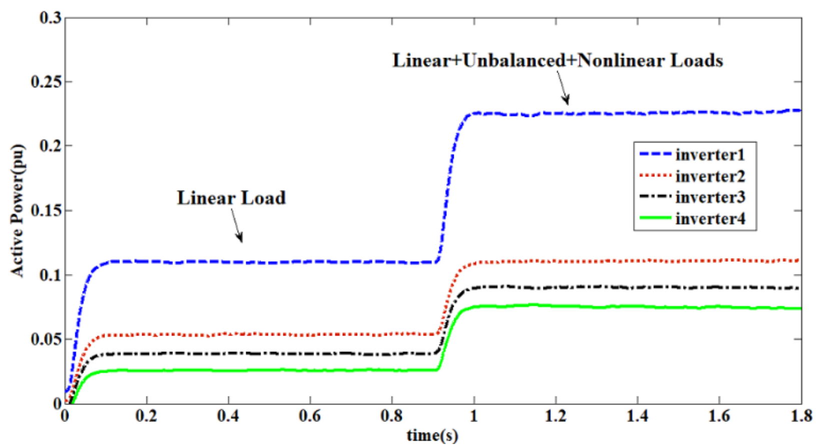
Fig.12. Inverter powers, Different droop gains



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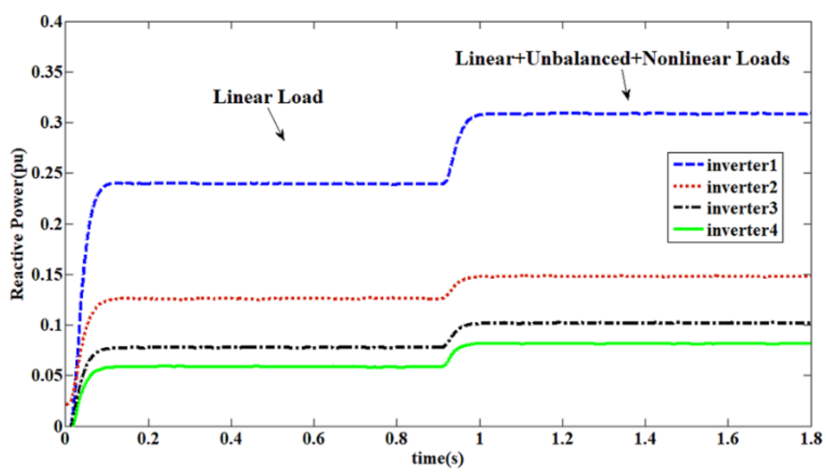
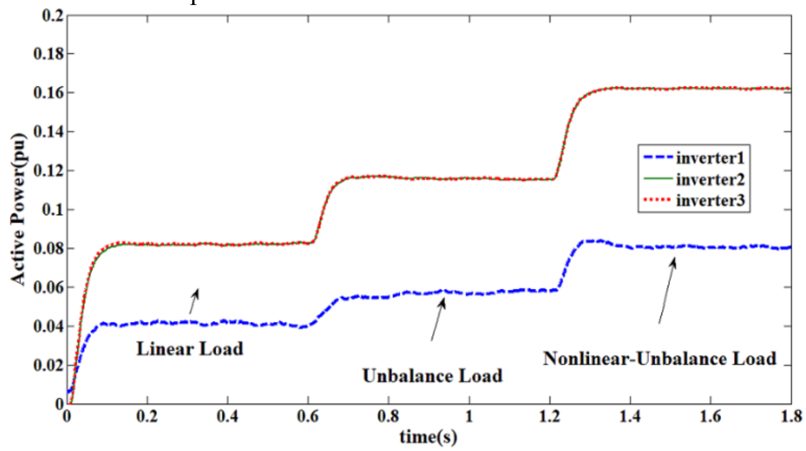


(b)

Fig.13. Different droop gains for 4 inverters: a) active power, b) reactive power

If two inverters have equal droop gains and the third inverter has different gain, the power sharing performance is acceptable due to Fig.14. Also in Fig.15 the equal droop gains power sharing have been shown.



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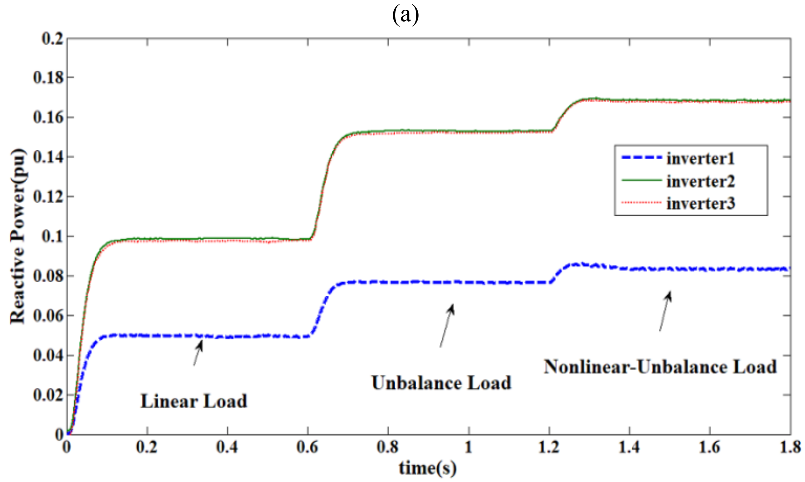

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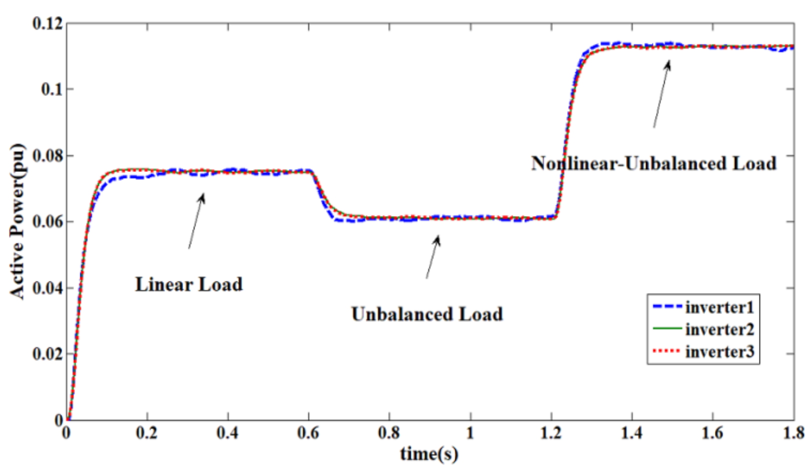
Fig.14. inverter powers, equal droop gains for inverters 2 and 3 and different for inverter 1



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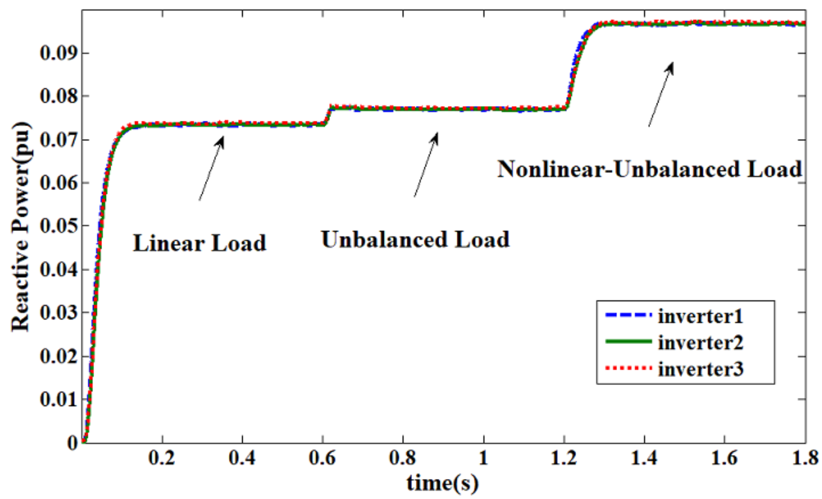

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Fig.15. inverter powers, equal droop gains for 3 inverters

4.5 Load Sharing among more than 4 Parallel Inverters

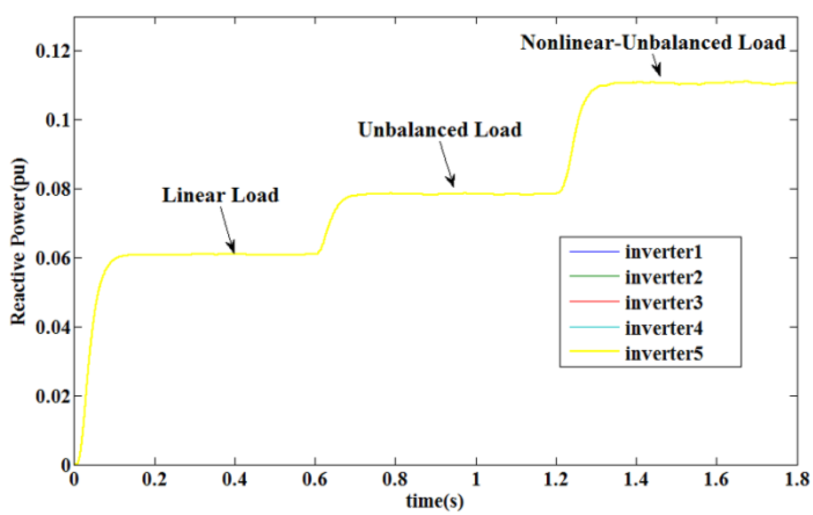
In this section Power sharing among five and six inverters has been simulated. Applying the suggested scheme results in balanced load sharing among the inverters considering the droop gains of them. In following these case studies is presented in equal and different droop gains separately.

4.5.1 Similar Droop Coefficients-five DGs (1:1:1:1:1):

Initially, in the state of similar droop coefficients, load sharing is depicted in Figs. 16.a and 16.b for reactive power and active power, respectively.

4.5.2 Different Droop Gains-five inverters

In the state of dissimilar droop coefficients, load sharing is depicted in Figs. 17.a and 17.b for reactive and active power respectively for five DGs.



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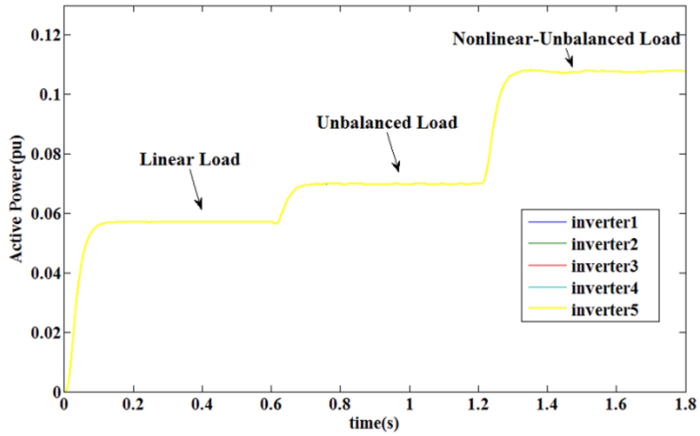

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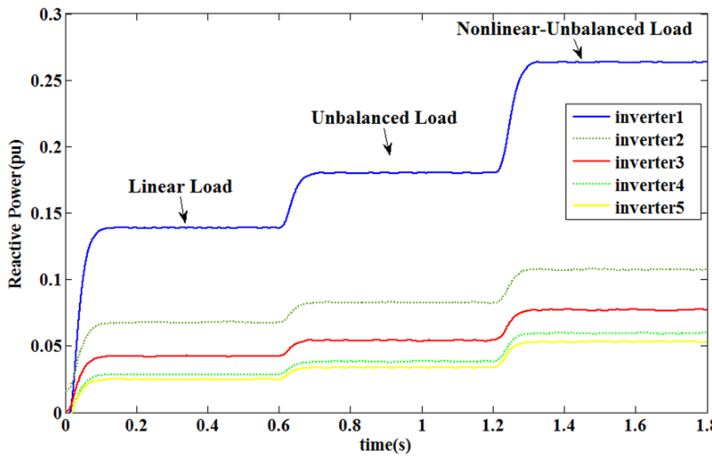
Fig.16. Load sharing applying the suggested strategy for 5 DGs, equal droop coefficients in different loads a) Reactive b) active.



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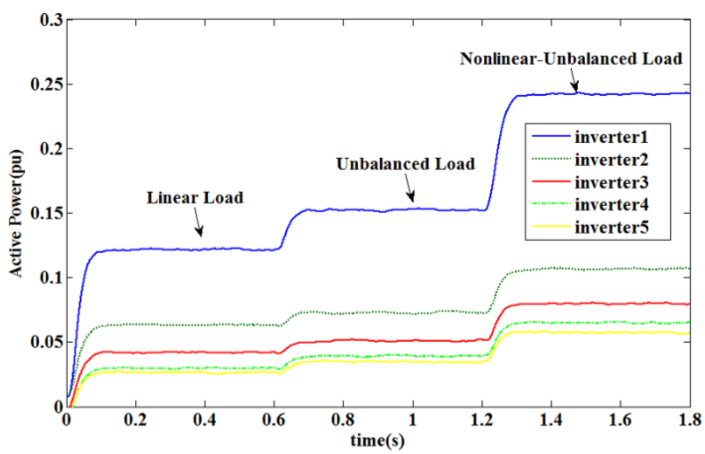

(b)

Fig.17. Load sharing by the suggested strategy for 5 DGs, dissimilar droop coefficients, a) Reactive b) active.

The same discussion is done for six inverters in the sequel and Figs. 18.a and 18.b depict the reactive and active load sharing in dissimilar droop gains (1:1.5:2:2.5:3:3.5) respectively.
As seen from above, the suggested strategy has an acceptable presentation in this state, too and six DGs in reactive and real power are shared relative to their droop gains.

5. Conclusions

In this article, joint power sharing and protection method are proposed for faulty and faultless condition of microgrid with different loads. Using reference current or reactive power injection, protection is achieved, and droop method is used for balanced power sharing among several parallel DGs. The plug and play property of this method is interesting and the extension to the multiple parallel DGs is straight forward due to proposed method.

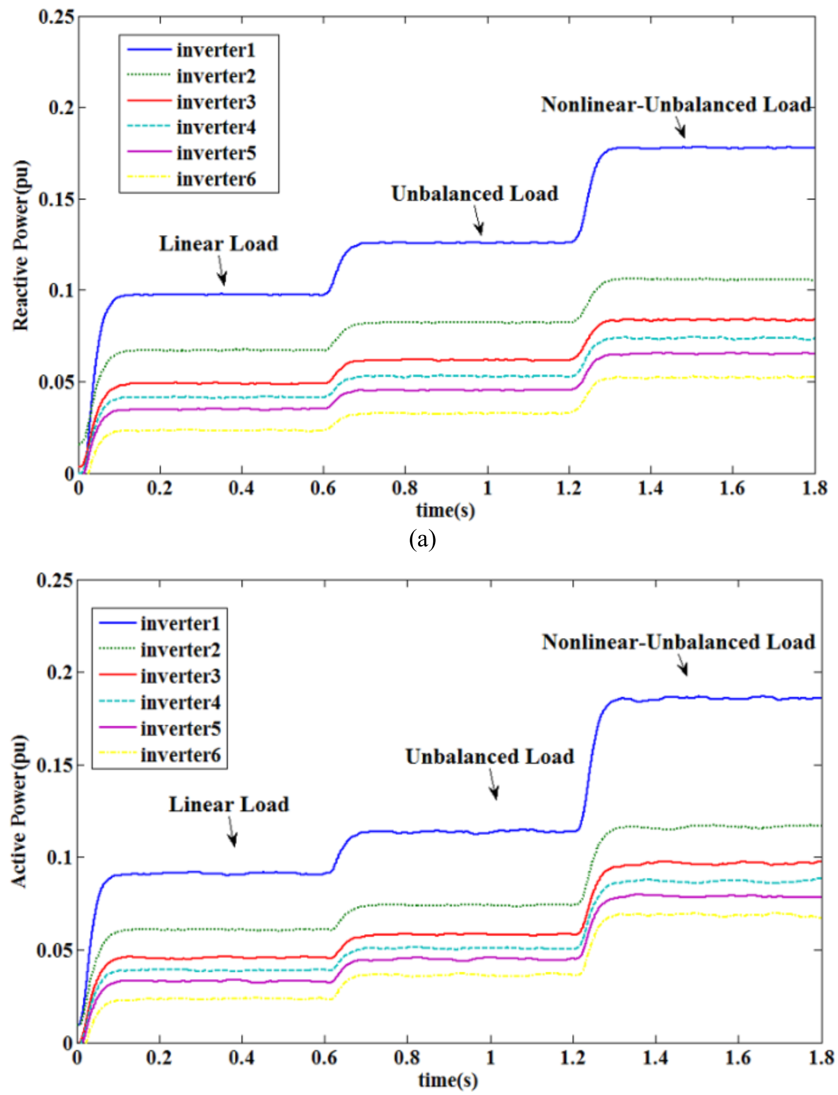

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Fig.18. Load sharing applying the suggested strategy for six DGs, dissimilar droop coefficients, a) Reactive b) active.

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