# An Accurate Power Sharing Method for Control of a Multi-DG Microgrid

M. Hamzeh, H. Karimi, H. Mokhtari and M. Popov

*Abstract*-**This paper presents an accurate control scheme for active and reactive power sharing in a microgrid consisting of two distributed generation (DG) units. Each DG unit within the microgrid utilizes a structurally simple controller for adjusting its power components. The proposed method combines the droop, and average power sharing (APS) schemes to improve the accuracy of reactive power sharing control. This method also employs the low-bandwidth digital communications to achieve accurate power sharing and restoration process. The simulation results verify the accuracy and effectiveness of the proposed method as compared to the conventional droop and APS methods.**

***Keywords*: average power sharing, droop method, microgrid.**

## I. INTRODUCTION

The expected high depth of penetration of distributed generation (DG) units in the utility distribution grid [1] has been the main impetus for the "*microgrid*" [2]–[3], "active distribution system" and "*smart grid*" [4] concepts.

There are many technical issues related to microgrid operation, e.g., interconnection schemes between a microgrid and the main grid [5], voltage-control schemes of a microgrid [6]-[9], and a frequency control during islanded operation [6].

In a multi-DG islanded microgrid, active and reactive power sharing among the DG units is one of the main tasks of the control system. The droop method is a well-known approach for power sharing in the multi-DG microgrids [10]. Although the droop controller does not need any communication link between the DGs, this method has its own disadvantages, which limits the proper operation in the widespread medium voltage (MV) microgrids. In particular, the reactive power sharing based on the conventional droop method is not accurate since the voltage/reactive power droop characteristic of each DG is only valid for an electrically small neighborhood of the corresponding DG. However, the active power sharing shows a better accuracy since the frequency/active power characteristic is globally valid in a distribution network.

Furthermore, the droop method results in system instability when the slope of the droop characteristics is small [10]-[12]. Another disadvantage of the droop method is frequency and voltage deviation from the nominal value for adjusting proper power sharing in microgrid.

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Hence, the frequency and the voltage restoration of a microgrid in an islanded mode is necessary for reconnection to the main grid.

The aforementioned problems can be overcome by using the low bandwidth communication links. A low bandwidth communication method can be applied to improve the performance of the conventional droop method by transmitting the restoration signals between the DG units. Each DG unit uses these signals to calculate the accurate reference signals for the controllers.

In this paper, a new power sharing strategy is developed for a medium voltage multi-DG microgrid. The proposed strategy consists of a structurally simple controller for adjusting the power components of the DG units. Based on the simulation studies carried out in the PSCAD/EMTDC software, the performance of the proposed scheme is also verified in this paper.

The paper is organized as follows. Section II describes the characteristics of the power sharing methods employed in this paper. Section III presents the details of the proposed control scheme. Performance of the proposed power sharing method is verified in Section IV. Section V concludes the paper.

## II. POWER SHARING METHOD IN A MV MICROGRID

The fast development of digital signal processors has brought about an increase in control techniques for the parallel operation of inverters. These control schemes can be classified into two main groups with regard to the use of control wire interconnections. The first technique is based on active load sharing, e.g., centralized, master–slave (MS) and average power sharing. Although these control schemes achieve both good output-voltage regulation and equal current sharing, they need critical intercommunication lines among modules that could reduce the system reliability and expandability [17].

The second control scheme for the parallel operation of inverters is mainly based on the droop method [10]–[12]. This technique consists of adjusting the frequency and voltage amplitude in terms of the active and reactive power injected by the inverter. The droop method is more reliable and flexible than the communication based methods, as it utilizes the local measurements. The theory of operation of the droop and APS methods, which are the basis of the proposed method, is described in this section.

### *A. Droop Method*

The droop method is based on a well-known concept in the conventional power systems, which indicates that the frequency drops when the output power of an ac generator increases [10-13]. This concept has been widely used in the power sharing control of parallel connection of UPS and DG systems. In the case of electronically coupled DG systems with parallel structure, the active and reactive power components supplied to the ac bus are measured and averaged, and the resulting signals are applied to adjust the frequency and amplitude of the inverter voltage reference. The droop characteristics in its simplest form for a DG system can be expressed as follows.

$$f = f^* - m(P - P^*) \qquad (1)$$

$$E = E^* - n(Q) \qquad (2)$$

Where E*and f*are the voltage magnitude and frequency at no load, respectively. The parameters m and n are called the droop frequency and amplitude coefficients, and P* is the reference signal of the active power.

### B. APS Method

In this method, the active and reactive power components are measured and used for adjusting the phase and amplitude of each DG unit [15]. Based on this technique, each DG unit controls its power components in order to match the average of power components of the system. To match the average power, the method adjusts the phase and the amplitude of its own inner output-voltage reference.

An earlier work has used this method to achieve the power sharing between two UPS modules [16]. This control scheme can be extended to several units by making use of the active and reactive average power-sharing buses. This technique does not require any master or slave unit, and only a low-bandwidth digital communication scheme is required to achieve good P and Q sharing.

## III. Proposed Method for Accurate Reactive Power Sharing in a Multi-DG Microgrid

As mentioned before, the main advantage of the droop method is that it is not a communication based method and consequently it is a reliable technique. For this reason, the method is widely used in the power sharing controller of the microgrids. However, the droop method has some disadvantages which can limit its performance.

The accuracy of the reactive power sharing in a widespread MV microgrid which contains the long MV lines between DGs and loads is degraded considerably when the droop method is employed. This is due to the large and different impedances between DGs and loads. Thus, any change in load may deviate the voltage amplitude at each bus from its rated value. Therefore, the DGs that are close to a certain bus have more effect for reactive power compensation.

The active power sharing in the droop method is accomplished by deviating the frequency. Due to the global characteristic of the frequency droop, the active power sharing in a widespread microgrid is more accurate than that of the reactive power.

It should be noted that because the droop method cannot provide accurate frequency and voltage magnitude, it shows some issues when reconnecting to the main grid. Therefore, a method to restore the voltage and frequency is required to modify the droop control scheme.

To overcome the drawbacks of the droop method a PI controller for modifying the reactive power sharing is used. Furthermore, a frequency-voltage restoration unit is used for reconnecting the main grid and microgrid. Fig. 1 shows the structure of the proposed method. The output signals of the droop controller which contains the frequency and the amplitude of the reference voltage are added to modifier value for improving the power sharing accuracy and restoration process. The frequency and the amplitude of the reference voltage are calculated as below.

$$f = f_{droop} + \Delta f \qquad (3)$$

$$E = E_{droop} + \Delta E_0 + \Delta E \qquad (4)$$

In (3) and (4), Δf and ΔE are the restoration signals, which are received by each DG from a low bandwidth communication link. These signals are generated by restoration unit, which is located at the PCC where the microgrid and main grid are connected. These signals are used

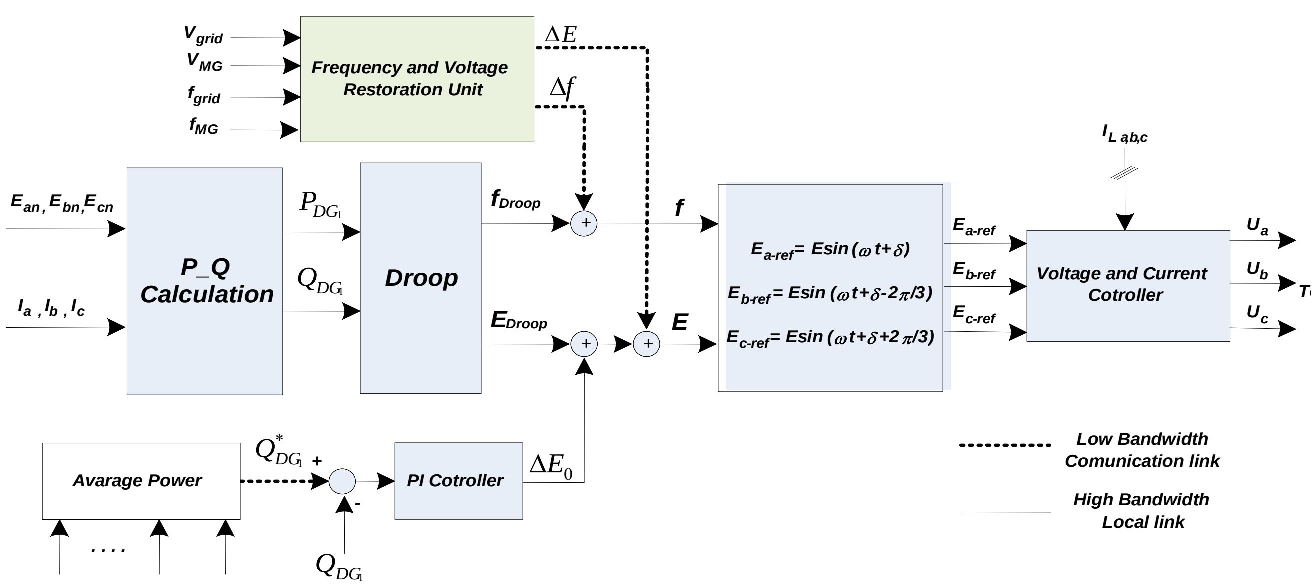


Fig. 1.The proposed scheme for accurate power sharing and frequency-voltage restoration.

at the time of reconnection and are set to zero for the rest of the time. In (2), $\Delta E_0$ is a modifier value for accurate reactive power sharing. In the proposed method, each DG within the microgrid sends the output power components to the rest of the DGs via the communication link. Each DG receives these signals and calculates the reference of the reactive power by considering the reactive power capacity of the DGs. The reference of the reactive power for the $i_{th}$ DG is calculated as

$$Q^*_{DG_i} = \frac{Q_{\max\_DG_i}}{\sum_{j=1}^{N} Q_{\max\_DG_j}} \sum_{j=1}^{N} Q_{DG_j} \quad for\ k = 1, \dots, N. \quad (5)$$

In this equation, $Q_{max\_DGj}$ is the maximum reactive power of each DG and $Q_{DGj}$ is the measured output reactive power. The PI controller is used for adjusting reactive power and reference reactive power in each DG. The PI controller has a large settling time and for a short term transient has no effect on the output power. For a long term, this controller adjusts the accurate reactive power in a few second.

In the case of reactive power change, the voltage controller of each DG depending on the impedance between them and loads increases or decreases its power in a very short term. Then the droop controller by deviating the amplitude and the frequency of the reference voltage shares the real and reactive power of loads between DGs in a short time. Thereafter, the PI controller compensates the reactive power error of the droop method by adding $\Delta E_0$ to the amplitude of the reference voltage.

Although the proposed method requires the communication link between DGs, in the future smart microgrid, for an optimum control and protection of a microgrid the existence of a communication link is necessary. In addition, for secure voltage and frequency restoration, the communication link is required. One of the most drawbacks of a communication link is the reduction of reliability in the microgrid. However, in the proposed method when the communication link is disconnected, the modifier and the restoration signals are set to zero and the decentralized feature of the droop controller guarantees the proper operation of microgrid.

## IV. Simulation Results

Fig. 2 shows a MV microgrid comprising three 20kV feeders, which are linked to the low voltage distribution network by a MV line. Two electronically-coupled DG units are connected to feeders 1 and 3 through the step-up transformers. The parameters of the microgrid components and DGs are given in Table I.

TABLE I
THE SIMULATED SYSTEM PARAMETERS

| Parameters | | Value |
|---|---|---|
| $L_{f1}$ , $L_{f2}$ | | 0.3mH (0.6545 pu) |
| $R_{f1}$ , $R_{f2}$ | | 0.0015Ω (0.0104 pu) |
| $C_{f1}$, $C_{f2}$ | | 2200μF (0.09952 pu) |
| $f_{switching}$ | | 2kHz |
| $V_{dc}$ | | 1500V |
| $P_{max\text{-}DG1}$ , $P_{max\text{-}DG2}$ | | 2.5MW (1pu) |
| $Q_{max\text{-}DG1}$ , $Q_{max\text{-}DG2}$ | | 1.5MVAr (0.6 pu) |
| $R_{line}$ | $R_{line1}$ | 1Ω (0.00625 pu) |
| | $R_{line2}$ | 0Ω |
| | $R_{line3}$ | 0.2Ω (0.00125 pu) |
| $L_{line}$ | $L_{line1}$ | 10mH (0.0196 pu) |
| | $L_{line2}$ | 0mH |
| | $L_{line3}$ | 2mH (0.00393 pu) |

The active and reactive power of the feeder loads is depicted in Fig. 4. In islanded mode condition, at t=3sec, a sudden load change is occurred in feeder 2. For demonstrating, the performance of the applied method, the active and reactive power of the DGs is depicted in the same figure. The maximum active and reactive power capacity of each DG is equal as in Table I in all simulations.

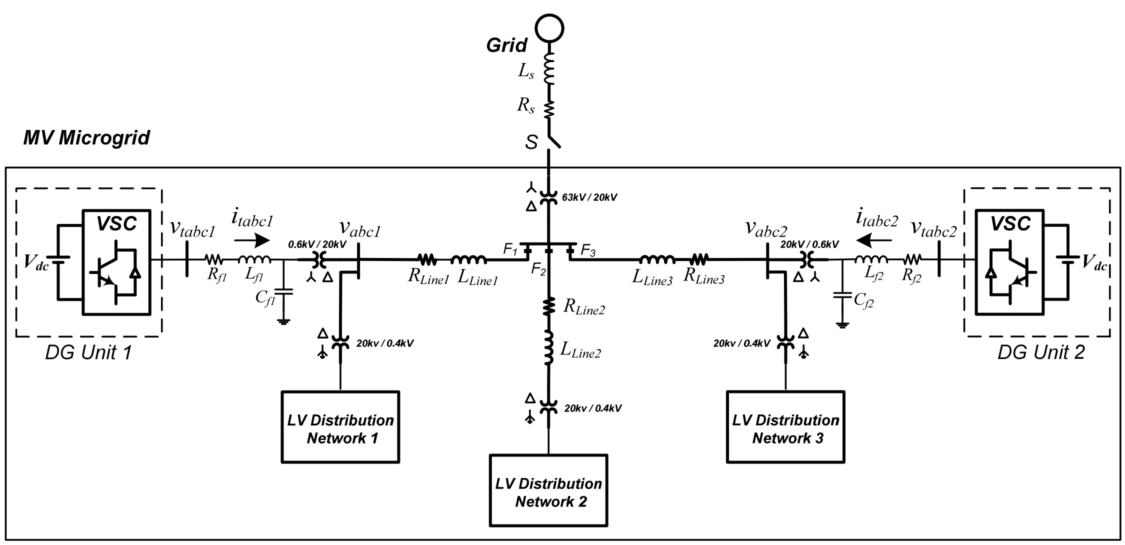


Fig. 2. A MV Microgrid consisting of two DGs

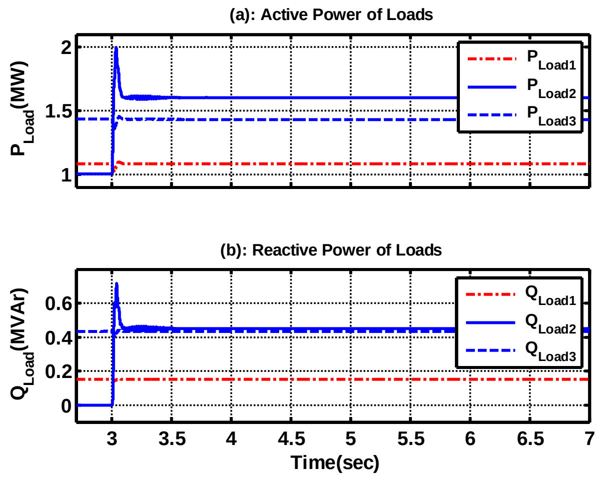


Fig. 3. A sudden load change in feeder 2. (a) Active power and (b) Reactive power of 20 kV feeders.

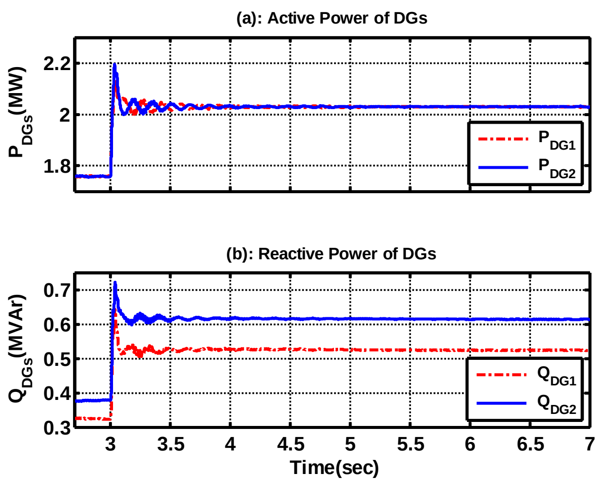


Fig. 4. The output power of DGs when a sudden load change is occurred in feeder 2 while the droop method is used for power sharing. (a) Real power, (b) Reactive power of DGs

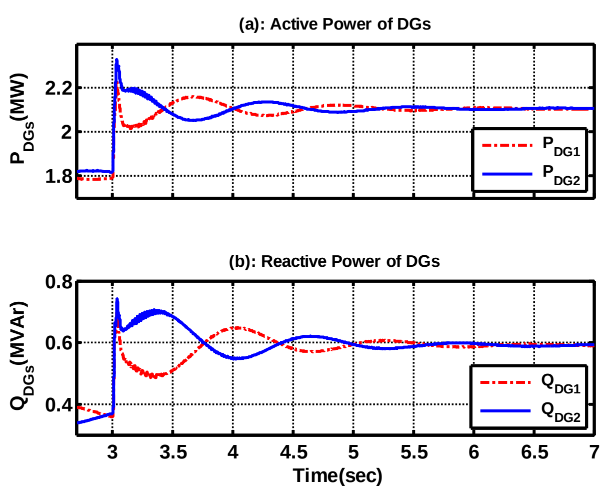


Fig. 5. The output power of DGs when a sudden load change is occurred in feeder 2 while APS method is used for power sharing. (a) Real power, (b) Reactive power of DGs

For comparing the proposed method to the conventional droop and APS method, each power sharing scheme is simulated separately. In Fig. 5 the active and reactive power of

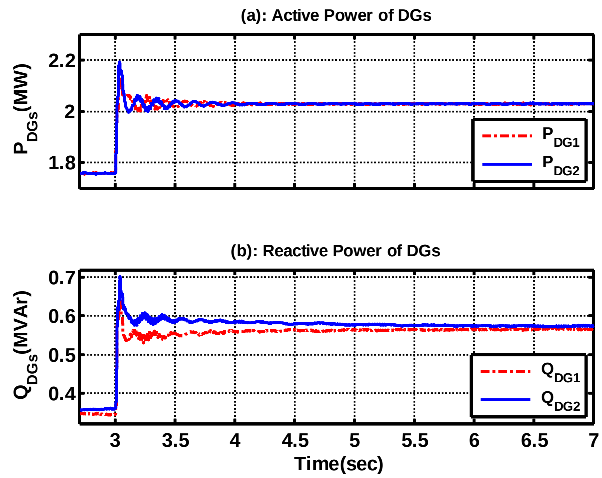


Fig. 6. The output power of DGs when a sudden load change is occurred in feeder 2 while the proposed method is used for power sharing. (a) Real power, (b) Reactive power of DGs

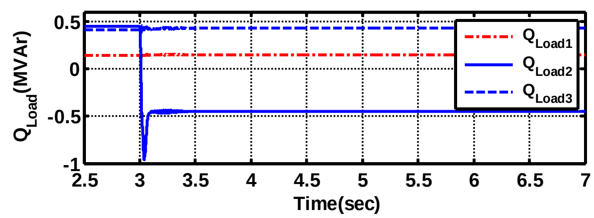


Fig. 7. Reactive power of 20kV feeders when a capacitor load switching is occurred in feeder 2.

the DGs is demonstrated while each DG applies conventional droop method for power sharing. As shown in Fig. 5(a) the accuracy of the active power sharing is good because of the global characteristic of the frequency in microgrid. Each DG increases its active power by drifting its reference frequency according to P-f droop curve. Fig. 5(b) shows that the accuracy of the reactive power sharing in this case is very poor. Because of the different impedance between DGs and loads and the different loads in the feeders, the amplitude voltage of the DG terminal in each feeder, is not same. Pursuant to this, the accuracy of the reactive power sharing is degraded.

In Fig. 5 APS method is used for power sharing. As compared to the droop method, the speed of tracking the active and reactive power reference is slower but the accuracy of reactive power sharing is better. In this method, the PI controllers calculate the phase-angle and amplitude of the terminal voltage of each DG unit. The phase-angle and the voltage magnitude are used by the gating signal generator to produce the gating pulses for each converter.

Fig. 6 shows the power components of each DG unit when each inverter applies the proposed method for power sharing. The reactive power sharing has high accuracy as compared with the droop method.

In another simulation case, a capacitor switching takes place in feeder 2 at t=3 sec. The reactive power of each feeder is depicted in Fig. 7. The output reactive power of each DG is shown in Fig. 8 for the droop, the APS and the proposed method. In this case, simulation results show that the accuracy

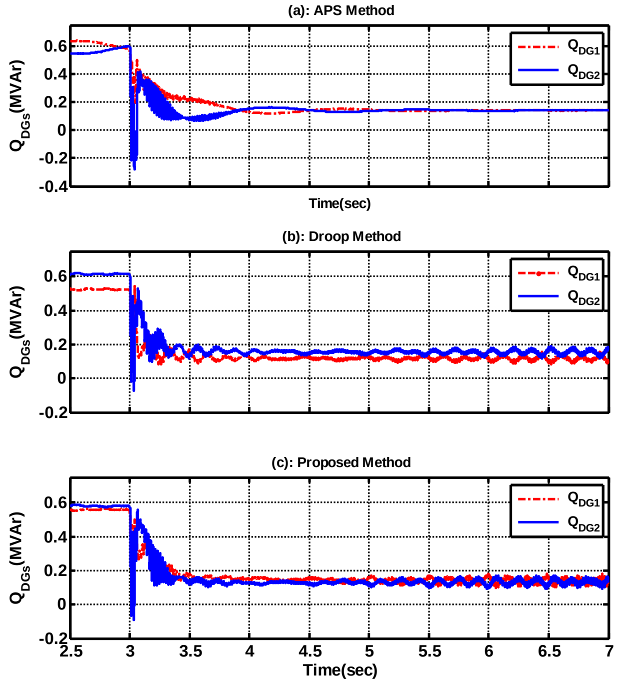


Fig. 8. The output power of DGs when a capacitor load switching is occurred in feeder 2 while (a) the droop method, (b )APS method and (c) proposed methods are used for power sharing.

of the droop method is increased when the capacitive load connection occurs and the error of the reactive power sharing decreases in this case. Furthermore, Fig. 8(c) shows that the proposed method has a good performance in all types of load switching.

In the next simulation case, the voltage and the frequency restoration process is studied. The restoration unit which is located in 63/20 kV substation sends Δf and ΔE signal to each DG and the DGs restore amplitude and frequency to the main grid.

In Fig. 9 the frequency and the voltage are drifted by the droop controller for power sharing operation. The frequency deviation is 0.24Hz, and the voltage deviation is 0.038p.u. At t=2.5 sec the restoration process is started and the voltage and the frequency of the microgrid restores to the main grid voltage and frequency at t=6sec. The voltage and frequency restoration minimize the severe transient effect on the reconnection process.

## V. Conclusions

This paper presents a new control scheme for the accurate reactive power sharing in a multi-DG MV microgrid. The microgrid consists of two DG units which are connected to the local loads through the power electronics converter. The proposed method employs a low bandwidth communication scheme to improve the performance of the droop method. The method eliminates the steady-state error of the reactive power sharing of the droop method using a PI controller. The communication link transmits the adjusting signals to each DG unit. The DG units correct the set-points of the reactive power based on the restoration signals.

The performance of the proposed scheme is verified based on

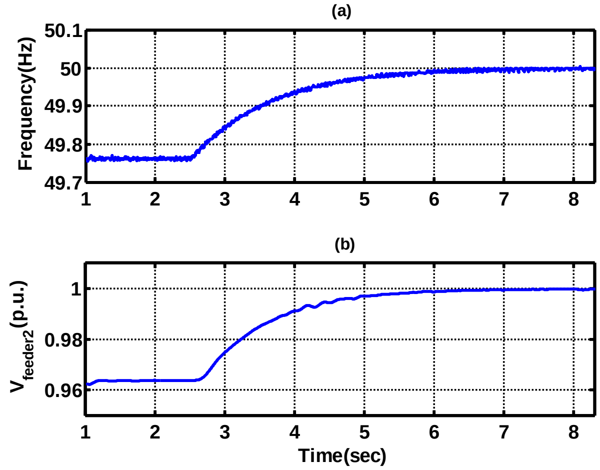


Fig. 9. Frequency and voltage restoration process of microgrid which start in t=2.5se .(a) Frequency of PCC, (b) Voltage of PCC

the simulation studies carried out in PSCAD/EMTDC software environment. The results show that the proposed method has a better accuracy as compared with the droop method. Furthermore, the method is more reliable when compared to the APS method.

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