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Droop based Control Strategy for a Microgrid

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Droop based Control Strategy for a Microgrid

Soha Mansour [α], Mostafa I. Marei [σ] & Ahmed A. Sattar [ρ]

Abstract- Integration of microgrids into the main power systems imposes major challenges regarding reliable operation and control. Reliable operation means to be able to manage the microgrid in its two modes of operation; grid-connected and islanded, as well as handling the transition between these two modes. Several control strategies have been established in this area. This paper utilizes droop based control method due to its advantages of great flexibility, no communication needed, high reliability, and free laying. In this paper, one DG unit is controlled to set the voltage and frequency of the microgrid, VF mode. In contrast, the other DG units of the microgrid control their active and reactive power sharing, PQ mode. Controlling one inverter in VF mode results in a smooth transition between grid-connected and islanded operation. This action eliminates the need for islanding detection. The proposed microgrid system with three DG units is investigated using PSCAD/EMTDC under different operating conditions in both modes of operation. The results reveal that the proposed system succeeded to maintain the adequate frequency level, voltage level, and load sharing with smooth transition.

Keywords: distributed generation, droop control method, microgrid, smooth transition, voltage control.

I. Introduction

The implementation of distributed generation (DG) has been highly increasing. Compared to the conventional centralized power generation, DG units have many advantages such as higher energy utilization efficiency, flexibility in installation location, and less power transmission losses. Nowadays microgrid is one of the most up-to-date and important topics in the scope of power systems [1]. The microgrid concept was first proposed in the USA by the Consortium for Electrical Reliability Technology Solutions [2].

A microgrid is defined as a cluster of DG units and loads, serviced by a distribution system, and can operate in 1) the grid-connected mode, 2) the islanded (stand-alone) mode, and 3) ride-through between these two modes [3].

Islanding; which is the separation of the microgrid from the main grid, may be either planned or accidental. Appropriate detection of such incident is essential to be able to operate the microgrid properly, as well as tracking the changes in both steady state and dynamic characteristics of the microgrid to successfully implement the adopted control technique. The basic functions of a microgrid are [4]:

1. Regulating the microgrid's voltage magnitude and frequency within their normal ranges during autonomous mode.
2. Controlling active power and reactive power flow from DG units to loads while working in autonomous mode.
3. Managing power flow between microgrid and the main grid during grid-connected mode.
4. Providing a smooth transition between islanded mode and grid-connected mode.

Most DG units are connected to the microgrid through DC/AC inverter interface. Thus, by proper control of those inverters, microgrid energy management is sufficiently accomplished. The fundamental control variables of a microgrid are active power, reactive power, voltage, and frequency. In grid-connected mode, the microgird frequency and the voltage at the Point of Common Coupling (PCC) are predominantly dictated by the main grid. In this case, the major function of the microgrid control is to manage both active and reactive powers produced by the DG units and the load requirements. Injecting reactive power into the main power grid can be used to provide ancillary services such as power factor correction, elimination of harmonics, or voltage control. In some cases, the utility may not permit voltage control at PCC by DG units to prevent interfering with similar actions provided by the utility.

In islanded mode, the microgrid works totally independent. Therefore, this situation is more difficult than being connected to the main grid, as maintaining load-supply equilibrium necessitates the application of precise load sharing mechanisms to adjust and equlibrate any unexpected power mismatches. Neither Voltages nor frequency of the microgrid are still determined by the main grid, thus they must be controlled by the DG units. Power balance is guaranteed either by local controllers using local data, or using a centralized controller that calculates and sends set points to local controllers of various DG sets and controllable loads ensuring that all DG units share in feeding the load in a pre-determined way. Any deviation in the magnitude, phase shift or frequency of the output voltage of one of the DG units can lead to severe circulating currents [5].

For microgrid control, two unique opposite approaches are recognized: centralized or decentralized. In centralized control methodology vast communication among the central controller and local controllers is required. Any loss of communication link or faulty operation of the master unit can shut down the

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entire system [6]. However, in the decentralized control methodology, each unit is controlled using its local controller that receives only local measurements without considering other system variables or other controllers' actions.

Various techniques have been adopted to parallel inverters [7]. They have different architectures and modes of operation. In master/slave techniques, a voltage controlled inverter is used as a master unit to maintain proper output sinusoidal voltage and generate a distributive current command to be tracked by the current controlled slave inverters [8]. Another technique is the current/power sharing where the total load current is measured then divided by the number of inverters to get the mean inverter current. Subsequently, the difference between the actual unit current and the average one is used to derive the control signal for load sharing [8]. The frequency/voltage droop based technique has been accepted as the most popular decentralized control strategy [9]. In this method the inverters operate in parallel with no auxiliary interconnections as the above methods. This technique allows the independent inverters to share the load in proportion to their capacities. In this paper, droop control method is adopted for the proposed microgrid with smooth transition capability between the grid-connected and islanded modes of operation.

II. Overview of Droop Control Method

The droop control method is based on locally measured data, does not depend on communication signal, accordingly eliminating the difficulties imposed by physical location. The droop method has other advantages such as great flexibility, high reliability, simple structure, easy implementation, free laying, and different power ratings [10].

In power grids, the active power and the reactive power have strong coupling with the frequency and the voltage, respectively [8]. Accordingly, the relationship between the active power/frequency and the reactive power/voltage can be expressed as:

$$f = f_o + K_{Pf}(P_o - P) \tag{1}$$

$$V = V_o + K_{QV}(Q_o - Q) \tag{2}$$

where f_o and V_o are the rated values for the system frequency and voltage, respectively, where f and V are the measured frequency and voltage of the DG unit, respectively, and P_o and Q_o are the momentary set points of the active and reactive power references of the inverter, respectively, and P and Q are the measured active and reactive powers, respectively, K_{Pf} and K_{QV} symbolize the droop coefficients which are chosenrelying on steady state performance criteria [5],[11],[12]. The droop coefficients are calculated from:

$$K_P = \frac{\Delta f}{P_{max}} \tag{3}$$

$$K_Q = \frac{\Delta V}{Q} \tag{4}$$

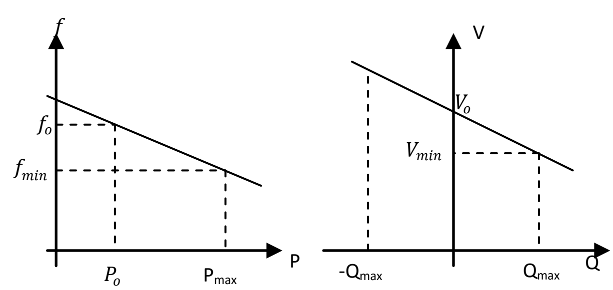
where P_{max} and Q_{max} are the maximum active and reactive powers delivered by the inverter, respectively, $\Delta f$and ΔV are the maximum allowable frequency and voltage magnitude deviations, respectively. According to the EN 50160, Δf should be within ± 2% of the nominal frequency, while ΔV should not exceed ± 10% of the nominal voltage magnitude [13], [14]. A conventional P-f and Q-V droop characteristics are shown in Fig. 1(a) and Fig. 1(b), respectively. At nominal voltage operating conditions, the DG units are supposed not to deliver any reactive power to the main grid, which means supplying active power at unity power factor in this working condition. In Fig. 1, f_{min} and V_{min} identify the minimum acceptable frequency and voltage of the DG unit, respectively [14].

For several DG units connected in parallel constituting a microgrid, the load power sharing depends on the slope of the droop characteristics. The main idea is that when there is an increase in the load, the frequency reference is decreased. Similarly, reactive power is shared using the droop characteristic of the voltage magnitude. The mechanism of active power sharing based on droop control is [11]:

$$\Delta P_1 K_{P1} = \Delta P_2 K_{P2} = \cdots = \Delta P_n K_{Pn} \tag{5}$$

Similarly, the mechanism of reactive power sharing using droop control is:

$$\Delta Q_1 K_{Q1} = \Delta Q_2 K_{Q2} = \cdots = \Delta Q_n K_{Qn} \tag{6}$$



3(a) 3(b)

Figure 1: Conventional droop characteristics (a) P-f droop (b) Q-V droop

III. The Proposed Control Systems

Two control technique approaches are used to operate the inverter; active/reactive power (PQ) control mode and voltage-frequency (VF) control mode [12]. The inverters are usually operated in PQ mode when the micorgrid works in grid connected status. The references of active and reactive powers for each inverter may be predetermined by several ways, for example using a microgrid central controller or by a local Maximum Power Point Tracking (MPPT) based control strategy. On the other hand, during islanded mode of operation, at least one inverter must be operated in VF mode and synchronized with the main grid, while the other DG units can still be controlled in PQ mode. When the microgrid moves to the islanded mode, the system will be unstable if all the inverters operate in PQ control mode because we have to set up the system frequency/voltage using this VF operated inverter, as well as properly share the load power among all the parallel inverters.

a) PQ control mode

The PQ controlled inverter operates by injecting into the grid a pre-specified power defined locally or centrally. Fig. 2 illustrates the block diagram of the droop based control system for the VF inverter to share the load power. The droop equations can be written as:

$$P = P_o + K_{fP}(f_o - f) \tag{7}$$

$$Q = Q_o + K_{VQ}(V_o - V) \tag{8}$$

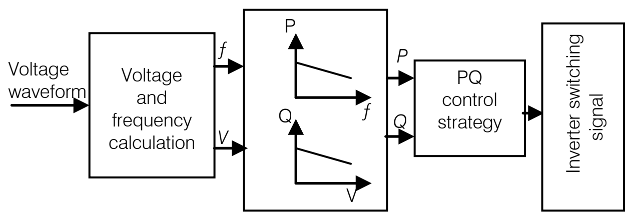


Figure 2: Droop based control system for the PQ inverter

The actual voltage and frequency are passed to the droop unit to generate the reference signals for the active and reactive power, P and Q. These references are compared with their actual values and the errors are processed through PI controllers to generate reference direct axis and quadrature axis currents, Idrefand Iqref, respectively, as shown in Fig. 3. The three-phase reference currents, Iaref, Ibref, and Icref, are obtained using the inverse Park transform, dq/abc. The Hysteresis Current Control (HCC) technique is used to produce the appropriate switching signals for the inverters. The HCC is characterized by its fast dynamics, high bandwidth, simple structure, tight and accurate control of current, and excellent transient response [15].

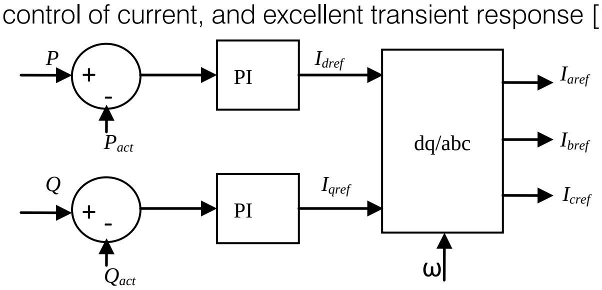


Figure 3: Block diagram of PQ inverter control system

b) VF control mode

In this case, the reference signals of voltage and frequency are extracted directly from the droop characteristics. The block diagram of the droop control system for the VF inverter is shown in Fig. 4. Inverter output voltage and current are measured, thus calculating active and reactive powers of the inverter and processing them through the inverter droop characteristics represented by (1) and (2) to obtain the voltage and frequency reference, V and F.

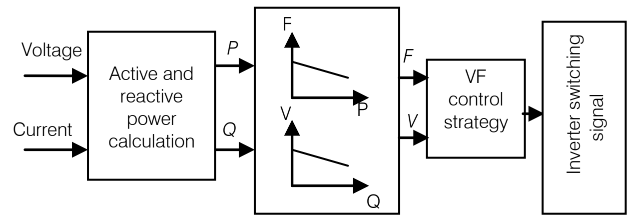


Figure 4: Droop based control system for the VF inverter

Fig. 5 displays the block diagram of the VF inverter control strategy. The voltage reference, V, is compared with the actual bus voltage, Vact, and the error processed by a PI controller to produce the modulation index, M. This modulation index along with the reference frequency, F, and appropriate phase shift, δ, are used to generate the three-phase reference voltage for the inverter Varef, Vbref, and Vcref. The SPWM is used due to its simplicity and easy implementation. The reference voltages waveforms are compared with the carrier signal to generate the switching signals for the inverter.

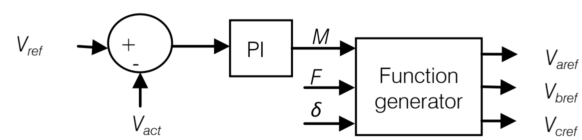


Figure 5: Block diagram of VF inverter control system

A smooth transition between grid-connected mode and autonomous mode is required for the reliability of the autonomous microgrid. Smooth transfer implies that the voltage phase, amplitude and frequency of the microgrid do not change abruptly at the transition moment. Accordingly, transient currents are eliminated and the load receives uninterrupted high quality power. To achieve smooth transfer, one DG unit is controlled in VF mode during the grid-connected and islanded mode of operations to set the microgrid voltage, while the other DG units are controlled in PQ mode.

IV. The Microgrid Under Study

Fig. 6 portrays the single line diagram of the proposed microgrid system with three electronically interfaced DG units. The three DG units are assumed identical. A base load and a switched load are connected to a common ac bus. The microgrid is connected to the utility through a STS. For the sake of simplicity, the DC bus voltage of each unit is assumed constant and equal. The system parameters are listed in Table 1.

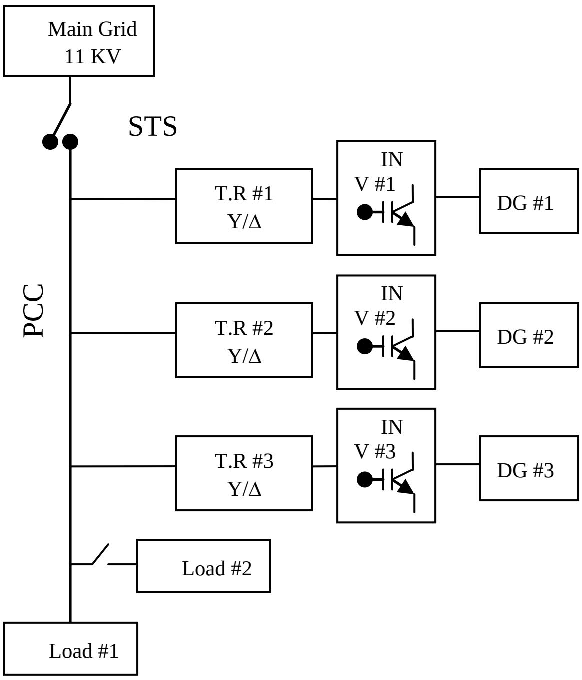


Figure 6: Single line diagram of the proposed system.

Table 1: System parameters

Nominal voltage Vo	11 KV
Nominal frequency fo	50 Hz
K_{Pf1}	10 Hz/MW
K_{QV1}	1.6667 pu voltage/MVAR
$K_{fP2,3}$	0.1 MW/Hz
$K_{VQ2,3}$	0.6 MVAR/pu voltage
Active power setting Po	0.1 MW
Reactive power setting Qo	0.03 MVAR
Switching frequency	2000 Hz
Filter capacitance	2 µF

Inverter one operates in VF control to generate the reference voltage to be followed by the other DG units in the microgrid. Allowing this inverter to work as grid forming in both grid-connected and islanded operation provides the smooth transition required between the two operation modes of the microgrid. On contrary, inverters two and three operate in PQ control during the grid-connected and the islanded operation modes of microgrid.

V. Simulation Results

The microgrid system presented in Fig. 6 is simulated using the PSCAD/EMTDC software package. The droop characteristics of each unit are adjusted to supply rated active power at rated frequency and zero reactive power at nominal voltage. The dynamic performance of the proposed control strategy is tested under different modes of operations and dynamic load change.

a) Grid-connected mode

In this mode, the main grid dictates its voltage and frequency while the microgrid simply exchanges real and reactive powers. When the load requirement is less than the rated capacity of DGs units, the excess power flows into the main grid. While when the load requirement is greater than the rated capacity of DGs units, the grid feeds the deficit power.

Initially, the microgrid supplies a load of about 300 KW and 150 KVAR as illustrated in Fig. 7(a) and Fig. 8(a), respectively. Figs. 7(c), (d), and (e) indicates that the proposed control system succeeds to equally share the active power among the three DG units of the microgrid. Since the load power equals to the nominal power of the micrgrid, zero active power exchange with the main grid is demonstrated in Fig. 7(b). At t= 1.8 sec, a sudden load increase to 415 KW and 165 KVAR occurs and lasts for 1.2 seconds. Fig. 7(c) illustrates the frequency reference F1ref, obtained from the droop characteristics, of the first DG unit. It is obvious that the actual frequency follows its reference signal. Moreover, the high frequency ripples are reflected in the generated active power P1, exhibited in Fig. 7(c). As the frequency is set by the main grid, each DG unit is supposed to deliver its rated active power regardless the loading condition.

On the other hand, the load reactive power is mainly supplied by the main grid and the filtering capacitors of the microgrid inverters. Fig. 8(c) shows the reactive power fed from the first DG unit, controlled in VF mode. Due to the drop in the grid impedance, the pu voltage at the PPC is lower than unity as indicated in Fig. 8(f). The little PCC voltage drop excites the V-Q droop characteristics of the second and third DG units, controlled in PQ mode, to feed the grid with restraint amounts of reactive power as illustrated in Fig. 8(d) and (e), respectively. Moreover, the reactive powers supplied from the second and third DG units are increased when the load is raised due to the increased drop in the PCC voltage.

These results reveal the success of the proposed droop based control strategy in providing accurate performance for the DG units during grid-connected mode.

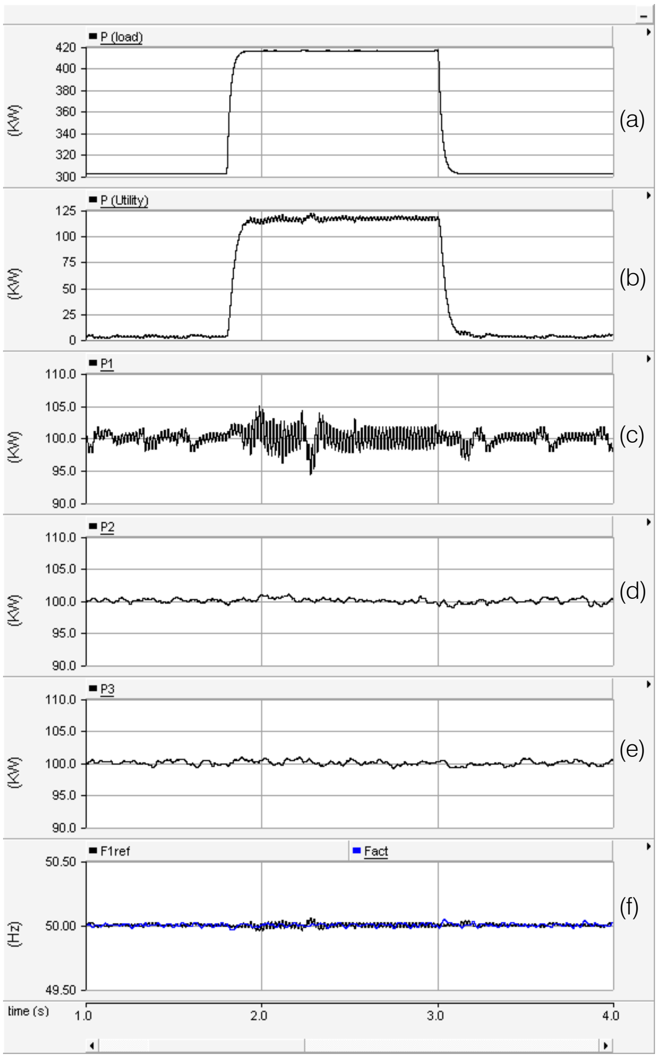


Figure 7: Active power of: (a) load, (b) utility, (c) first DG unit, (d) second DG unit, (e) third DG unit, and (f) frequency of the microgrid during the grid-connected mode.

b) Transition from gird-connected mode to islanded mode

At t = 4 sec, the static transfer switch disconnects the microgrid from the main grid. Consequently, the microgrid transits to islanded mode. Figs. 9 and 10 show the active and reactive powers of different DG units in the microgrid during transition incident. As seen, the VF control of inverter one during both grid connected and islanded modes of operations offered a smooth transition without the need for detecting the islanding incident. This action provides reliable and continuous operation of the autonomous microgrid.

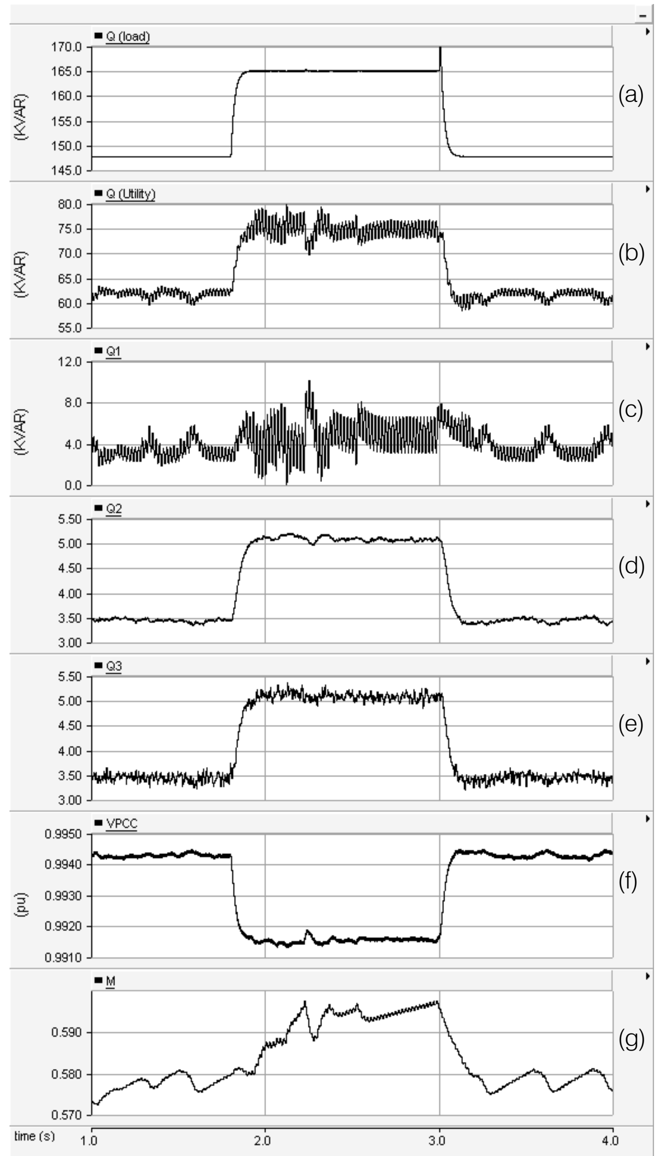


Figure 8: Reactive power of: (a) load, (b) utility, (c) first DG unit, (d) second DG unit, (e) third DG unit, (f) PCC voltage, and (g) modulation index of the first DG inverter during the grid-connected mode.

c) Islanded mode

In islanded mode, the total power demand of the load has to be supplied by the DG units while regulating the system frequency and voltage. Figs. 11 and 12 illustrate the dynamic behavior of the different DG units in the microgrid. Since the PCC voltage decreases after islanding, as indicated Fig. 10(f), the droop based controllers of the three DGs units increase their reactive power injection to the microgrid as depicted in Fig. 12. In addition, the reduction in PCC voltage results in a little reduction of the load power as shown in Fig. 11(a). In proportional, the injected active power

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from the DG units are decreased as demonstrated in Fig. 11(c), (d), and (e). In turn, the frequency is lightly increased above 50Hz as shown in Fig. 10(f) and Fig.11(f).

To evaluate the dynamic performance of the proposed microgird system, the load is suddenly increased, at t=6.5 s, similar to that of the grid-connected case and last for two seconds. As shown in Figs. 11 and 12, the system is succeeded again to track the dynamic load change by increasing the DG units output power while maintaining system frequency and voltage within their permissible limits. In addition, equal power sharing between the DG units is demonstrated from the results. Finally, the system smoothly returns back to its initial operating conditions when the sudden load is removed.

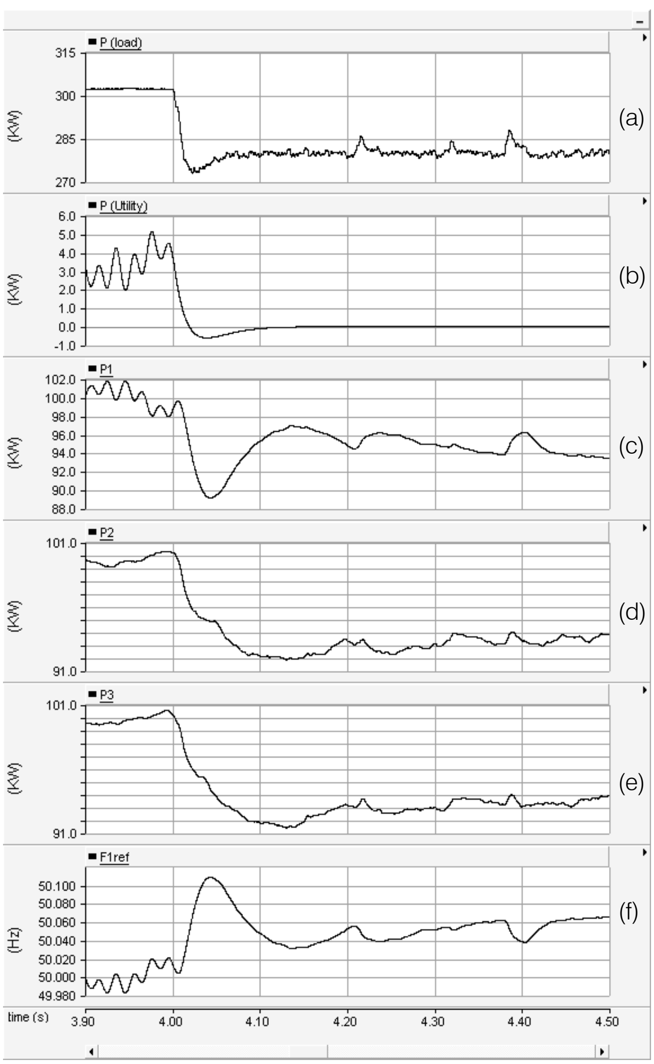

Figure 9: Active power of: (a) load, (b) utility, (c) first DG unit, (d) second DG unit, (e) third DG unit, and (f) frequency of the microgrid during the transition to islanding mode.

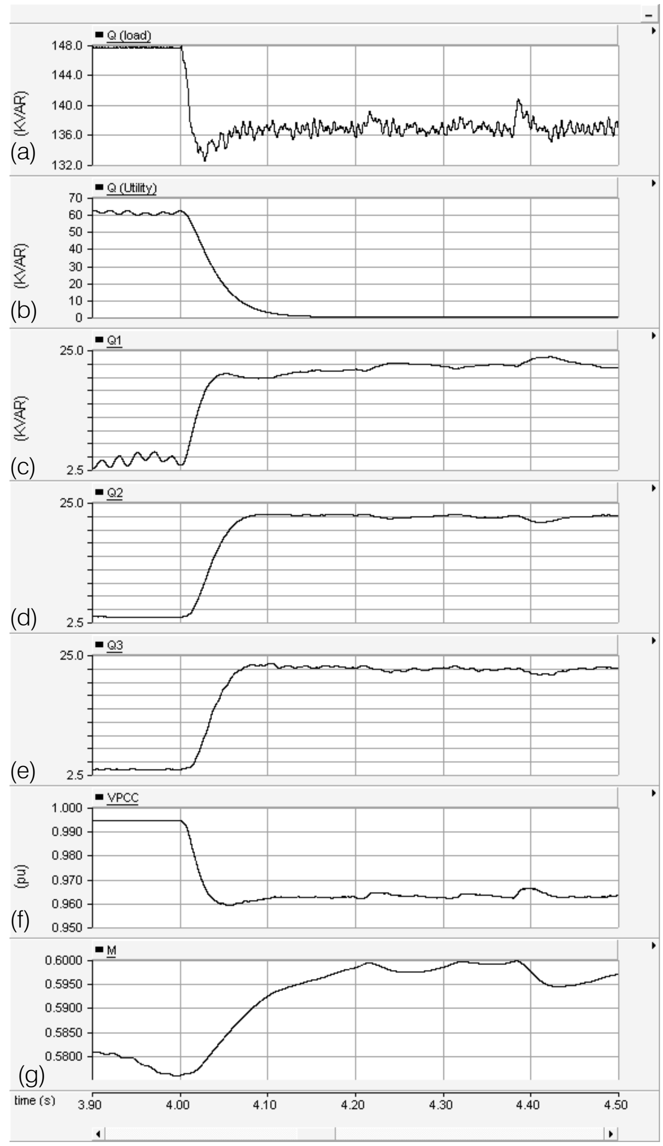

Figure 10: Reactive power of: (a) load, (b) utility, (c) first DG unit, (d) second DG unit, (e) third DG unit, (f) PCC voltage, and (g) modulation index of the first DG inverter during the transition to islanding mode.

VI. Conclusion

The control strategy of the DG interface system greatly influences the microgrid performance. In this paper, the droop characteristics of frequency-versus-active power and voltage-versus-reactive power are adapted to control three identical DG units in a microgrid. One inverter is set to operate in VF control mode, while the other two inverters are controlled by PQ mode during grid-connected and islanded operation of the microgrid. The VF controlled DG unit of the proposed microgrid system has the capability of providing smooth transition from grid-connected to islanded mode without the need to wait for the islanding detection signal or mode switching. This action results in autonomous operation of the microgrid and enhancing the system reliability. Computer simulations using PSCAD/EMTDC are carried out to study the effectiveness of the proposed control approach under dynamic loading conditions during both islanded and grid-connected modes. Simulation results show that the proposed system succeeded in regulating the voltage and the frequency of the microgrid while, preserving the required load sharing among DG units.

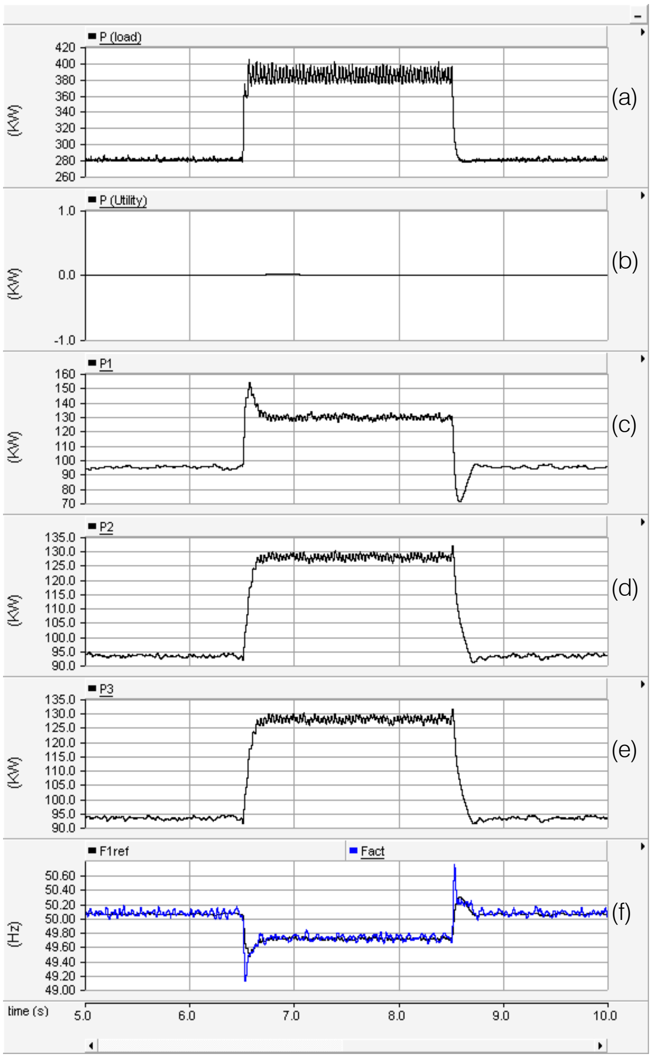

Figure 11: Active power of: (a) load, (b) utility, (c) first DG unit, (d) second DG unit, (e) third DG unit, and (f) frequency of the microgrid during the islanding mode.

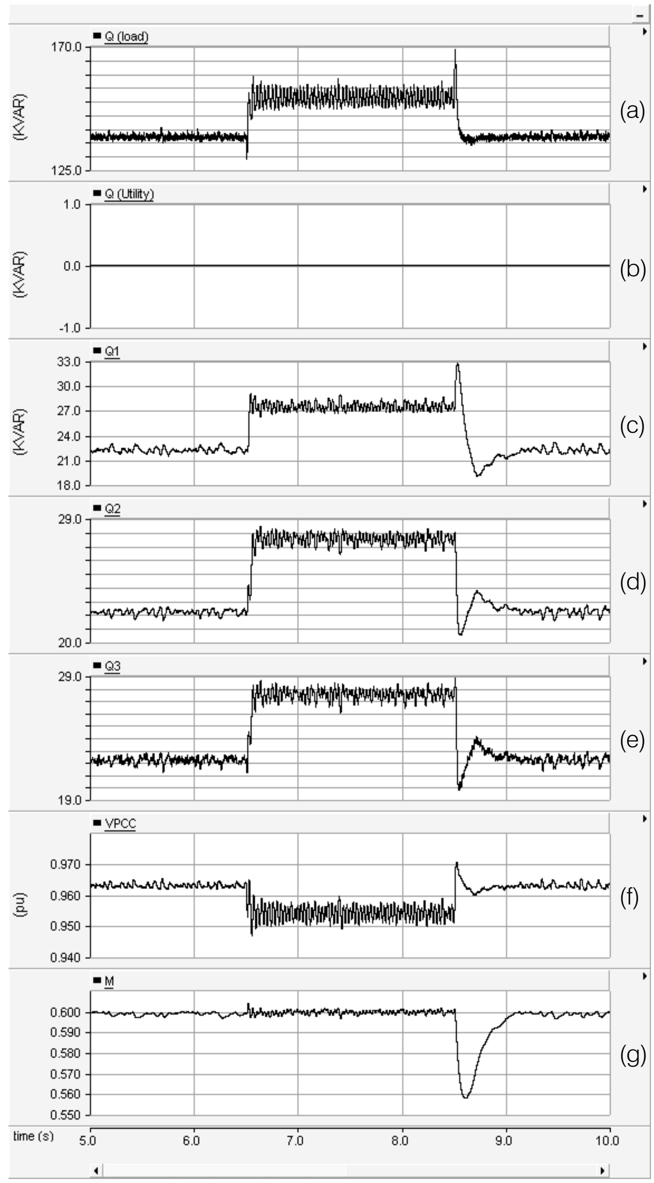

Figure 12: Reactive power of: (a) load, (b) utility, (c) first DG unit, (d) second DG unit, (e) third DG unit, (f) PCC voltage, and (g) modulation index of the first DG inverter during the islanding mode.

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