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Analysis of Voltage-Frequency (VF) Droop Control Method for AC Microgrid Application

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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. Microgrid based on droop control can achieve automatically adjust voltage and frequency, without the aid of communication, which can improve system reliability, and easy to implement micro-power and load plug and play. We designed specifically simulation circuit of the droop control strategy for a micro grid. This project utilizes droop based control method due to its advantages of great flexibility, no communication needed, high reliability, and free laying. A droop control scheme uses only PCC voltage and current to detect changes in the system and adjust the operating points of the system accordingly. The droop control uses the real power out of a generator to calculate the ideal operating frequency. Hear used droop control technique to enhance power sharing and the voltage/ frequency synchronization are real power–frequency (P–F) droop control and reactive power–voltage magnitude (Q– V) droop control. In this project, one PV unit is controlled to set the voltage and frequency of the microgrid, VF mode. Droop control is reviewed and simulations in MATLAB R2014a will be used to determine the effectiveness of the droop controller for microgrid application..

Keywords: Distributed Generators (DGs), Droop Control, Distributed Energy Storage Devices (DESUs), Microgrid(MG) and Point of Common Coupling (PCC)

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 two modes: grid-connected mode and islanded mode. 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 equilibrate 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 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 adapted 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

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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 inter connections 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.

There are many practical concerns associated with microgrid operation such as interconnection patterns among microgrids and the main grid; voltage-control strategies within a microgrid; and frequency control during islanded operation. This project surveyed on appropriate power sharing and frequency-control schemes for optimal performance of a microgrid with manifold DGs. The reason to concentrate on optimum power sharing is, for the reliable operation of microgrid to optimize the voltage profile and also to reduce losses. Appropriate power sharing in island mode can be acquired only by means of control schemes. Among various control schemes, this paper highlighted on droop control techniques. The droop control types such as conventional droop control (P-F droop control & Q-V droop control) and modified conventional droop control (P-V & Q-F droop control, V-F droop control and Angle droop) are spotted in this work.

The primary focus of droop control is to retain the fundamental frequency & the voltage magnitude of microgrid with manifold DGs in autonomous mode so that the appropriate powers are shared. Frequently used droop control technique to enhance power sharing and the voltage/ frequency synchronization are real power–frequency (P–F) droop control and reactive power–voltage magnitude (Q– V) droop control. Consequently its implementation is simple and it empowers decentralized control of manifold distributed generations (DGs) [12]. Previous studies on the use of droop control within the context of controlling distributed generation focus on the idea those inverters will tie the energy source into the electrical system. Studies on control schemes for power balance, fault tolerance and system stability have been conducted but focus on the control of the power electronics topology and switching schemes to obtain results.

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

$$f = f_0 + K_{pf}(P_0 - P) \qquad (1)$$

$$V = V_0 + K_{QV}(Q_0 - Q) \qquad (2)$$

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 measure active and reactive powers, respectively, K_{Pf} and K_{QV} symbolize the droop coefficients which are chosen relying on steady state performance criteria. The droop coefficients are calculated from,

$$K_p = \frac{\Delta f}{P_{max}} \quad (3)$$

$$K_Q = \frac{\Delta V}{Q} \quad (4)$$

where P_{max} and Q_{max} are the maximum active and reactive powers delivered by the inverter, respectively, Δf 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. 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(a), $f$min and Vmin identify the minimum acceptable frequency and voltage of the DG unit, respectively.

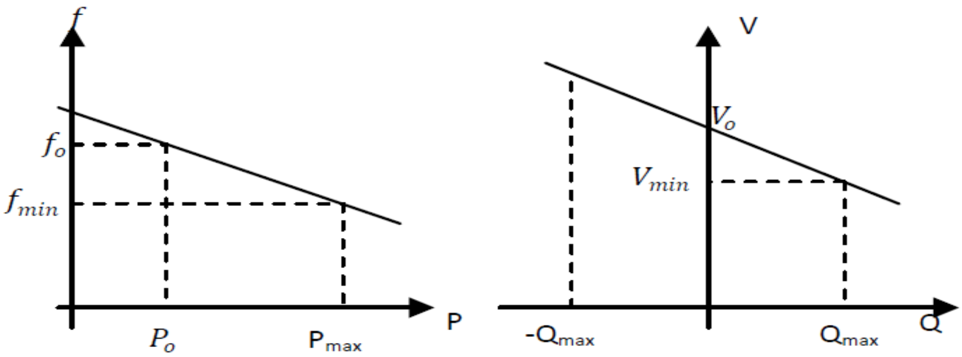

Figure 1: Conventional droop characteristics (a) P-f droop (b) Q-V droop

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,

$$\Delta P_1 K_{P1} = \Delta P_2 K_{P2} = \cdots = \Delta P_n K_{Pn} \quad (5)$$

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

$$\Delta Q_1 K_{Q1} = \Delta Q_2 K_{Q2} = \cdots = \Delta Q_n K_{Qn} \quad (6)$$

III. THE PROPOSED CONTROL SYSTEMS (VF control mode)

Two control technique approaches are used to operate the inverter; active-reactive power (PQ) control mode and voltage-frequency (VF) control mode. The inverters are usually operated in PQ mode when the microgrid 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

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(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.

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. 2. 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.

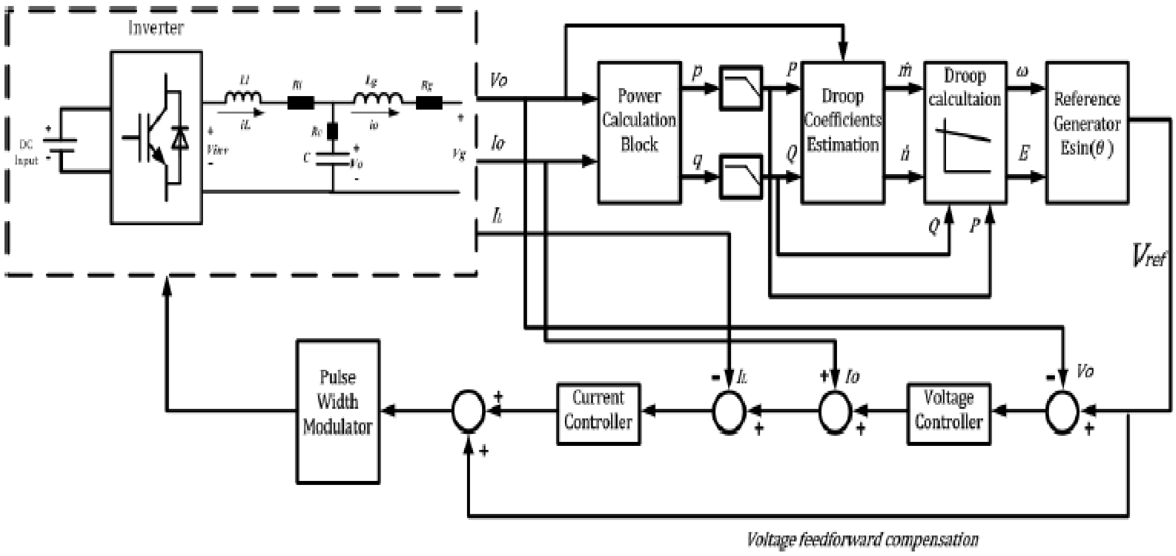

Figure 2: Droop based control system for the VF inverter

Block diagram of the proposed droop control scheme is shown in figure 2. If this block diagram is compared to the block diagram of traditional droop control based inverters in or in some other articles, then the only prominent difference will be the droop coefficients estimation block. The traditional droop control scheme uses only fixed droop values for their droop control mechanism regardless of any change in output active and reactive power demand. While this thesis work has proposed a new droop control technique and this new estimated droop control block uses an online estimation mechanism for droop values rather than using fixed values (conventional method) and then these values are adapted by droop control block to control active and reactive power flow.

VI. SIMULATION RESULTS

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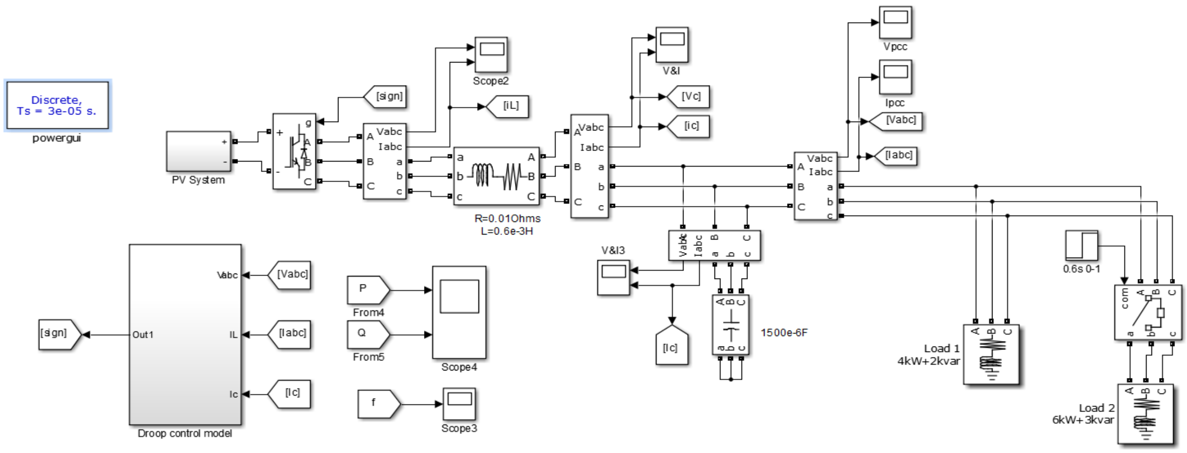


Figure 3: Single line diagram of the proposed microgrid system

Fig. 3 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.

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. The microgrid system presented in Fig. 3 is simulated using the MATLAB R2014a 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. 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. 4(c) shows the reactive power fed from the first DG unit, controlled in VF mode. These results reveal the success of the proposed droop based control strategy in providing accurate performance for the DG units during grid connected mode.

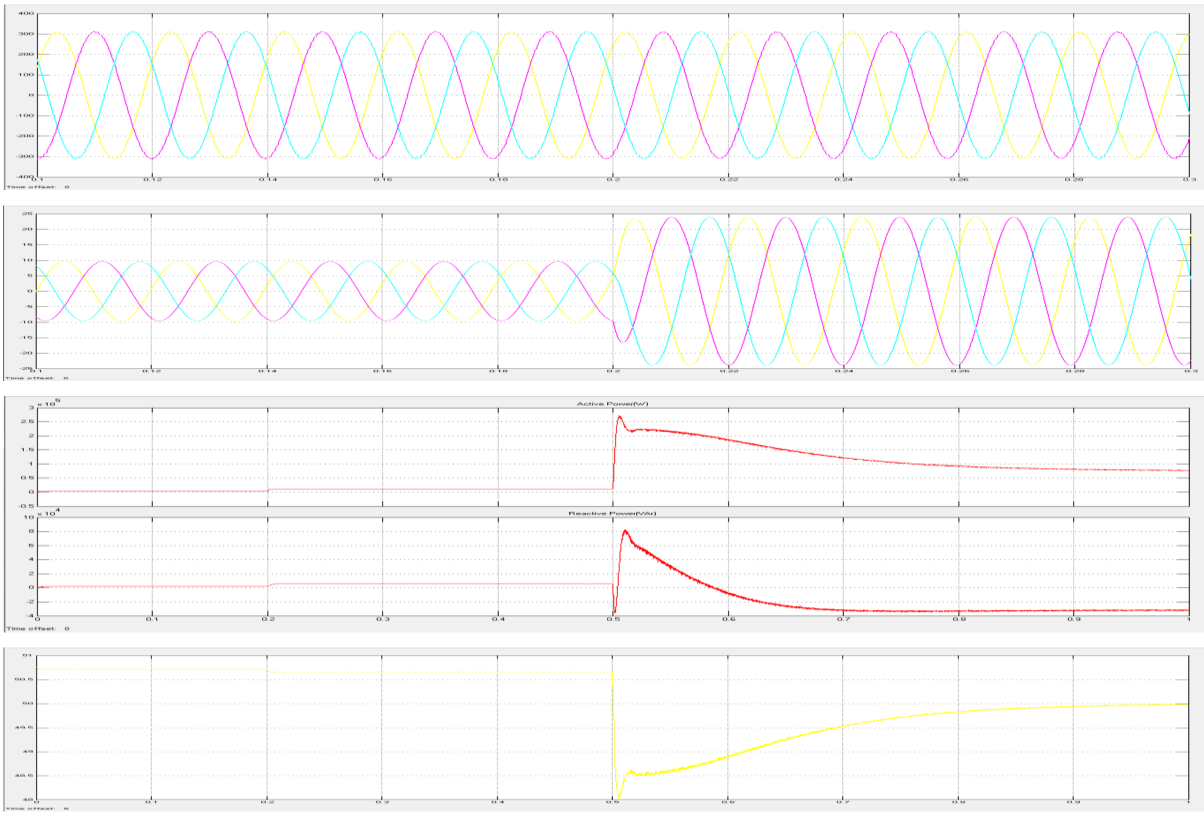
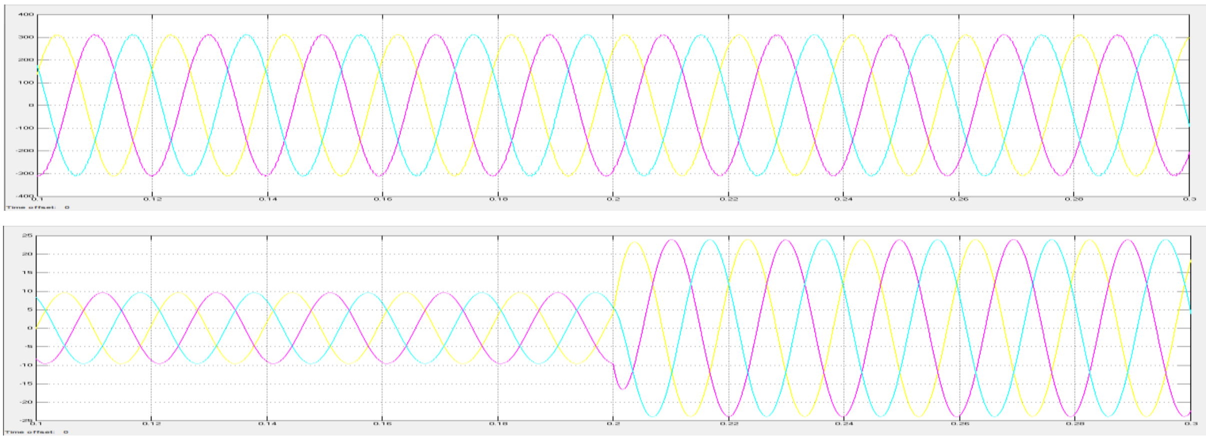


Figure 4: (a) PCC voltage, (b) load current, (c) active and reactive power sharing & (d) frequency of the microgrid during the grid-connected mode.

b) 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. Since the PCC voltage constant after islanding, as indicated Fig. 5(a), the droop based controllers of the three DGs units increase their reactive power injection to the microgrid.



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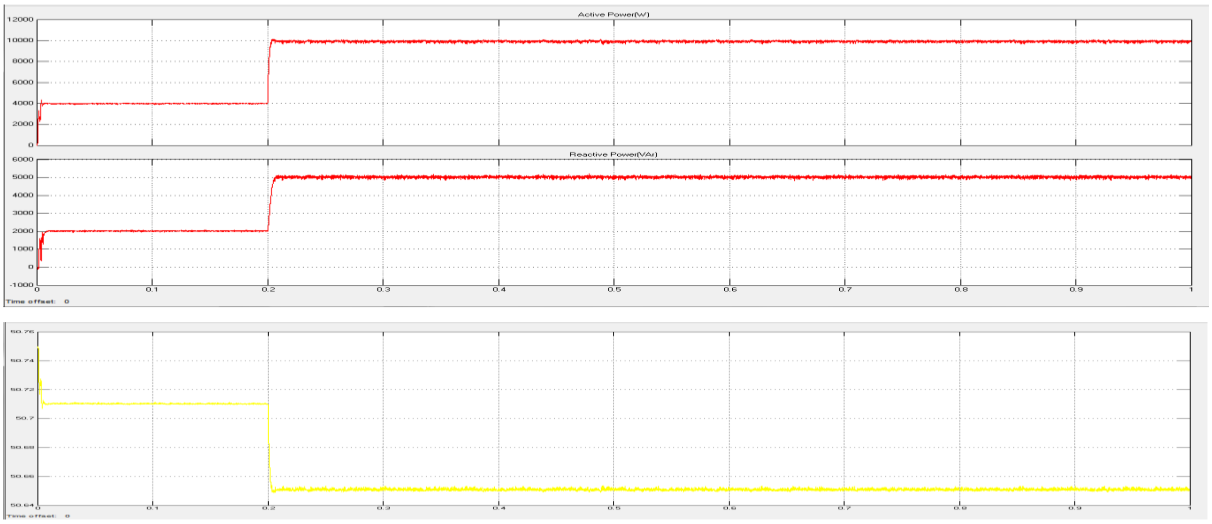

Figure 5: (a) PCC voltage, (b) load current, (c) active and reactive power sharing & (d) frequency of the microgrid during the Islanded mode

System quantities	Values
Nominal Voltage of PCC	311V
Line impedance	R=0.01Ohms L=0.6e-3H
Nominal Frequency	50 Hz
DC Link Voltage (PV System)	$V_{dc} = 800V$
Droop Coefficients	$K_{pf} = 1e\text{-}5$ $K_{QV} = 3e\text{-}4$
Load Parameter	Load 1 4kW+2kvar Load 2 6kW+3kvar Unbalance Load 3 $Z_{la} = 30 + j62{:}8\,\Omega$; $Z_{lb} = 40 + j78{:}5\Omega$; $Z_{lc} = 50 + j50{:}24\,\Omega$

Table 1.The system parameters

V. CONCLUSION

The new 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 along with Modified droop control (V-F droop control) are adapted to control performance of AC 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. Also properly share the load power among all the parallel inverters and having constant PCC Voltage in both condition. This action results in autonomous operation of the microgrid and enhancing the system reliability. Simulation results show that the proposed system succeeded in regulating the voltage and the frequency of the microgrid.

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