Seamless Transition between Islanded and Grid Connected Three-Phase VSI-based Microgrids

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Abstract-Microgrids (MGs) are the emergent solution to overcome the current electricity demand. The MGs provide the facility to operate in both isolated and grid-connected modes. For both operating modes, Distributed Generation (DG) inverters are operating under grid forming or grid following control modes. During mode switching, the MG experiences enormous fluctuations, which occur due to the unidirectional islanding event. This paper presents a control strategy by using the modified power control scheme, current controller, and DC linked voltage controller scheme to ensure the operational mode transfer smoothly from the grid-connected to the islanded mode and vice versa. The proposed control scheme is applied to a three-phase distributed energy resource-based MG system with fixed loads. The simulation results validate the effectiveness of the control technique while tested at the point of common coupling and also at the time of mode transfer.

Keywords-grid forming; grid following; seamless transition; droop control

I. INTRODUCTION

Microgrids (MGs) provide a promising solution to overcome the electricity shortage in a reliable way. Distributed Generation (DG) utilized in MGs is pretty common nowadays. DGs like solar, wind, and Combined Heat Power (CHP), that are attached to Grid Connected Mode (GCM) or Islanded Mode (IM) protocols with connecting loads have many advantages over the traditional grid [1-2]. Although the MGs provide an alternative with bidirectional communication, there are some control issues, particularly regarding power, voltage, and frequency deviations that may occur when the MG changes its operational mode from GCM to IM [3-4]. Generally, the control schemes in terms of transition are divided into two categories. The first one is the single control scheme for regulating voltage [5-10], which is non-linear theory-based such as the Lyapunov-based control. The second one is the control with two schemes with pre-allotted intents [11-16], based on the model predictive control scheme. However, in both control techniques, high computational values and the complexity of the schemes do not allow efficient implementation of the control schemes. On the contrary, linear control schemes are less complicated and can be easily implemented without any complex computational burden [5]. Feedback and feed-forward procedures can be a good alternative to make the control structure simple and convincing

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with the provision of seamless transition either from GCM to IM or IM to GCM [17-18]. During the mode transition from grid following to grid-forming mode, frequency deviations may occur which may lead the MG system to instability. Moreover, voltage and current errors may also occur during the mode transition, while the voltage during the switching process must follow the IEEE standard criteria [19]. A proper synchronization algorithm is needed in order to have smooth switching from one mode to another. Switching between modes can be done with the help of an operator or automatically. In the first case, the control of transition intensity can be controlled with the MG functional point's readjustment. In the second case, unidirectional islanding is used to readjust the operational points of the MG, but faces various issues related to frequency and voltage errors and system stability concerns. In [8-9, 14, 16, 20-23], different solutions have been presented to compensate the errors that occur during transition. Most of the control solutions are based on switching, but the droop-based control scheme [8, 19] does not need any kind of switching. This control scheme can be used for the transition from IM to GCM or GCM to IM.

In [5, 9, 16, 21], nonlinear control schemes with adaptive feedback stepping technique have been introduced to solve the voltage frequency deviations and were applied to both operation modes. The Model Predictive Control (MPC) technique [5] is applied to the single phase multi bus inverter-based MG system with automatic tuning functionality for seamless transition. The interaction between different inverter controllers used in the same system still needs to be investigated because during the IM, frequency and power sharing errors occur. Hence, the damping ratio needs to be improved in this case. In order to achieve smooth operation the frequency deviations are mitigated by utilizing the virtual inertia [23]. Virtual Synchronous Generators (VGSs) with droop control are used to improve the dynamic performance of the system. However, active power sharing accuracy is not achieved [24]. If the droop control parameters are selected accurately as per system requirements, the active power sharing errors can be controlled and the control strategy could be more efficient as compared to the control using VGS [25]. The Proportional Resonant (PR) controller is implemented to mitigate the frequency errors during mode transition in [26]. Moreover, phase angle correction with autonomous operation was also ensured in the control scheme. Modified PQ control technique with tracking V/f controller [27-28] needs constant communication between the IM and the main grid. A two separate synchronization compensator-based control system was implemented in [29] to mitigate the voltage and phase angle deviations but the system stability was not ensured. To get an effective MG operation during mode switching, a fast seamless transient control technique should be implemented which will not compromise the permissible standards in terms of power sharing accuracy, voltage, and frequency.

This paper presents a control strategy that uses a modified power control scheme, consisting of the current controller and a DC linked voltage controller scheme to ensure the operational mode transfer smoothly from GCM to IM transitions and vice versa. The proposed control scheme is applied to a three phase Distributed Energy Resources-based MG system with fix loads. The simulation results validate the effectiveness of the control technique in terms of voltage, frequency, and power sharing behavior at the Point of Common Coupling (PCC) and at the time of mode transfer.

II. MICROGRID CONFIGURATION AND OPERATION

A three phase MG system with three DGs is shown in Figure 1. A constant DC source is connected separately to all the DGs. An LCL filter is connected with each DG and the loads are connected to the PCC. All the Voltage Source Inverters (VSIs), explored for voltage, power sharing, and frequency, are connected to the main grid with the help of a circuit breaker installed just after the PCC.

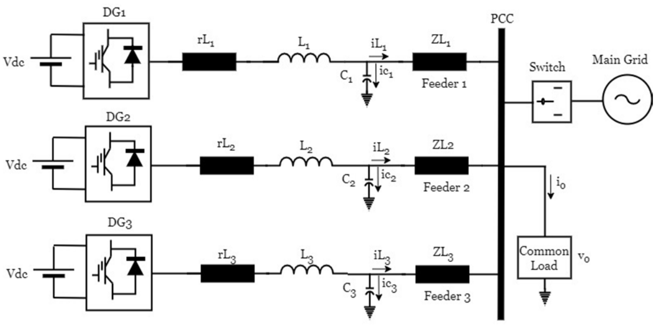

Fig. 1. A microgrid with three DG inverters connected in parallel.

A common load is connected to the PCC and the parallel connected inverters can be detached from the main grid for IM operation. GCM and IM operational modes are further explained below.

A. Grid Connected Mode

Generally the GCM control is implemented in a grid-feeding control scheme. A control structure based on a PI controller with a dq reference frame work is established by using the convention current control structure [30-31]. The current control structure block arrangement is shown in Figure 2.

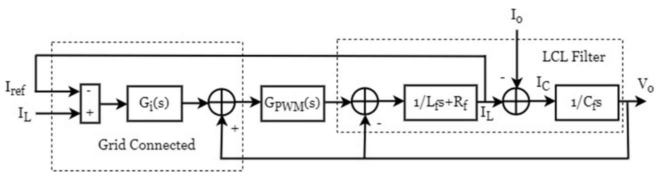

Fig. 2. Current control.

B. Islanded Mode

During the IM control mode, when a change occurs between frequency and voltage because they are designed separately for load and generation, ultimately the P and Q sharing accuracy is decreased [30-31]. It is therefore essential to overcome this mismatch according to the load requirements. In a parallel connected MG system, when multiple DGs are connected in the same network, the load sharing also needs to be equally distributed to all the DGs as per their capacities so the droop characteristics need to be incorporated in the system to cope up with the load sharing issue as shown in Figure 3.

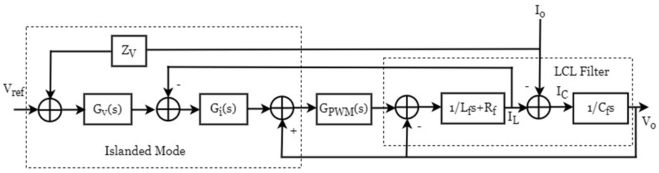

Fig. 3. Voltage control.

Active and reactive powers are calculated by using LPF with very small cutoff frequency. The block diagram for grid forming is shown in Figure 3. The output voltage can be expressed as:

$$V_o = G(s)V_{ref} - Z_o I_o \quad (1)$$

III. THE PROPOSED CONTROL SCHEME

The control loops consists of a droop controller, a current controller, and a linked voltage controller. For these controllers, the control design procedure is given below which is further categorized into GCM and IM control schemes.

A. Modified Power Control

Droop control technique provides P-ω and Q-f droop control with decentralized and communication free facilities. The active and reactive powers of each inverter are depending on voltage and frequency at the PCC which is managed by conventional droop control in the IM mode control scheme. Moreover, another PI controller is also applied for ensuring proper tracking of V_{ref}. The power calculation mechanism is given in Figure 4.

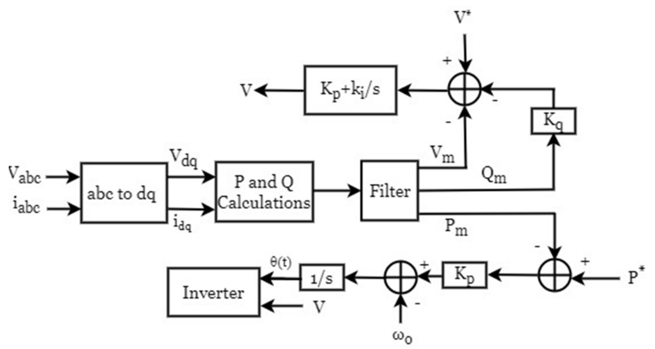

Fig. 4. Active and reactive power calculations.

B. Current Controller

Higher bandwidth is required in the design of the current controller. It is preferred to get faster response, so low switching frequency is needed. In the closed loop system, the bandwidth is taken 10 times smaller than the switching frequency. The block diagram in Figure 5 shows the current controller configuration. The transfer function for the current control strategy is:

$$\frac{G_c(s)G_{inv}(s).\frac{1}{R_f + sL_f}}{\frac{1}{R_f + sL_f}} = \frac{1}{\tau s + 1} \quad (2)$$

where τ can be considered as a constant of the PI controller transfer function G_c.

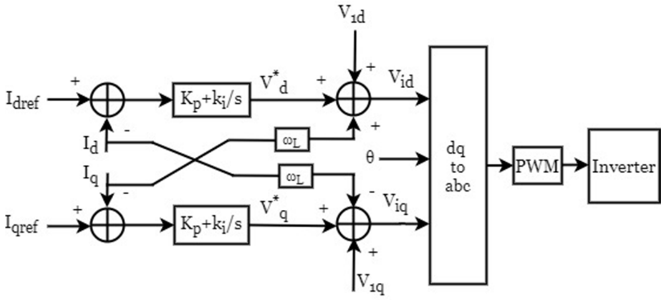

Fig. 5. Current controller.

C. DC Linked Voltage Controller

Both side inverter currents are equalized for the voltage DC linked controller before designing the controller:

$$V_{dc}I_{dc} = 3I_{ph}V_{ph} \quad (3)$$

where $I_d = \sqrt{2}I_{rms}$ and can be is expressed as:

$$I_{dc} = \sqrt{3/2}\,\frac{V_L - L}{V_{dc}} I_d = K_{DC}I_d \quad (4)$$

and I_{dc} relates to the capacitor current which is given as:

$$Idc = C\frac{dV_{dc}}{dt} \quad (5)$$

So, the basic functionality of the voltage controller is to maintain the voltage. The configuration of the DC linked voltage controller is given in Figure 6.

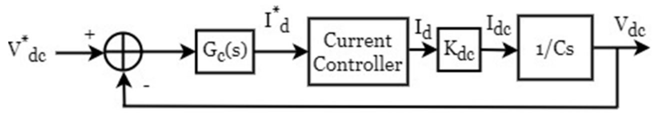

Fig. 6. DC lined voltage controller.

IV. SIMULATION RESULTS

The validation of the proposed control mechanism for the seamless transition of MGs between the two operational modes was carried out in MATLAB/Simulink. The system specifications are given in Table I, and the overall MATLAB/Simulink model is given in Figure 11.

A. Case 1: Grid Connected Mode

In the GCM control scheme it is necessary for a MG system to operate in constant PQ mode. To attain constant PQ, the inverter is operated in dq-reference framework to get current control. In the transformation dq-abc, the observation time scale is very high and so it is preferred to consider the average model to get the voltage at the abc domain. In the GCM mode, the imbalance occurs due to the generated power and load at the point of connection and the excess power is supplied by the DC bus capacitor. The occurring reduction in the bus voltage due to the supply needs to be maintained again. However, an inner loop is established to balance the DC bus voltage and current controller.When the breaker of the proposed model is closed towards the GCM, the grid connection mode operation is established. In GCM the voltage and frequency at the PCC must always be in a fixed allowable range. As shown in Figure 7(a), voltage and frequency are in the permissible range. The frequency is almost constant throughout the operation from t=0 to t=10s. At t=0.8s, voltage maintains the fixed magnitude. The inverter current is successfully tracking the reference current as shown in Figure 7(b). The active and reactive powers are shared accurately as shown in Figure 7(c) just after some delay at t=0.6s.

(a)

(b)

(c)

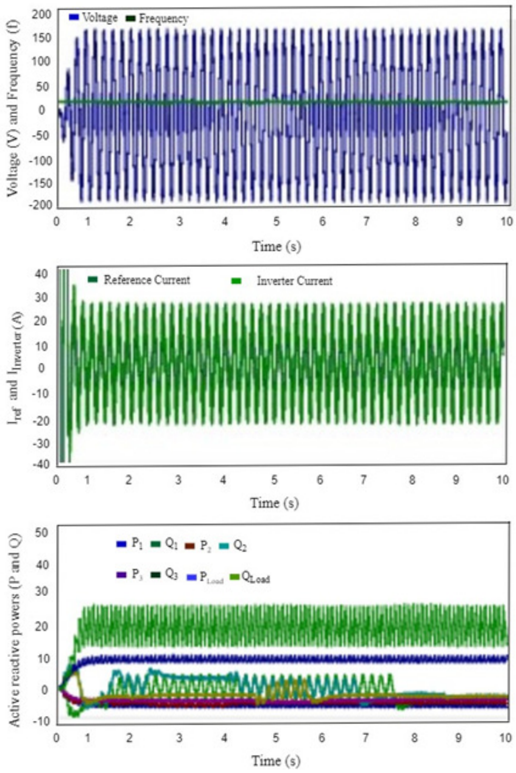

Fig. 7. GCM results: (a) Voltage and frequency, (b) reference and inverter currents, (c) active and reactive powers.

B. Case 2: Transition between GCM and IM

This section shows the results when transition occurs from GCM to IM. The PCC voltage and frequency waveform are shown in Figure 8(a). At t=5s there is a little deviation which is compansated in a very short time interval. The same happens in the case of deviating frequency. Figure 8(b) shows the behavior of the currents. $I_{inverter}$ decreases at t=5s which is cuccessfully tracked by the reference current. Figure 8(c) shows the power sharing accuracy of the DG inverters durreng the change in the operational mode. From t=5s the active and reactive powers are shared equally.

(a)

(b)

(c)

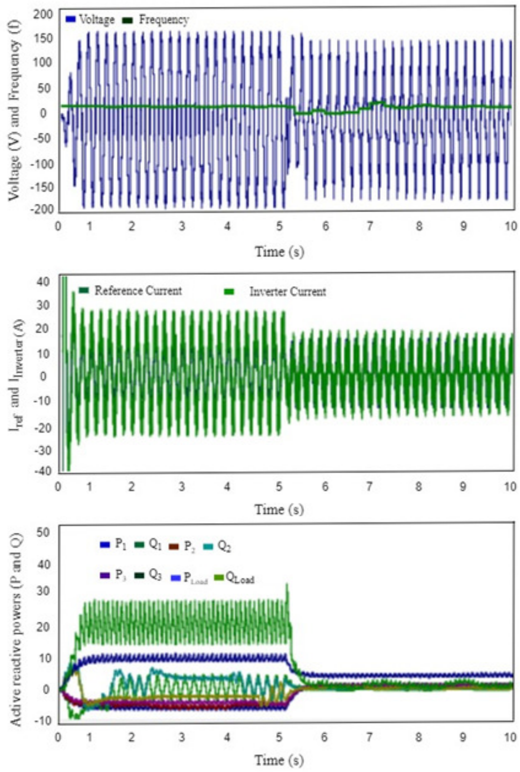

Fig. 8. Transition from GCM to IM: (a) Voltage and frequency, (b) reference and inverter currents, (c) active and reactive powers.

(a)

(b)

(c)

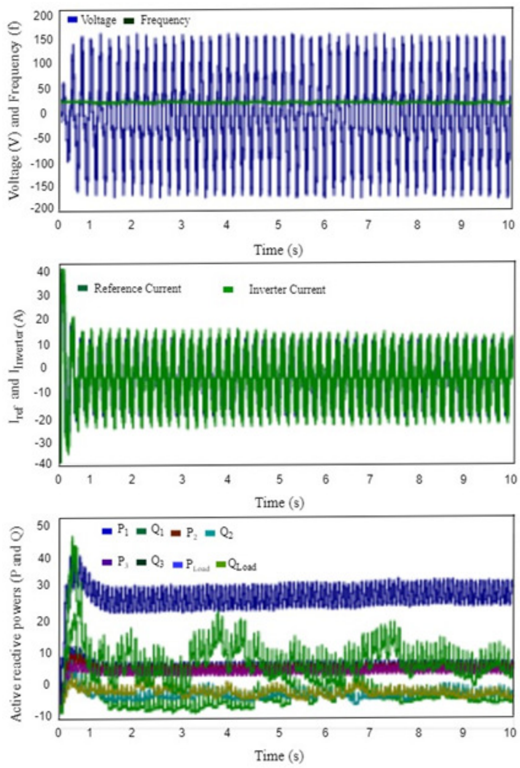

Fig. 9. IM results: (a) Voltage and frequency, (b) reference and inverter currents, (c) active and reactive powers.

C. Case 3: Islanded Mode

In Case 3, the IM of the MG is discussed with respect to the behavior of voltage, current, and powers. As shown in Figure 9(a), voltage and frequency are in the permissible range. The frequency is constant throughout the simulation and the voltage magnitude is constant just after 0.8s. The inverter current is successfully tracking the reference current as shown in Figure 9(b). Figure 9(c) shows the PQ sharing in IM.

D. Case 4:Transition from IM to GCM

It is shown in Figure 10(a) that when the reconnection of the MG from IM to GCM takes place, there is a small deviation in the voltage waveform and the frequency shows some deviations before returning to a smooth level just after *t*=5s. Figure 10(b) shows the behavior of the inverter and reference currents which are tracking each other successfully at *t*=5s. In Figure 10(c) the power sharing accuracy of the proposed control scheme is shown when the MG is shifted to GCM from IM operation. The results show that the active and reactive powers are shared accurately from *t*=5s.

TABLE I. SYSTEM PARAMETERS

Parameter	Value	Parameter	Value
V_{DC}	400 V	Load	130 Ω,0.22 H
f_{Sw}	10kHz	Z_{grid}	0.4+j0.6 Ω
f	50 Hz	C	15 μF
Z_{L1}, Z_{L2} and Z_{L3}	0.3+j0.5 Ω, 1.3+j2.65 Ω & 2.4+j3.54 Ω		

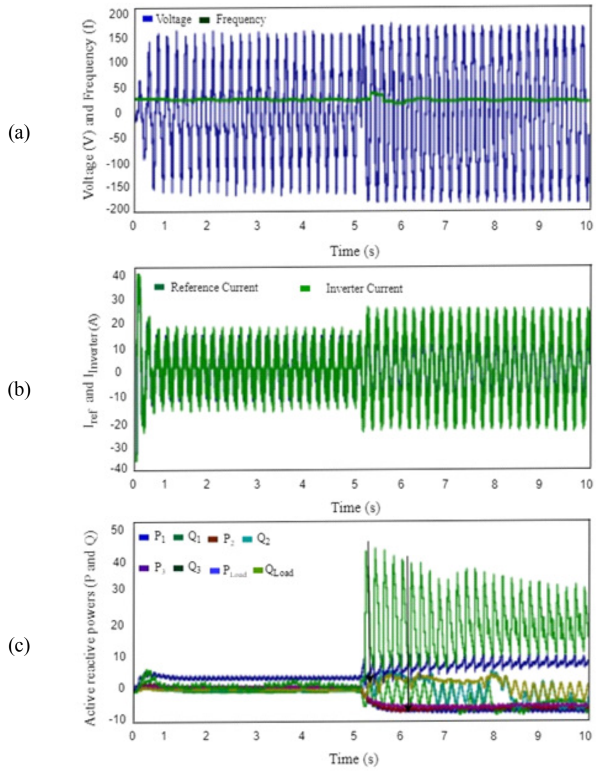

Fig. 10. Transition from IM to GCM: (a) Voltage and frequency, (b) reference and inverter currents, (c) active and reactive powers..

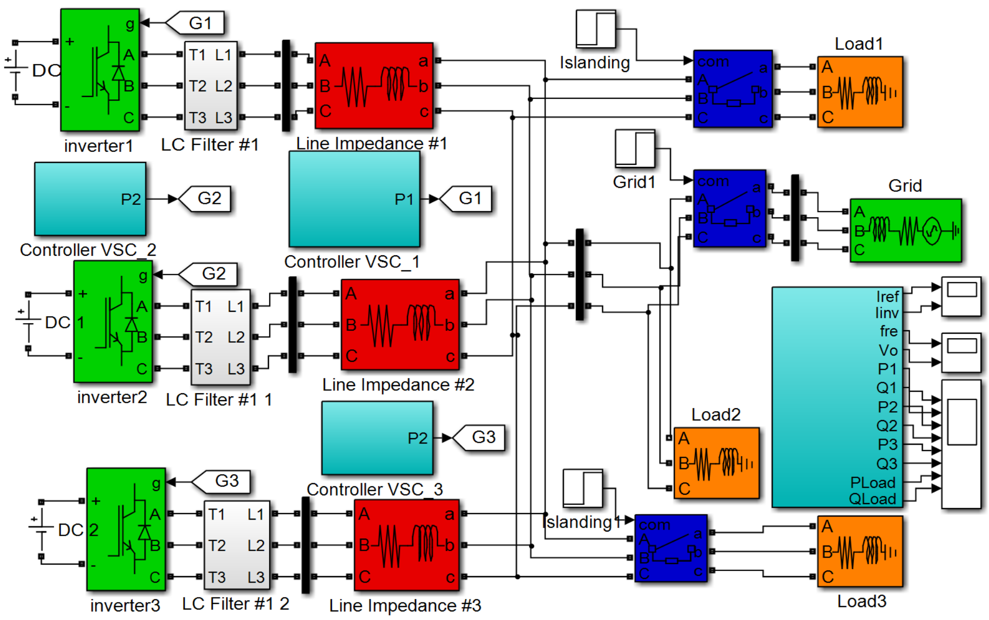

Fig. 11. MATLAB/Simulink model.

V. CONCLUSION

In this paper, the transition from GCM to IM and vice versa was studied in detail. A simple approach by modifying the power, current, and DC linked voltage controllers was presented. A smooth transfer from one operational mode to another was conducted without affecting the active and reactive power sharing among the DG inverters connected in parallel and the voltage, frequency, reference current, and inverter current the at the PCC have been explored. The proposed control scheme is applied to a three Distributed Energy Resource system with fixed load. The simulation results validate the effectiveness of the control scheme in terms of voltage, frequency, and power sharing behavior at the PCC and at the time of mode transfer.

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