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A Multi-loop Control Strategy for Three Phase Inverter Operation in Distribution Generation

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ABSTRACT: This paper presents a cohesive control strategy that enables both islanded and grid-tied operations of three-phase inverter in distributed generation, with no need for switching between two corresponding controllers or critical islanding detection. The pro-posed control strategy composes of an inner inductor current loop, and a new voltage loop in the synchronous reference frame. The inverter is regulated as a current source just by the inner inductor current loop in grid-tied operation, and the voltage controller is automatically activated to regulate the load voltage upon the occurrence of islanding. Furthermore, the waveforms of the grid current in the grid-tied mode and the load voltage in the islanding mode are distorted under nonlinear local load with the conventional strategy. And this issue is addressed by proposing a unified load current feed forward in this paper. Additionally, this paper presents the detailed analysis and the parameter design of the control strategy. Finally, the effectiveness of the proposed control strategy is validated by the simulation.

KEYWORDS: Distributed generation (DG), grid tie mode, islanding, load current, phase locked loop (PLL), three-phase inverter, cohesive control.

I. INTRODUCTION

Distributed generation (DG) is promising as a feasible alternative when renewable or nonconventional energy resources are available, such as wind turbines, solar, fuel cells. Most of these resources are connected to the utility through power electronic interfacing converters, i.e., three-phase inverter. Moreover, DG is a suitable form to offer high reliable electrical power supply, as it is able to operate either in the grid-tied mode or in the islanded mode.

In the grid-tied operation, DG deliveries power to the utility and the local critical load. Upon the occurrence of utility outage, the islanding is formed. Under this circumstance, as soon as possible the DG must be tripped and cease to energize the portion of utility. However, in order to improve the power reliability of some local critical load, the DG should disconnect to the utility and continue to feed the local critical load. The load voltage is key issue of these two operation modes, because it is fixed by the utility in the grid-tied operation, and formed by the DG in the islanded mode, respectively. Therefore, upon the happening of islanding, DG must take over the load voltage as soon as possible, in order to reduce the transient in the load voltage. And this issue brings a challenge for the operation of DG.

Droop-based control is used widely for the power sharing of parallel inverters, which is called as voltage mode control in this paper, and it can also be applied to DG to realize the power sharing between DG and utility in the grid-tied mode. In this situation, the inverter is always regulated as a voltage source by the voltage loop, and the quality of the load voltage can be maintained as constant during the transition of operation modes. However, the limitation of this approach is that the dynamic performance is poor, because the bandwidth of the external power loop, realizing droop control, is much lower than the voltage loop. Moreover, the grid current is not controlled directly, and the issue of the inrush grid current during the transition from the islanded mode to the grid-tied mode always exists, even though phase-locked loop (PLL) and the virtual inductance are adopted.

The hybrid voltage and current mode control is a popular alternative for DG, in which two distinct sets of controllers are employed .The inverter is restricted to work as a current source by one sets of a controller in the grid-tied mode, while as a voltage source by the other sets of controller in the islanded mode. As the voltage loop or current loop is just utilized in this approach, a nice dynamic performance can be achieved. Besides, the output current is directly controlled in the grid-tied mode, and the inrush grid current is almost eliminated.

In the hybrid voltage and current mode control, there is a need to switch the controller when the operation mode of DG is changed. During the interval from the occurrence of utility outage and switching the controller to voltage mode, the load voltage is neither fixed by the utility, nor regulated by the DG, and the length of the time interval is determined by the islanding detection process. Therefore, the main issue in this approach is that it makes the quality of the load voltage heavily reliant on the speed and accuracy of the islanding detection method.

Another problem associated with the abovementioned approaches is the waveform quality of the grid current and the load voltage under nonlinear local load. In the grid-tied mode, the output current of DG is generally desired to be pure sinusoidal. When the nonlinear local load is fed, the harmonic component of the load current will fully flow into the utility.

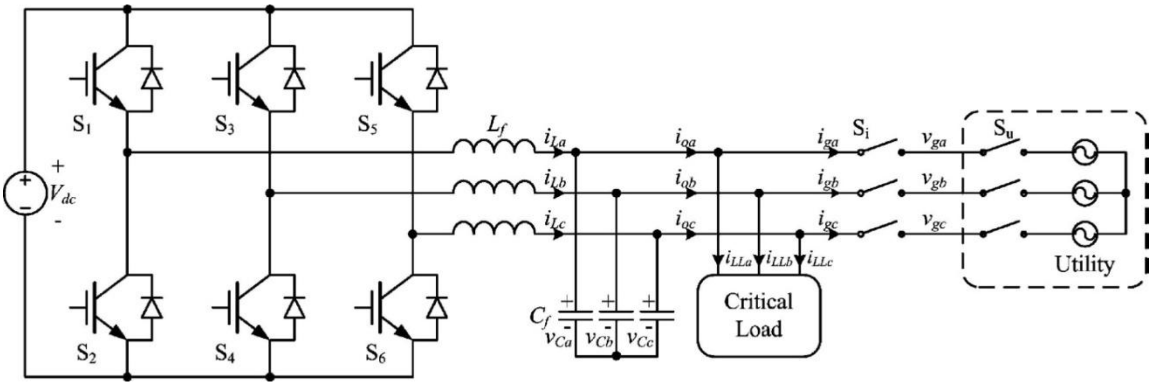

Fig. 1. Schematic diagram of the DG based on the proposed control strategy.

The voltage mode control is improved by controlling the DG to emulate a resistance at the harmonic frequency, and then the harmonic current flowing into utility can be mitigated. In the islanded mode, the nonlinear load may distort the load voltage; the quality of load voltage can be improved by using some control schemes like resonant controllers, multi loop control method, sliding mode control. However, existing control strategies dealt on either the quality of the grid current in the grid-tied mode or load voltage in the islanded mode, and improving both of them by a unified control strategy is not often.

This paper proposes a unified control strategy that avoids the abovementioned problems. First, the inductor current loop is employed to control the three-phase inverter in DG to act as a current source with a given reference in the synchronous reference frame (SRF). Second, a novel voltage controller is used to supply reference for the inner inductor current loop, where a proportional-plus-integral (PI) controller and a proportional (P) controller are employed in *D*-axis and *Q*-axis, respectively. In the grid-tied operation, the load voltage is dominated by the utility, and the voltage compensator in *D*-axis is saturated, while the output of the voltage compensator in *Q*-axis is forced to be zero by the PLL. Therefore, the reference of the inner current loop cannot regulated by the Voltage loop and the DG is controlled as a current source just by the inner current loop. Upon the occurrence of the grid outage, the load voltage is no more determined by the utility, and the voltage controller is automatically activated to regulate the load voltage. These happen naturally, and, thus the proposed control strategy does not need a forced switching between two distinct sets of controllers. Further, there is no need to detect the islanding quickly and accurately, and the islanding detection method is no more critical in this approach. Moreover, the proposed control strategy, benefiting from just utilizing the current and voltage feedback control, endows a better dynamic performance, compared to the voltage mode control.

Third, the proposed control strategy is enhanced by introducing a unified load current feed forward, in order to deal with the issue caused by the nonlinear local load, and this scheme is implemented by adding the load current into the reference of the inner current loop. In the grid-tied mode, the DG injects harmonic current into the grid for compensating the harmonic component of the grid current, and thus, the harmonic component of the grid current will be mitigated. Moreover, the benefit of the proposed load current feed forward can be extended into the islanded operation mode, due to the improved quality of the load voltage.

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II.PROPOSED CONTROL STRATEGY

A. Power Stage

This paper presents a unified control strategy for a three-phase inverter in DG to operate in both islanded and grid-tied modes. The schematic diagram of the DG based on the
Proposed control strategy is shown by Fig. 1. The DG is equipped with a three-phase interface inverter terminated with a *LC* filter. The primary energy is converted to the electrical energy, which is then converted to dc by the front-end power converter, and the output dc voltage is regulated by it. Therefore, they can be represented by the dc voltage source V_{dc} in Fig. 1. In the ac side of inverter, the local critical load is connected directly.

The Fig. 1 contains two switches and represented as S_u and S_i, and their functions are different. The inverter transfer switch S_i is controlled by the DG, and the utility protection switch S_u is directed by the utility. When the utility is normal, both switches S_i and S_u are ON, and the DG in the grid-tied mode injects power to the utility. When the utility is in fault, the switch S_u is tripped by the utility instantly, and then the islanding is formed. After the islanding has been confirmed by the DG with the islanding detection scheme, the switch S_i is disconnected, and the DG is transferred from the grid-tied mode to the islanded mode. When the utility is restored, the DG should be resynchronized with the utility first, and then the switch S_i is turned ON to connect the DG with the grid.

B. Basic Idea: With the hybrid voltage and current mode control, the inverter is controlled as a current source to generate the reference power P_{DG} + j Q_{DG} in the grid-tied mode. And its output power P_{DG} + j Q_{DG} should be the sum of the power injected to the grid P_g + j Q_g and the load demand P_{load} + j Q_{load}, which can be expressed as follows by assuming that the load is represented as a parallel RLC circuit:

$$P_{load} = \frac{3}{2} \cdot \frac{V_m^2}{R} \quad (1)$$

$$Q_{load} = \frac{3}{2} \cdot V_m^2 \cdot \left(\frac{1}{\omega L} - \omega C\right) \quad (2)$$

Where v_m and ω represent the magnitude and frequency of load voltage, respectively. During the time interval from the interval from the instant of islanding happening to the moment of switching the control system to voltage control mode, the load voltage is neither fixed by the utility nor regulated by the inverter, so the load voltage may drift from normal range. And this phenomenon can be explained as below by the power relationship. During this time interval, the inverter is still controlled as a current source, and its output power is kept almost unchanged. However, the power injected to utility decreases to zero rapidly, and then the power consumed by the load will be imposed to the output power of DG. If both active power P_g and reactive power Q_g injected into the grid are positive in the grid-tied mode, then P_{load} and Q_{load} will increase after the islanding happens.

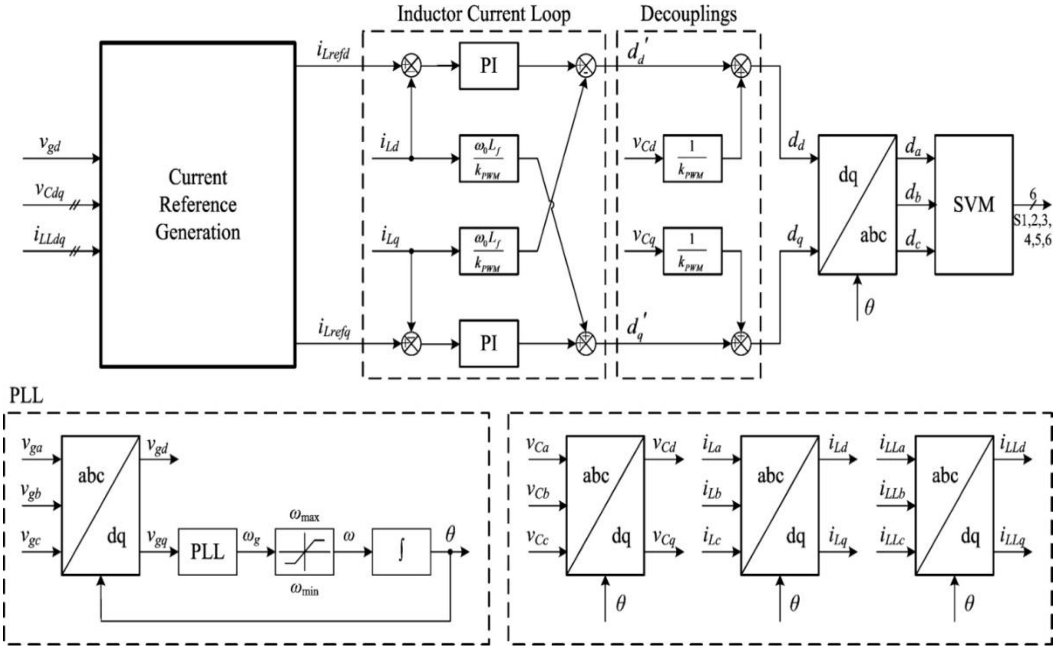


Fig. 2. Overall block diagram of the proposed multi control strategy.

With the previous analysis, if the output power of inverter $P_{DG} + jQ_{DG}$ could be regulated to match the load demand by changing the current reference before the islanding is confirmed, the load voltage excursion will be mitigated. In the proposed control strategy, the output power of the inverter is always controlled by regulating the three – phase inductor current $i_{Labc,}$ while the magnitude and frequency of the load voltage v_{Cabc} are monitored. When the islanding happens, the magnitude and frequency of the load voltage may drift from the normal range, and then they are controlled to recover to the normal range automatically by regulating the output power of the inverter.

C. Control scheme: The overall block diagram for the proposed multi loop control strategy is shown in Fig. 2. Where the inductor current i_{Labc}, the utility voltage v_{gabc} the load voltage $v_{Cabc,}$ and the load current $i_{LLabc,}$ are sensed. The three-phase inverter is controlled in the SRF, in which, three phase variable will be represented by dc quantity. The control diagram is mainly composed by the inductor current loop, the PLL, and the Current reference generation module. In the inductor current loop, the PI compensator is employed in both *D*- and *Q*-axes, and a decoupling of the cross coupling denoted by $\omega_0 L_f/K_{PWM}$ is implemented in order to mitigate the couplings due to the inductor. The output of the inner current loop d_{dq}', together with the decoupling of the capacitor voltage denoted by $1 / K_{PWM}$, sets the reference for the standard space vector modulation that controls the switches of the three-phase inverter. It should be noted that K_{PWM} denotes the voltage gain of the inverter, which equals to half of the dc voltage in this paper.

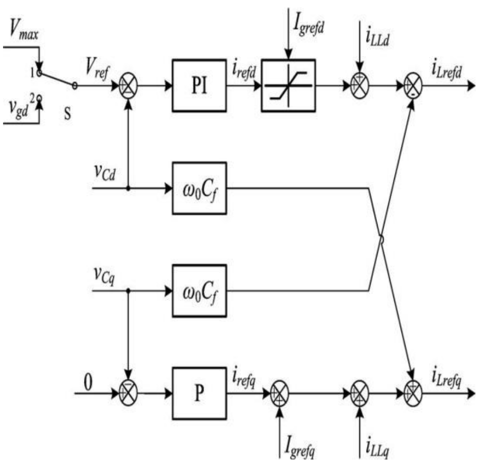


Fig. 3. Block diagram of the current reference generation module.

The PLL in the proposed control strategy is based on the SRF PLL, which is widely used in the three-phase power converter to estimate the utility frequency and phase. Furthermore, a limiter is inserted between the PI compensator G_{PLL} and the integrator, in order to hold the frequency of the load voltage within the normal range in the islanded operation.

In Fig. 2, it can be found that the inductor current is regulated to follow the current reference i_{Lrefdq} , and the phase of the current is synchronized to the grid voltage $v_{g\ abc}$. If the current reference is constant, the inverter is just controlled to be a current source, which is the same with the traditional grid-tied inverter. The new part in this paper is the current reference generation module shown in Fig. 2, which regulates the current reference to guarantee the power match between the DG and the local load and enables the DG to operate in the islanded mode. Moreover, the unified load current feed forward, to deal with the nonlinear local load, is also implemented in this module.

The block diagram of the proposed current reference generation module is shown in Fig. 3, which provides the current reference for the inner current loop in both grid-tied and islanded modes. In this module, it can be found that an unsymmetrical structure is used in *D*- and *Q*-axes. The PI compensator is adopted in *D*-axes, while the P compensator is employed in *Q*-axis. Besides, an extra limiter is added in the *D*-axis. Moreover, the load current feed forward is implemented by adding the load current i_{LLdq} to the final inductor current reference i_{Lrefdq} . The benefit brought by the unique structure in Fig. 3 can be rep-resented by two parts: 1) seamless transfer capability without critical islanding detection; and 2) power quality improvement in both grid-tied and islanded operations. The current reference i_{Lrefdq} composes of four parts in *D*- and *Q*-axes respectively: 1) the output of voltage controller i_{refdq} ; 2) the grid current reference I_{grefdq} ; 3) the load current i_{LLdq} ; and 4) the current flowing through the filter capacitor C_f.

In the grid-tied mode, the load voltage $v_{C\ dq}$ is clamped by the utility. The current reference is irrelevant to the load voltage, due to the saturation of the PI compensator in *D*-axis, and the output of the P compensator being zero in *Q*-axis, and thus, the inverter operates as a current source. Upon occurrence of islanding, the voltage controller takes over automatically to control the load voltage by regulating the current reference, and the inverter acts as a voltage source to supply stable voltage to the local load; this relieves the need for switching between different control architectures.

Another distinguished function of the current reference generation module is the load current feedforward. The sensed load current is added as a part of the inductor current reference i_{Lrefdq} to compensate the harmonic component in the grid current under nonlinear local load. In the islanded mode, the load current feedforward operates still, and the disturbance from the load current, caused by the nonlinear load, can be suppressed by the fast inner inductor current loop, and thus, the quality of the load voltage is improved.

The inductor current control in Fig. 2 was proposed in previous publications for grid-tied operation of DG, and the motivation of this paper is to propose a unified control strategy for DG in both grid-tied and islanded modes, which is represented by the current reference generation module in Fig. 3. The contribution of this module can be summarized in two aspects. First, by introducing PI compensator and P compensator in *D*-axis and *Q*-axis respectively, the voltage controller is inactivated in the grid-tied mode and can be automatically activated upon occurrence of islanding. Therefore, there is no need for switching different controllers or critical islanding detection, and the quality of the load voltage during the transition from the grid-tied mode to the islanded mode can be improved. The second contribution of this module is to present the load current feed forward to deal with the issue caused by the nonlinear local load, with which, not only the waveform of the grid current in grid-tied is improved, but also the quality of the load voltage in the islanded mode is enhanced.

III. OPERATION PRINCIPLE OF DG :

The operation principle of DG with the proposed unified control strategy will be illustrated in detail in this section, and there are in total four states for the DG, including the grid-tied mode, transition from the grid-tied mode to the islanded mode, the islanded mode, and transition from the islanded mode to the grid-tied mode.

A. Grid-Tied Mode:

When the utility is normal, the DG is controlled as a current source to supply given active and reactive power by the inductor current loop, and the active and reactive power can be given by the current reference of *D*- and *Q*-axis independently. First, the phase angle of the utility voltage is obtained by the PLL, which consists of a Park transformation expressed by (3), a PI compensator, a limiter, and an integrator,

Second, the filter inductor current, which has been trans-formed into SRF by the Park transformation, is fed back and compared with the inductor current reference i_{Lrefdq} , and the inductor current is regulated to track the reference i_{Lrefdq} by the PI compensator G_I .

The reference of the inductor current loop i_{Lrefdq} seems complex and it is explained as below. It is assumed that the utility is stiff, and the three-phase utility voltage can be expressed as

$V_{ga} = v_g \cos □^*$
$V_{gb} = v_g \cos(□^* - \frac{2\pi}{3})$ (3)
$V_{gc} = v_g \cos(□^* + \frac{2\pi}{3})$ (4)

Where v_g is the magnitude of grid voltage, $□^*$ is the actual phase angle. By the peak transformation, the utility voltage is transformed into SRF, which is shown as,

$V_{gd} = v_g \cos(□^* - □)$
$V_{gq} = v_g \sin(□^* - □)$ (5)

V_{gq} is regulated to zero by the PLL, so V_{gd} equals the magnitude of the utility voltage V_g. As the filter capacitor voltage equals the utility voltage in the grid-tied mode, V_{cd} equals the magnitude of the utility voltage V_q , and V_{cq} equals zero, too.

In the d-axis, the inductor current reference i_{Lrefd} can be expressed by (6), according to Fig. 3,

$i_{Lrefd} = i_{grefd} + i_{LLd} - \omega_0 c_f v_{cq}$. (6)

In the *Q*-axis, the inductor current reference i_{Lrefq} can be expressed as,

$i_{Lrefq} = i_{grefq} + i_{LLq} + v_{cq}.k_{cvq} + \omega_0 c_f v_{cd}$ (7)

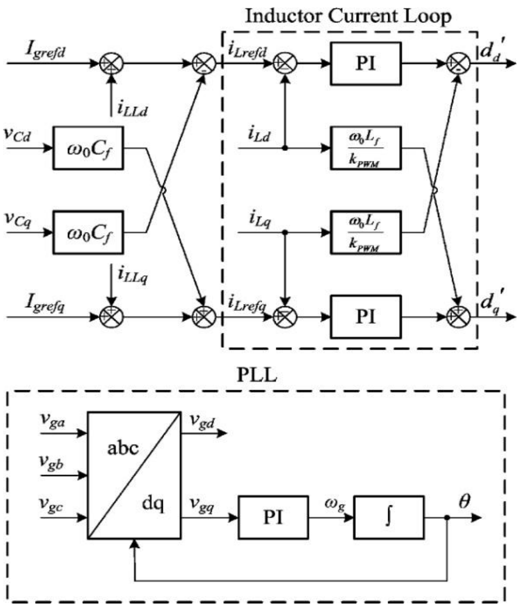


Fig. 4. Simplified block diagram of the unified control strategy when DG operates in the grid-tied mode.

With the previous analysis, the control diagram of the inverter can be simplified as Fig. 4 in the grid-tied mode, and the inverter is controlled as a current source by the inductor current loop with the inductor current reference being determined by the current reference i_{grefdq} and the load current i_{LLdq}. In other words, the inductor current tracks the current reference and the load current. If the steady state error is zero, i_{grefdq} represents the grid current actually, and this will be analyzed in the next section.

A. Transition from Grid – Tied mode to the Islanded mode:

When the utility switch Su opens, the islanding happens, and the amplitude and frequency of the load voltage will drift due to the active and reactive power mismatch between the DG and the load demand. The transition, shown in Fig. 5, can be divided into two time interval.

islanding is confirmed. The second time interval begins from the instant of turning off inverter switch Si .
During the first time interval, the utility voltage *vgabc* is still the same with the load voltage *vCabc* as the switch Si is in ON state.

However, the trend of the load voltage in *Q*-axis v_{Cq} is uncertain because the first term decreases and the second term increases, and it is not concerned for a while

$$V_{cd} = i_{LLd}.R_s - i_{LLq}.X_s \qquad (11)$$
$$V_{cq} = i_{LLq}.R_s + i_{LLd}.X_s \qquad (12)$$

With the increase of the load voltage in *D*-axis *vCd*, when it reaches and exceeds *V*max, the input of the PI compensator *GV D* will become negative, so its output will decrease. the output of limiter will not imposed to *Igref d* any longer, and the current reference *iLref d* will drop. With the regulation of the inductor current loop, the load current in *D*-axis *iLLd* will decrease. As a result, the load voltage in *D*-axis *vCd* will drop and recover to *V*max. After *iLLd* has almost fallen to the normal value, the load voltage in *Q*-axis *vCq* will drop according to (12) .

B. Transition From the Grid-Tied Mode to the Islanded Mode :

When the utility switch Su opens, the islanding happens, and the amplitude and frequency of the load voltage will drift due to the active and reactive power mismatch between the DG and the load demand. The transition, shown in Fig. 5, can be divided into two time interval. The first time intervals is from the instant of turning off Su to the instant of turning off Si when islanding is confirmed.

In grid-tied mode, it is assumed that the DG injects active and reactive power into the utility, which can be expressed by (8) and (9), and that the local critical load, shown in (10), represented by a series connected *RLC* circuit with the lagging power factor

$$P_g = \frac{3}{2} \cdot v_{cd} \cdot i_{gd} \qquad (8)$$
$$Q_g = -\frac{3}{2} \cdot v_{cd} \cdot i_{gq} \qquad (9)$$
$$Z_{sload} = R_s + jX_s \qquad (10)$$

voltage and current are varying dramatically, the angle frequency of the load voltage can be considered to be not varied. The dynamic process in this time interval can be described by Fig. 6, and it is illustrated later.

When islanding happens, *igd* will decrease from positive to zero, and *igq* will increase from negative to zero. At the same time, the load current will vary in the opposite direction. The load voltage in *D*- and *Q*-axes is shown by (11) and (12), and each of them consists of two terms. It can be found that the load voltage in *D*-axis v_{cd} will increase.

With the previous analysis, it can be concluded that the drift of the amplitude and frequency in the load voltage is restricted in the given range when islanding happens. And the inverter is transferred from the current source operation mode to the voltage source operation mode autonomously. In the hybrid voltage and current mode control , the time delay of islanding detection is critical to the drift of the frequency and magnitude in the load voltage, because the drift is worse with the increase of the delay time. However, this phenomenon is avoided in the proposed control strategy.

C. Islanded Mode:

In the islanded mode, switching Si and Su are both in OFF state. The PLL cannot track the utility voltage normally, and the angle frequency is fixed. In this situation, the DG is controlled as a voltage source, because voltage compensator *GV D* and *GV Q* can regulate the load voltage v_{Cdq}. The voltage references in *D* and *Q*-axis are *V*max and zero, respectively. And the magnitude of the load voltage equals to *V*max approximately. Consequently, the control diagram of the three-phase inverter in the islanded mode can be simplified as shown in Fig. The load current i_{LLdq} is partial reference of the inductor current loop. So, if there is disturbance in the load current, it will be suppressed quickly by the inductor current loop, and a stiff load voltage can be achieved.

D. Transition from the Islanded Mode to the Grid-Tied Mode:

If the utility is restored and the utility switch Su is ON, the DG should be connected with utility by turning on switch Si .However, several preparation steps should be performed before turning on switch Si .First, as soon as utility voltage is restored, the PLL will track the phase of the utility voltage. As a result, the phase angle of the load voltage v_{Cabc} will follow the grid voltage v_{gabc}. If the load voltage v_{Cabc} is in phase with the utility voltage, v_{gd} will equal the magnitude of the utility voltage according to (5).Second, as the magnitude of the load voltage *V*max is larger than the utility voltage magnitude *Vg* , the voltage reference *V*ref will be changed to *Vg* by toggling the selector S from terminals 1 to 2. As a result, the load voltage will equal to the utility voltage in both phase and magnitude. Third, the switch Si is turned on, and the selector S is resetto terminal 1. In this situation, the load voltage will be held by the utility. As the voltage reference *Vref* equals *V*max, which is larger than the magnitude of the utility voltage *Vg*, so the PI compensator *GV D* will saturate, and the limiter outputs its upper value *Igref d*. At the same time, *vCq* is regulated to zero by the PLL according to (5), so the output of *GV Q* will be zero. Consequently, the voltage regulators *GV D* and *GV Q* are inactivated, and the DG is controlled as a current source just by the inductor current loop.

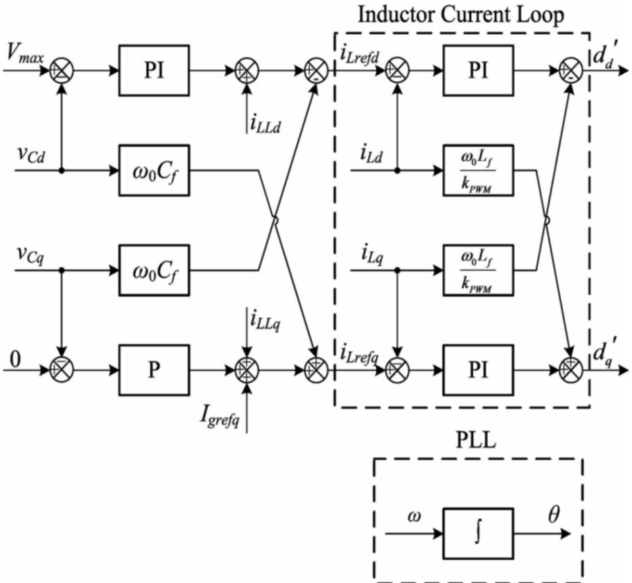


Fig. 5. Simplified block diagram of the unified control strategy when DG operates in the islanded mode.

IV. SIMULATION AND EXPERIMENTAL RESULTS

A. Simulation Results

To investigate the feasible of the proposed control strategy, the simulation has been done in PSIM. The power rating of a three-phase inverter is 3kWin the simulation. The parameters in the simulation are shown in Tables I and II. The RMS of the rated phase voltage is 115 V, and the voltage reference *V*max is set as 10% higher than the rated value. The rated utility frequency is 50 Hz, and the upper and the lower values of the limiter in the PLL are given as 0.2 Hz higher and lower than the rated frequency, respectively.

In the grid-tied mode, the dynamic performance of the conventional voltage mode control and the proposed unified control strategy is compared by stepping down the grid current reference from 9 A to 5 A. The simulation result of the voltage mode control is shown in Fig. 6(a), and the current reference is changed at the moment of 14 s. It is found that dynamic process lasts until around 15.2 s. In the proposed unified control strategy, the simulation result is represented in Fig. 6(b) and the time interval of the dynamic process is less than 5 ms. Comparing the simulation results above, it can be seen that the dynamic performance of the proposed unified control strategy is better than the conventional voltage mode control.

During the transition from the grid-tied mode to the islanded mode, the proposed unified control strategy is compared with the hybrid voltage and current mode control, and the simulation scenario is shown as follows: 1) Initially, the utility is normal, and the DG is connected with the utility; 2) at 0.5 s, islanding happens; and 3) at 0.52 s, the islanding is confirmed.

Simulate results with the hybrid voltage and current mode control is shown in Fig. 9. It can be seen that the grid current drop to zero at 0.5 s, and that the load voltage is seriously distorted from 0.5 to 0.52 s.

Then, the load voltage is recovered to the normal value after 0.52 s. Fig. 5 presents the simulate results with the proposed unified control strategy. Initially, he magnitude of grid current is 9 A and follows the current reference I_{grefdq} . The magnitude and frequency of the load voltage are held by the utility. After the islanding happens, the amplitude of the load voltage increases a little to follow the voltage reference *V*max, and the output current of DG decreases autonomously to match the load power demand.

TABLE I
PARAMETERS IN THE CONTROL SYSTEM

Parameters	Value
Voltage reference V_{max}	179 V
Rated current reference I_{grefd}	9 A
Rated current reference I_{grefq}	0 A
Upper value of the limiter ω_{max}	50.2×2π rad/s
Lower value of the limiter ω_{min}	49.8×2π rad/s

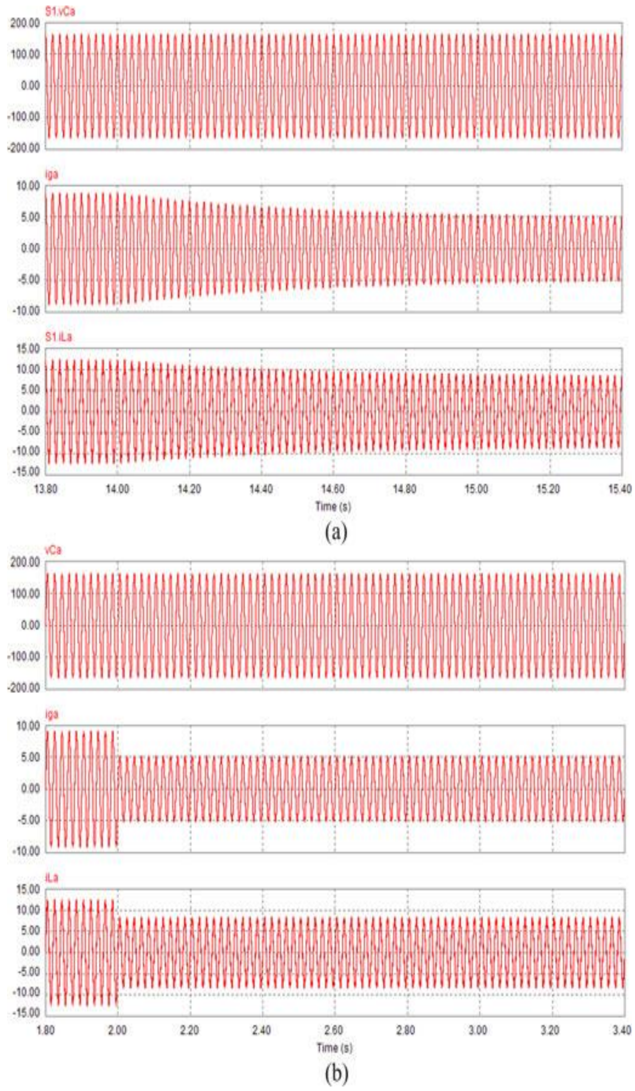
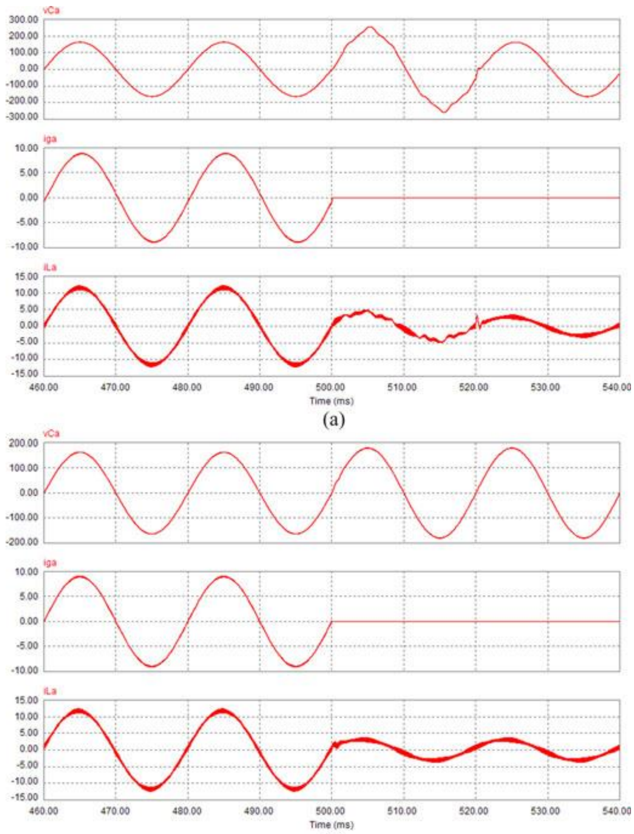


Fig. 6. Simulation waveforms of load voltage V_{Ca}, grid current i_{ga} and inductor current i_{La} when DG is in the grid-tied mode under condition of the step down of the grid current reference from 9 A to 5 A with: (a) conventional voltage mode control, and (b) proposed unified control strategy.

V. CONCLUSION

A unified control strategy was proposed for three-phase inverter in DG to operate in both islanded and grid-tied modes, with no need for switching between two different control architectures or critical islanding detection. A novel voltage controller was presented. It is inactivated in the grid-tied mode, and the DG operates as a current source with fast dynamic performance. Upon the utility outage, the voltage controller can automatically be activated to regulate the load voltage. Moreover, a novel load current feedforward was proposed, and it can improve the waveform quality of both the grid current in the grid-tied mode and the load voltage in the islanded mode. The proposed unified control strategy was verified by the simulation and experimental results.



(b)

Fig. 7. Simulation waveforms of load voltage $v_{C\,a}$, grid current *iga*, and inductor current i_{La} when DG is transferred from the grid-tied mode to the islanded mode with: (a) conventional hybrid voltage and current mode control, and (b) proposed unified control strategy.

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