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A New Advanced DG Based Three Phase Inverter For The Grid-Tied and Islanded Operation

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ABSTRACT:

This paper presents an A 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 proposed control strategy composes of an inner inductor current loop, and a novel 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. Finally, the effectiveness of the proposed control strategy is validated by the simulation results.

Index Terms:
Distributed generation (DG), islanding, load current, seamless transfer, three-phase inverter.

I.INTRODUCTION:

A. Distributed generation Distributed generation (DG) is emerging as available alternative when renewable or nonconventional energyresources are available, such as wind turbines, photovoltaic arrays, fuel cells, microturbines. 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, 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. 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 issue associated with the aforementioned 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. A single-phase DG, which injects harmonic current into the utility for mitigating the harmonic component of the grid current, is presented in. However, existing control strategies, dealing with the nonlinear local load in DG, mainly focus on either the quality of the grid current in the grid-tied mode or the one of the load voltage in the islanded mode, and improving both of them by a unified control strategy is seldom.

II.PROPOSED SYSTEM:

This paper proposes a unified control strategy that avoids the aforementioned shortcomings.

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First, the traditional 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 presented to supply reference for the inner inductor current loop, where a proportional-plus-integral (PI) compensator and a proportional (P) compensator are employed in D-axis and Q-axis, respectively. In the grid-tied operation, theload 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. 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.

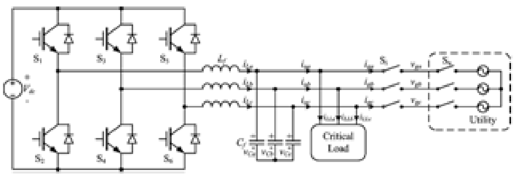

Fig. 1. Schematic diagram of the DG based on the proposed control strategy.

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 byadding the load current into the reference of the inner current loop. the harmonic component of the grid current will be mitigated.

III.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. 3. 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 Vdc in Fig. 1. In the ac side of inverter, the local critical load is connected directly. B.Basic idea With hybrid voltage and current mode control, the inverter is controlled as a current source to generate the reference power PDG+jQDG in the grid-tied-mode. And its output power PDG+jQDG should be sum of the power injected to the grid Pg+jQg and the load demand Pload+jQload,which can be expressed followed by as assuming that the load is represented as a parallel RL circuit.

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

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

(1) and (2), Vm and ωrepresent the amplitude and frequency of the load voltage, respectively. When the nonlinear local load is fed, it can still be equivalent to the parallel RLC circuit by just taking account of the fundamental component. C.

Control Scheme:

Fig. 2 describes the overall block diagram for the proposed unified control strategy, where the inductor current iLabc , the utility voltage vg abc , the load voltage vCabc , and the load current are sensed. And 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 ω0Lf /kPWM is implemented in order to mitigate the couplings due to the inductor. The output of the inner current loop ddq together with the decoupling of the capacitor voltage denoted by 1/kPWM , sets the reference for the standard space vector modulation that controls the switches of the three-phase inverter. It should be noted that kPW M denotes the voltage gain of the inverter, which equals to half of the dc voltage in this paper. In Fig. 4, it can be found that the inductor current is regulated to follow the current reference iL r efdq , and the phase of the current is synchronized to the grid voltage vg 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. 3, 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 feedforward, 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. 5, 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. More-over, the load current feedforward is implemented by adding the load current iL L dq to the final inductor current reference iL r efd.

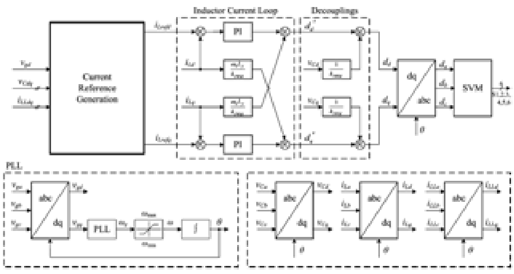

Fig. 2. Overall block diagram of the proposed unified control strategy.

In the grid-tied mode, the load voltage vCdq 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. The inductor current control in Fig. 3 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. 5. 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 feedforward 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.

IV. OPERATION PRINCIPLE OF DG :

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

A. Grid-Tied Mode:

When the utility is normal, the DG is controlled as a currentsource to supply given active and reactive power by the inductorcurrent loop, and the active and reactive power can be givenby 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, alimiter, and an integrator

$$\begin{pmatrix} x_d \\ x_q \end{pmatrix} = \frac{2}{3}\begin{pmatrix} \cos\theta & \cos\left(\theta-\frac{2}{3}\pi\right) & \cos\left(\theta+\frac{2}{3}\pi\right) \\ -\sin\theta & -\sin\left(\theta-\frac{2}{3}\pi\right) & -\sin\left(\theta+\frac{2}{3}\pi\right) \end{pmatrix} \times \begin{pmatrix} x_a \\ x_b \\ x_c \end{pmatrix}. \quad (3)$$

Second, the filter inductor current, which has been transformedinto SRF by the Park transformation, is fed back andcompared with the inductor current reference iLref dq , and theinductor current is regulated to track the reference iLref dq bythe PI compensator GI .The reference of the inductor current loop iLref dq seemscomplex and it is explained as below. It is assumed that the utilityis stiff, and the three-phase utility voltage can be expressed as

$$\begin{cases} v_{ga} = V_g \cos\theta^* \\ v_{gb} = V_g \cos\left(\theta^* - \frac{2\pi}{3}\right) \\ v_{gc} = V_g \cos\left(\theta^* + \frac{2\pi}{3}\right) \end{cases} \quad (4)$$

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where Vg is the magnitude of the grid voltage, and θ is the actualphase angle. By the Park transformation, the utility voltage istransformed into the SRF, which is shown as

$$\begin{cases} v_{gd} = V_g \cos(\theta^* - \theta) \\ v_{gq} = V_g \sin(\theta^* - \theta). \end{cases} \quad (5)$$

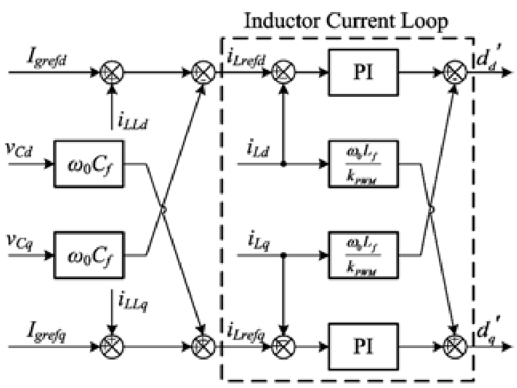
vgq is regulated to zero by the PLL, so vgd equals the magnitudeof the utility voltage Vg . As the filter capacitor voltageequals the utility voltage in the gird-tied mode, vCd equals themagnitude of the utility voltage Vg , and vCq equals zero, too.In the D-axis, the inductor current reference iLref d can beexpressed by (6) according to Fig. 3

$$i_{Lrefd} = I_{grefd} + i_{LLd} - \omega_0 C_f \cdot v_{Cq}. \quad (6)$$

The first part is the output of the limiter. It is assumed thatthe given voltage reference Vmax is larger than the magnitudeof the utility voltage vCd in steady state, so the PI compensator,denoted by GV D in the following part, will saturate, and thelimiter outputs its upper value Igref d. The second part is theload current of D-axis iLLd, which is determined by the characteristicof the local load. The third part is the proportional part−ω0Cf • vCq, where ω0 is the rated angle frequency, and Cfis the capacitance of the filter capacitor. It is fixed as vCq dependson the utility voltage. Consequently, the current referenceiLref d is imposed by the given reference Igref d and the loadcurrent iLLd, and is independent of the load voltage.In the Q-axis, the inductor current reference iLref q consistsof four parts as

$$i_{Lrefq} = v_{Cq} \cdot k_{Gvq} + I_{grefq} + i_{LLq} + \omega_0 C_f \cdot v_{Cd} \quad (7)$$

where kGvq is the parameter of the P compensator, denoted byGV Q in the following part. The first part is the output of GV Q,



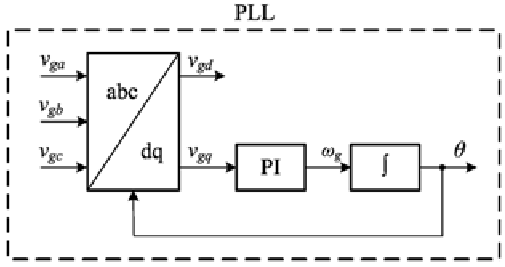


Fig. 4. Simplified block diagram of the unified control strategy when DGoperates in the grid-tied mode.

which is zero as the vCq has been regulated to zero by the PLL.The second part is the given current reference Igref q , and thethird part represents the load current in Q-axis. The final partis the proportional part −ω0Cf • vCd, which is fixed since vCddepends on the utility voltage. Therefore, the current referenceiLref q cannot be influenced by the external voltage loop and isdetermined by the given reference Igref q and the load currentiLLq .With the previous analysis, the control diagram of the invertercan be simplified as Fig. 4 in the grid-tied mode, and the inverteris controlled as a current source by the inductor current loopwith the inductor current reference being determined by thecurrent reference Igref dq and the load current iLLdq . In otherwords, the inductor current tracks the current reference and theload current. If the steady state error is zero, Igref dq representsthe grid current actually, and this will be analyzed in the nextsection.

B Islanded Mode:

In the islanded mode, switching Si and Su are both in OFF-state. The PLL cannot track the utility voltage normally, and theangle frequency is fixed. In this situation, theDGis controlled asa voltage source, because voltage compensator GV D and GV Qcan regulate the load voltage vCdq . The voltage references inDandQ-axis are Vmax and zero, respectively. And the magnitudeof the load voltage equals to Vmax approximately, which will

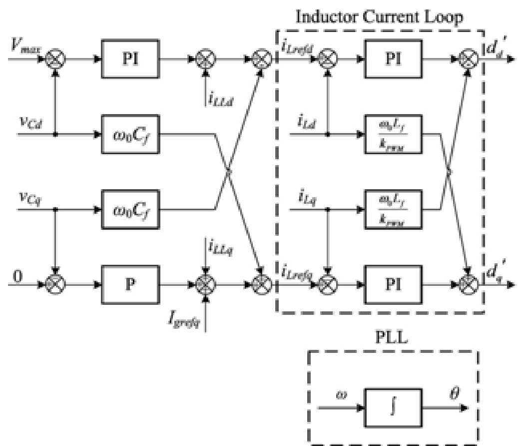


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Fig. 5. Simplified block diagram of the unified control strategy when DG operates in the islanded mode.

be analyzed in Section IV. Consequently, the control diagram ofthe three-phase inverter in the islanded mode can be simplifiedas shown in Fig. 7.In Fig. 7, the load current iLLdq is partial reference of theinductor current loop. So, if there is disturbance in the loadcurrent, it will be suppressed quickly by the inductor currentloop, and a stiff load voltage can be achieved.

V.SIMULATION RESULTS:

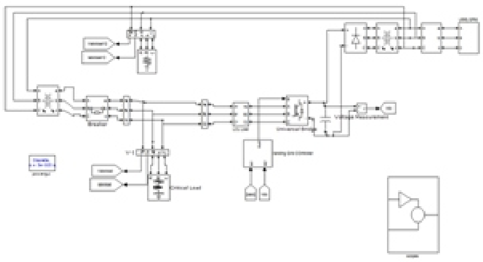

Fig.6 Grid Mode Circuit

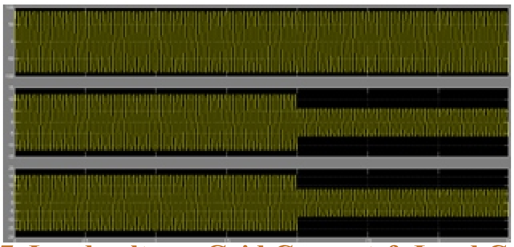

Fig.7. Load voltage, Grid Current & Load Current

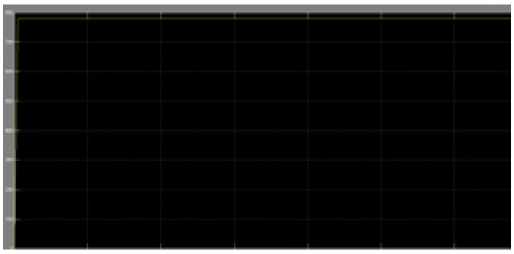

Fig.8 Dc voltage

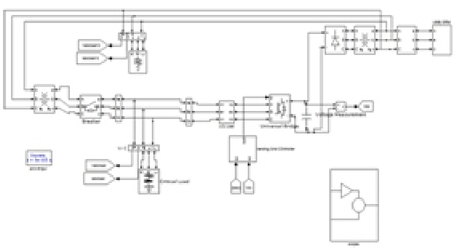

Fig.9 Islanded Mode circuit

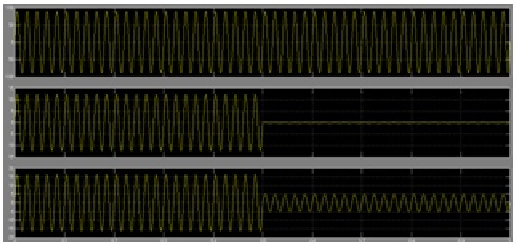

Fig.10 Load voltage, Grid Current & Load Current.

VI. CONCLUSION:

An Automatic Island-mode 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 controller architectures or critical islanding detection. A novel voltage controller was presented. It is inactivated in the grid-tied mode, and the DG operates as acurrent source with fast dynamicperformance. Uponthe utility outage, the voltage controller can automatically be activated to regulate the load voltage. More-over, 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 and also reduce the harmonics. The proposed control strategy was verified by the simulation results.

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