Analysis of Effective Control Strategy for Three-Phase Inverter in Distributed Generation

K.Raj Kumar¹, Kodepaka Jehoshama²

¹ Assistant Professor, Dept. of EEE, Sr Engineering College, Warangal, Telangana, India
² M.Tech student [Power Electronics], Dept. of EEE, Sr Engineering College, Warangal, Telangana, India

ABSTRACT: The proposed control strategy comprises 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 inevitably 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.

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

I. INTRODUCTION

Renewable energy resources are being widely used now a days for power generation. Three phase inverter implemented in the unified control strategy is effective and gives the better inductor current [1]. Distributed generation (DG) is emerging as a viable alternative when renewable or nonconventional energy resources are available, such as wind turbines, photovoltaic arrays, fuel cells, micro turbines [2], [4]. 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 [3]. In the grid-tied operation, DG delivers 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 as soon as possible according to IEEE Standard 929-2000 [5]. 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. Distributed generation is not a new concept since traditional diesel generator as backup power source for critical load has been used for decades. However, due to its low efficiency, high cost, and noise and exhaust, diesel generator would be objectionable in any applications but emergency and fieldwork and it has never become a true distribution source on today’s basis. What endows new meaning to this old concept is technology.

Environmental friendly renewable energy sources, such as photovoltaic devices and wind electric generators, clean and efficient fossil-fuel technologies, such as micro gasturboines, and hydrogen electric devices-fuel cells, have provided great opportunities for the development in distributed generation. Gas fired micro turbines in the 25-100kW range can be mass produced at low cost which use air bearing and recuperation to achieve reasonable efficiency at 40% with electricity output only and 90% for electricity and heat micro-cogeneration. Fuel cells have the virtue of zero emission, high efficiency, and reliability and therefore have the potential to truly revolutionize power generation. The hydrogen can be either directly supplied or reformed from natural gas or liquid fuels such as alcohols or gasoline.

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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 cooperate either in the grid-tied mode or in the islanded mode [2]. In the grid-tied operation, DG delivers 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.

A fuel cell converts chemical energy of a fuel directly into electrical energy. It consists of two electrodes and an electrolyte, retained in a matrix. The operation is similar to that of a storage battery except that the reactant and products are not stored, but are continuously fed to the cell. During operation, the hydrogen rich fuel and oxidant are separately supplied to the electrodes.

This paper proposes a unified control strategy that avoids the aforementioned shortcomings. First, the traditional inductor current loop is employed to control the three-phase inverter in DG to act as an 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.

II. PROPOSED CONTROL STRATEGY

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 $V_{dc}$ in Fig. 3. In the ac side of the inverter, the local critical load is connected directly.

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 as follows by assuming that the load is represented as a parallel RL circuit.

\[
P_{\text{load}} = \frac{3}{2} \frac{V_m^2}{R} \quad \ldots \ldots \quad (1)
\]

\[
Q_{\text{load}} = \frac{3}{2} V_m \cdot \left( \frac{1}{\omega L} - \omega C \right) \quad \ldots \ldots \quad (2)
\]

In (1) and (2), \( V_m \) and \( \omega \) represent 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.

Fig. 4 describes the overall block diagram for the proposed unified control strategy, where the inductor current \( i_{L\text{abc}} \), the utility voltage \( v_{g\text{abc}} \), the load voltage \( v_{C\text{abc}} \), 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 \( \omega_0 L_f/k_{\text{PWM}} \) 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 \( 1/k_{\text{PWM}} \), sets thereference for the standard space vector modulation that controls the switches of the three-phase inverter. It should be noted that \( k_{\text{PWM}} \) denotes the voltage gain of the inverter, which equals to half of the dc voltage in this paper.

### III. 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 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.

Second, the filter inductor current, which has been transformed into SRF by the Park transformation, is fed back and compared with the inductor current reference \( i_{L\text{ref}dq} \), and the inductor current is regulated to track the reference \( i_{L\text{ref}dq} \) by the PI compensator \( G_i \). The reference of the inductor current loop \( i_{L \text{ref}dq} \) seems complex and it is explained as below.

The control diagram of the inverter can be simplified as Fig. 5 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 \( I_{g\text{ref}dq} \) and the load current \( i_{L\text{ldq}} \). In other words, the inductor current tracks the current reference and the load current. If the steady state error is zero, \( I_{g\text{ref}dq} \) represents the grid current.
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_{dq}. The voltage references in D and Q-axis are V_{max} and zero, respectively.

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_{abc} will follow the grid voltage v_{gabc}. If the load voltage v_{abc} 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 V_{g}, the voltage reference V_{ref} will be changed to V_{g} by toggling the selector S from terminal 1 to 2. As a result, the load voltage will equal to the utility voltage in both phase and magnitude. Third, the switch S_i is turned on, and the selector S is reset to terminal 1.

IV. SIMULATION AND EXPERIMENTAL RESULTS

To investigate the feasibility of the proposed efficient control strategy, the simulation has been done in SIMULINK. The power rating of a three-phase inverter is 3kW in the simulation. In the grid-tied mode, the dynamic performance of the conventional voltage mode control and the proposed control strategy is compared by stepping down the grid current reference. The simulation results can be seen that the dynamic performance of the proposed control strategy is better than the conventional voltage mode control. During the transition from the grid-tied mode to the islanded mode, the proposed control strategy is compared with the hybrid voltage and current mode control. The SIMULINK model for the proposed control strategy is shown in the Fig. 6.
V. CONCLUSION

An efficient control strategy was proposed for three-phase inverter in DG using Artificial neural networks to operate in both islanded and grid-tied modes, with no need for switching between two different control architectures or critical islanding detection. The voltage controller is inactivated in the grid-tied mode, and the DG operates as a current source with fast dynamic performance. Upon a utility outage, the voltage controller can automatically be activated to regulate the load voltage. Moreover, the loadcurrent feedforward can improve the waveform quality of both the grid current in the grid-tied mode and the load voltage in the islanded mode.

REFERENCES


Authors Profile:

K.Raj Kumar working as Assistant Professor, Department of EEE in Sr Engineering College, Warangal, Telangana, India. I received B.Tech degree in Electrical Engineering in 2012 from CJIT, and M.Tech in 2014 from S.R. Engineering College. My interested areas are power quality and power electronics applications in power systems.

Kodepaka Jehoshama received B.Tech degree in Electrical Engineering from JNTUH, Telangana, in 2014 and pursuing M.Tech in Power Electronics from Sr Engineering College, Warangal, Telangana, India.