Estimation of Three-Phase Grid Voltage Parameters Using Novel Adaptive Strategy

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Abstract— **The aspect of power quality issues has become serious with more and more penetration of renewable sources i.e. (weak grid) with the conventional utility grid i.e. (stiff grid). At PCC (Point of common coupling) it has become mandatory to provide an adaptive scheme as comprehensive solution to address control, protection and power quality issues. The control strategy proposed consists 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. This control strategy is validated by simulation results carried out in MATLAB for grid connected and islanding mode. The current harmonics get reduced and dynamic performance of the system is improved.**

Index Terms— **Adaptive scheme, Distributed generation, Islanding, Point of common coupling (PCC), Power quality issues, Three-phase inverter.**

I. Introduction

Recently, renewable sources such as wind energy and solar energy, often behaving as distributed power generation systems (DPGSs), have a high penetration in the grids [1]. When these renewable sources are connected to the grid, power converters, such as voltage source inverter (VSI) working as efficient and flexible energy conversion interfaces, are applied in a variety of applications of DPGSs [2] and active power filters (APFs) [3–5]. For the purpose of real time control of power systems, estimation of the grid voltage parameters is essential for power converters to synchronize the grid current with the grid voltage [6]. A classical method for the estimation of grid voltage parameters, known as the synchronous reference frame phase locked loop (SRF-PLL), has been widely used [7] in industry. However, the increasing applications of the renewable sources and the presence of various nonlinear loads in the modern grids often induce grid faults and harmonic disturbances. As a result, the traditional SRF-PLL is hard to be applied for an effective and satisfactory estimation of the grid voltage parameters when there exist unbalanced faults and harmonic voltage disturbances in the grids.

In the past decade, a number of methods have been proposed to address the estimation problem of the grid voltage parameters under unbalanced faults and harmonic disturbances. In the paper [10], the authors presented an estimation approach called zero-crossings detection (ZCD). The ZCD method is very simple. However, it has slow dynamic responses and often results in signal jitters. By comparison, a variable sampling frequency method proposed in the work [11] has a faster dynamic response. A disadvantage of the result in [11] is that adjusting the system sampling frequency is not easy, which, in turn, yields steady state estimation error.

To implement real-time control for power systems, we propose in this work an adaptive observer-based, closed loop feedback approach for the estimation of three-phase grid voltage parameters including fundamental and harmonic frequencies, amplitudes and phase angles. Although our estimation scheme is based on time-domain, it does not depend on PLL (phase-locked loop), QSG (quadrature signal generation) and complex filtering, and thus in this sense is different from many existing time-domain methods.

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 as soon as possible according to IEEE Standard 929-2000 [4]. 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 [5]. 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. Simulations and experiments are carried out, to demonstrate the effectiveness and performance of the proposed estimation scheme. As illustrated by simulations and experiments, the adaptive observer and control strategy is easy to be implemented, and capable of achieving a fast and accurate estimation of three phase grid voltage parameters with a unified load current feed-forward control strategy.

The next section presents proposed system and its contents.

II. ProPosed System

A. *Proposed Control Strategy*

The proposed control strategy for estimating the three phase grid voltage parameters has been explained below.

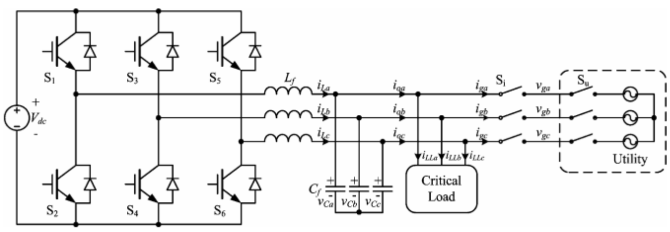


Fig. 1. Proposed Control Strategy

In this paper a unified control strategy for a three phase inverter in DG is presented 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. It should be noted that there are two switches, denoted by S_u and S_i, respectively, in Fig. 1, and their functions are different.

The inverter transfer switch Si is controlled by the DG, and the utility protection switch Su is governed by the utility. When the utility is normal, both switches Si and Su are ON, and the DG in the grid-tied mode injects power to the utility. When the utility is in fault, the switch Su 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 [13]–[17], the switch Si 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 Si is turned ON to connect the DG with the grid.

III. Basic Idea

We consider a general situation where the three-phase grid contains both fundamental voltage and various harmonic disturbances. The three-phase grid voltage can be described by

$v_{abc} = [v_a\ v_b\ v_c]^T$ or

$$v_{abc} = \sum_{i=1}^{n} m_i = (v_{abc\_pi} + v_{abc\_ni}) \qquad (1)$$

Where

$$v_{abc\_pi} = V_{pi} \begin{bmatrix} \cos(a_i\omega t + \phi_{pi}) \\ \cos(a_i\omega t - \frac{2\pi}{3} + \phi_{pi}) \\ \cos(a_i\omega t + \frac{2\pi}{3} + \phi_{pi}) \end{bmatrix}$$

$$v_{abc\_ni} = V_{ni} \begin{bmatrix} \cos(a_i\omega t + \phi_{ni}) \\ \cos(a_i\omega t + \frac{2\pi}{3} + \phi_{ni}) \\ \cos(a_i\omega t - \frac{2\pi}{3} + \phi_{ni}) \end{bmatrix}$$

In (1), subscripts *pi* and *ni* represent positive- and negative sequence components of the voltage vector v, respectively, and $a_1,\ldots,a_m$ are odd positive integers and represent orders of the harmonic voltages.

Using the Clarke's transformation

$$v_{\alpha\beta} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} v_{abc}, \qquad (2)$$

The grid voltage can be represented in the αβ-coordinates as

$$v_{\alpha\beta} = \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} \Sigma_{i=1}^{m}(v_{\alpha\_pi} + v_{\alpha\_ni}) \\ \Sigma_{i=1}^{m}(v_{\beta\_pi} + v_{\beta\_ni}) \end{bmatrix} \qquad (3)$$

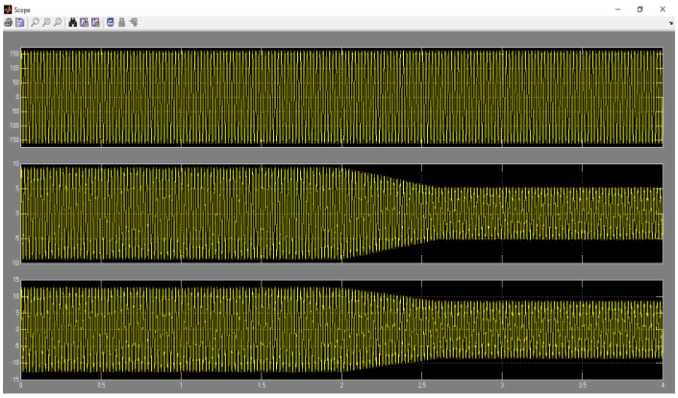
Where $v\alpha_{\_pi}$ and $v\beta_{\_pi}$ are the positive-sequence components of the i^{th}-order harmonic voltage in the αβ-coordinates, while $v\alpha_{\_ni}$ and $v\beta_{\_ni}$ are the negative-sequence components of the ith-order harmonic voltage.

IV. Simulation Results

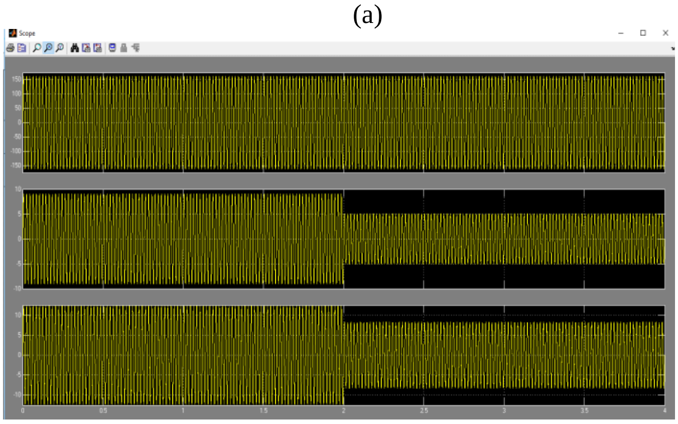
To investigate the feasibility of the proposed control strategy, the simulation has been done in MATLAB. The power rating of a three-phase inverter is 3 kW in the simulation. The parameters in the simulation are shown in Tables I and II. The RMS of the rated phase voltage is 115 V, and the voltage reference 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.

TABLE I.

Sr.No.	Parameters of the Control System	
	Parameters	***Value***
1	Voltage reference V_{max}	179 V
2	Rated current reference I_{grefd}	9V
3	Rated current reference I_{grefq}	0A
4	Upper value of limiter ω_{max}	50.2×2π rad/s
5	Lower value of limiter ω_{min}	49.8×2π rad/s



(a)



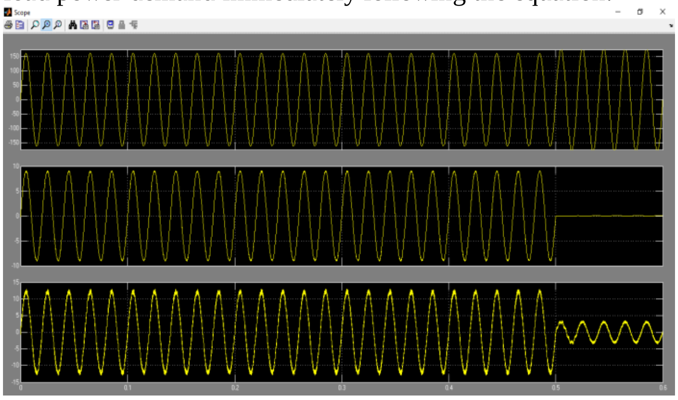
(b)

Fig. 2. 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.

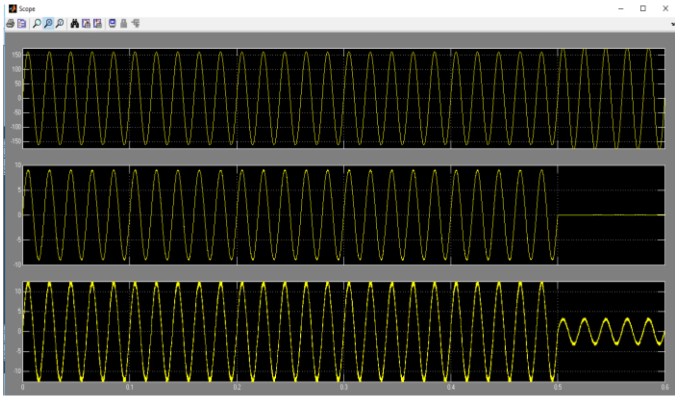
In the grid-tied mode, the dynamic performance of the conventional voltage mode control and the proposed unified control strategy is compared by stepping down the grid current reference from 9 A to 5 A. The simulation result of the voltage mode control is shown in Fig. 2(a), and the current reference 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. 2(b) and the time interval of the dynamic process is less than 5ms. 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.3 (a). 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. 3(b) presents the simulate results with the proposed unified control strategy. Initially, the magnitude of grid current is 9A 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 immediately following the equation.



(a)



(b)

Fig. 3. Simulation waveforms of load voltage V_{ca}, grid current i_{ga}, 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.

This work can be extended further by optimizing estimated grid voltage parameters using genetic algorithm and its advanced operators [18].

V. CONCLUSION

From the proposed unified control strategy we can observe that there is no need for switching between two different control architectures i.e. current controller and voltage controller and the dynamic performance of the system gets increased. The waveform quality of grid current gets improved in both grid-connected and islanded modes.

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