A New Compensation Control Strategy for Grid-connected Wind Turbine and Fuel Cell Inverters in a Microgrid

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ABSTRACT

The use of a new control method for grid-connected inverters for reducing the output current harmonic distortion in a wide range of grid-connected distributed generation (DG) applications, including wind turbine (WT) and fuel cell (FC) inverters is proposed in this paper. The control method designed to eliminate main harmonics in a microgrid (MG) and between MG and point of common coupling (PCC) and responsible for the correction of the system unbalance. Another advantage of the proposed control method is that it can be easily adopted into the DG control system without the installation of extra hardware. The proposed control method is comprised of the synchronous reference frame method (SRF). Results from the proposed control method are provided to show the feasibility of the proposed approach.

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1. INTRODUCTION

Three-phase grid-connected inverters have been widely employed in various applications, including renewable power generation and regenerative energy systems. This is due to the recent development trend constructing the electrical grid in terms of distributed generation (DG) systems, in which grid-connected inverters are connected in parallel with each other to form a microgrid (MG). The MGs are local distribution grids, which include three important part such as DGs, power electronics and control strategies [1]. Severe power quality problems have been brought by an increase of DGs, e.g., wind turbine (WT) systems and fuel cell (FC) systems, as well as the nonlinear loads. Traditionally, The DGs are normally connected to the utility grid through the grid-connected pulse width modulation (PWM) inverters, which supply the active and reactive powers to the main grid [2]. Besides the generation of real power, these inverters can improve power quality of the grid through control strategies. One problem in MGs is the total harmonic distortion (THD) of the interface inverters for current exchanged with the grid.

The Active power filter (APF) has been proved as a flexible solution for compensating the harmonic distortion caused by various nonlinear loads in power distribution power systems. In 1976, Gyugyi and Strycula [3], presented a family of shunt and series active power filters (APFs) and established the concept of an APF consisting of a PWM inverter using a power transistor. Hybrid compensation (HC) has the advantages of both passive and active filters for improving power quality problems. Unfortunately, the traditional APFs have several drawbacks, including higher cost, bigger size, higher power switches count, and the complexity of the control algorithms and interface circuits to compensate for unbalanced and nonlinear loads.

Traditionally, the interface inverters used in MGs have behaved as current sources when they are connected to the main grid. The interface inverter controller must be able to cope with unbalanced utility grid currents and current harmonics, which are within the range given by the waveform quality requirements of the local loads and MGs. The primary goal of a power-electronic interface inverter is to control the power injection [4]. However, compensation for the power quality problem, such as current harmonics, can be achieved through appropriate control strategies. Consequently, the control of DGs must be improved to meet the requirements when connected to the grid.

In the literature [5]–[9], several methods have been presented to control the DGs as the current harmonic compensator. The methods in these studies ([8] and [9]) have been proposed to compensate for current harmonics in grid-connected MGs. The proposed current controller is designed in the synchronous reference frame (SRF) and is composed of a proportional–integral (PI) controller and a repetitive controller (RC), as discussed in the literature [8]. The application of the active power filters as efficient interface for power quality improvement in distribution networks is gaining more attention with the advances in power electronics technology. However, the high cost of investment, poor performance under severe unbalanced and nonlinear load conditions are main challenges associated with active power filters. Hence, it is important to propose the improved control schemes to enhance the power quality of the power system.

In this article, a new current compensation control method for grid-connected inverters is presented. The proposed control strategy consists of a synchronous reference frame (SRF) control structure. This method proposed to control power injection to the grid, and also is used for harmonic current compensation. The proposed control method can simultaneously compensate for power quality problems. The focus of the present paper is the current quality at point of common coupling (PCC), namely, the reduction of THD at the PCC and MG. Another advantage of the proposed control method is that it can be easily adopted into the DG control system without the installation of extra hardware. Current harmonics and imbalance compensation in PCC and MGs as a new feature of the hybrid control methods are the main contributions of the present study. Furthermore, simulation studies are presented, discussed and analyzed.

2. THE PROPOSED CONTROL METHOD

Figure 1 shows, block diagram of proposed current control method for the grid-connected inverter on FC and WT.

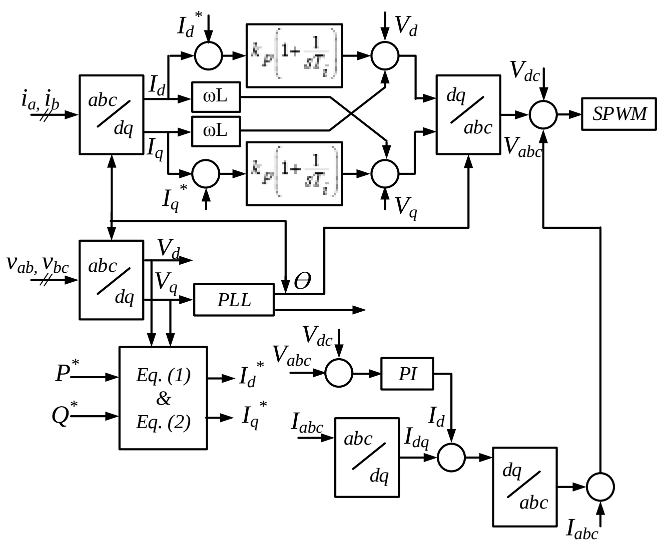

Figure 1. Block diagram of the proposed control method

Injecting a harmonic distortion, which is equivalent to a distortion caused by non-linear loads but with an opposite polarity, into the system can lead to correction of the waveform into a sine wave. Voltage distortion results from harmonic current emissions in the system impedance. Various control methods are based on the frequency domain or the time domain. The SRF control is also called the *dq* control [10] and is used to control the grid-connected inverter in this paper. This method uses a reference frame transformation module, *abc* to *dq*, to transform it into a reference frame that rotates synchronously using the transform of the grid current and the voltage waveforms. The SRF control strategy applied to the interface Inverter usually includes two cascaded loops. An external voltage loop controls the dc-link voltage, and a fast internal current loop regulates the grid current.

The current loop is designed for current protection and power quality issues; hence, harmonic compensation is an important property of the current controller. The Park transformation for an electrical power system analysis was extended. The application of the Park transformation to three generic three-phase quantities supplies their components in *dq0* coordinates. In general, three phase voltages and currents are transformed into *dq0* coordinates by matrix [L] as follows:

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = [L] \begin{bmatrix} u_A \\ u_B \\ u_C \end{bmatrix} \text{and} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = [L] \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} \quad (1)$$

$$[L] = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin\alpha & \sin\left(\alpha - \frac{2\pi}{3}\right) & \sin\left(\alpha + \frac{2\pi}{3}\right) \\ \cos\alpha & \cos\left(\alpha - \frac{2\pi}{3}\right) & \cos\left(\alpha + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \quad (2)$$

The three-phase load currents are transformed in *dq0* coordinates by [L]:

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \\ i_{L0} \end{bmatrix} = [L] \begin{bmatrix} i_{LA} \\ i_{LB} \\ i_{LC} \end{bmatrix} \quad (3)$$

Therefore, through averaging i_{Ld} and i_{Lq} in domain [0-2π] as achieved component of i_{Ld} and i_{Lq} . That is:

$$\bar{i}_{Ld} = \frac{1}{2\pi} \int_0^{2\pi} i_{Ld} \, d\,\omega t \quad (4)$$

$$\bar{i}_{Lq} = \frac{1}{2\pi} \int_0^{2\pi} i_{Lq} \, d\,\omega t$$

Where

$$i_{Ld} = \sqrt{\frac{2}{3}} \begin{bmatrix} i_{LA} \sin\omega t + i_{LB} \sin\left(\omega t - \frac{2\pi}{3}\right) + \\ i_{LC} \sin\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} \quad (5)$$

$$i_{Lq} = \sqrt{\frac{2}{3}} \begin{bmatrix} i_{LA} \cos\omega t + i_{LB} \cos\left(\omega t - \frac{2\pi}{3}\right) + \\ i_{LC} \cos\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} \quad (6)$$

as continue can be written:

$$a_{A1}^{(i)} = \sqrt{\frac{2}{3}}\bar{i}_d\left(t\right) \text{ and } b_{A1}^{(i)} = \sqrt{\frac{2}{3}}\bar{i}_q(t) \tag{7}$$

Equation (7) gives the relationship between the dc components of i_{Ld} , i_{Lq}, the coefficients of i_{Ls} and the compensating objective of the propose control method. Here, i_{Ls} and i_{PM} are calculated in *abc* coordinates.

$$i_{PM} = i_L - i_{LS} \tag{8}$$

3. SYSTEM CONFIGURATION

In a basic micro-grid architecture (Figure 2), the electrical system is assumed to be radial with several feeders and a collection of loads.

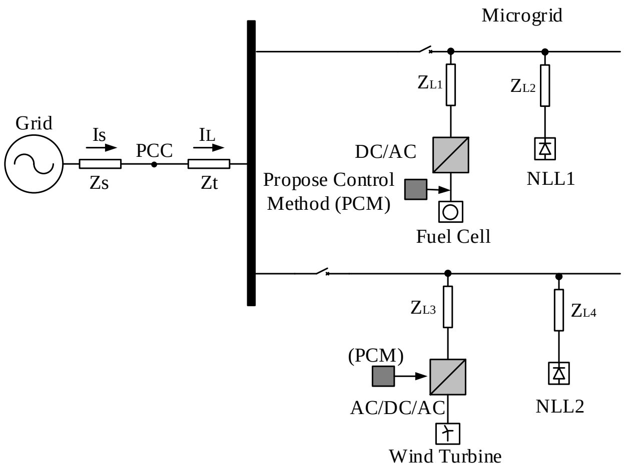

Figure 2. Study system configuration

This MG includes two DGs, such as the fuel cell (FC) and wind turbine (WT) which are connected to the grid by the interface inverter. The proposed control methods are applied to the WT and FC. The parameters of the load/DGs can be found in Tables 1.

Table 1. Load/DG Parameters

Load/DGs	Parameters	Values
Fuel cell	Inverter switching frequency	4 kHz
	Inverter resistance	4 Ω
	Inverter capacitance	5 µF
	DC-link voltage	545 V
Wind turbine	Inverter resistance	0.02 Ω
	DC-link voltage	720 V
Rating of nonlinear load 1	RL 30 kW, 10 kVAr	13A
Rating of nonlinear load 2	Resistor 0.3 Ω	24A

Thereafter, the dc voltage is applied to the interface inverter, which is controlled by the SRF controller.

4. SIMULATION RESULTS

To demonstrate the effectiveness of the proposed control strategy, the system in Figure 2 was simulated in MATLAB/Simulink. In the simulation, two case study are taken into account.

Case study I: Without compensation devices.

Case study II: Harmonic compensation just by using propose control method.

4.1. Case study I

In this case study, the resulting system waveforms are shown in Figure 4 without any compensation devices. DG sources and nonlinear loads make the system current non-linear and unbalanced. The Current and THD value of study system in case study I (before compensation) can be found in Tables 2.

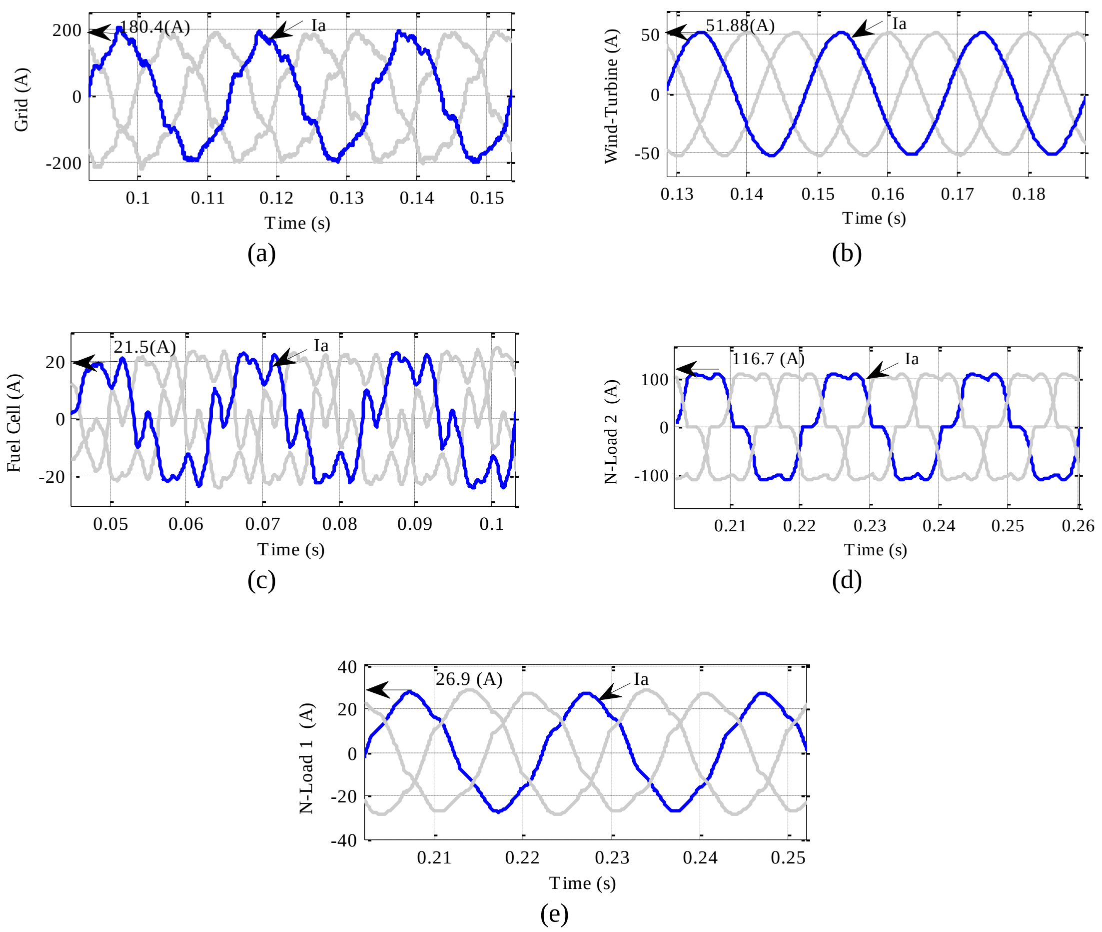

Figure 4. Grid, DG units and nonlinear loads current waveforms without any compensation: (a) Grid currents; (b) WT currents; (c) FC currents; (d) nonlinear load 1 currents and (e) nonlinear load 2 currents

4.2. Case study II

This case study has an improved power quality with the absence of compensation devices such as passive filter and active power filter in the MG. The main contribution of this study are the PCC and MG currents compensation. The compensated system currents are explained in this subsection. Figure 5 show the effective compensation values of the harmonic current for the system. This case study shows that the proposed control method can compensate for the current system (PCC current) and DGs with the absence of power compensation devices.

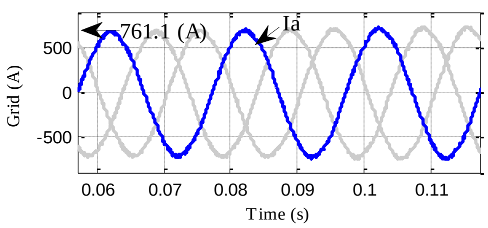

Figure 5. System currents waveforms with propose control method

When all of the loads and DGs are connected, the THD current without any compensation was 14.47%. As shown in Figure 5, THD is reduced to 1.73% in the proposed control method, it is capable of meeting the IEEE 519-1992 recommended harmonic standard limits. The Current and THD value of study system in case study II (after propose control method) is given in Tables 2.

Table 2. Current and THD Results

Identifier	Before Compensation THD %	After Propose Control Method THD %
Grid	**14.47**	**1.73**
WT	1.4	1.07
FC	39.26	2.19
NLL1	6.64	-
NLL2	18.12	-

5. CONCLUSIONS

This article proposes a new control strategy for harmonic current compensation for WT and FC inverters in a MG. The proposed control method is comprised of the synchronous reference frame control structure. The proposed control method is responsible for controlling the power injection to the grid, and also compensating for the main harmonic current due to the unbalanced load. This strategy can be used for single-phase and three-phase systems. The proposed control method can be ability to reduce the complexity, size as well as cost of the control in comparison with APFs. Fast dynamic response, simple design and stability analysis and fast transient response are other key features of the presented strategy The simulation results verify the feasibility and effectiveness of the newly designed control method for a grid-connected inverter in a MG.

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