A New Approach to Design Control Method for Grid-Connected WT and PV Inverters in Micro-Grid

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Abstract

Background/Objectives: The objective of this paper is to a simple but very effective method to achieve the predictive direct compensation current control for three phase grid-connected Wind Turbine (WT) and Photo-Voltaic (PV) inverters in micro-grid. Methods/Statistical Analysis: Our proposed grid-connected power inverter for PV consists of a switch mode DC-DC boost converter and Pulse-Width Modulation (PWM) inverter. The proposed control method is comprised of the Advance Synchronous Reference Frame (ASRF) method. Findings: The control method on PV designed to eliminate main harmonics and also is responsible for the injection power to the grid. The novel approach is able to increase the inverter output current around 8 times of conventional one. Applications/Improvements: The simulations for three-phase Bridge type inverter have been done in MATLAB/Simulink. To validate the simulation results, a scaled prototype model of the proposed inverter has been built and tested.

Keywords: Distributed Generation (DG), Grid-connected Inverter, Micro-Grid, Photovoltaic, Power Quality, Wind Turbine

1. Introduction

Growing interest has been devoted to developing the Distributed Power Generation System (DPGS) based on renewable energy for their environmental friendly features. As the interface between the DGS and the grid, the grid-connected inverter is essential to convert all kinds of generated power into a high quality ac power and inject it into the grid reliably1. The modern development of Wind Turbine (WT) systems started in the 1980’s with sites of a few tens of kilowatts to multi-megawatt range wind turbines today2,3. DG systems comprised of photovoltaic (PV) and WT are mostly based on grid-connected Inverters as an interface between the source and the grid4. Grid-connected PV and WT inverter are one the most demanding power electronic inverters nowadays4,5. It is due to the fact that solar and wind energies are considered as an alternate for the fossil fuels like coal and oil. The trend in wind turbine energy has been towards large capacity units in the range of multi megawatt levels5. Photovoltaic grid-connected inverters are divided into three main categories depending on the maximum injected power to the grid. They are micro, string and central inverters6. In the area of the string inverters, the power electronic inverter system consists of two circuits. A boost DC-DC converter that increases the DC voltage of the PV panels and a three phase inverter that injects sinusoidal current to the grid7. Due to the grid inverter influenced by various nonlinear factors, its output grid current waveform distortion is more serious. Therefore,
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Master photovoltaic grid-connected inverter technology is crucial. There are many kinds of grid inverter control strategy. Between DC-DC converter and DC-AC converter usually set up with a sufficient dc filter capacitor, at the same time, the dc filter capacitor energy level changes before and after in the buffer, and it also played a decoupling role on the front and rear level control. As illustrated above, Grid-connected inverter is actually active inverter, and the grid-connected inverter generally adopts full control switch device, therefore, grid-connected inverter can also be called PWM grid-connected inverter. The use of current control for grid connected PWM inverters is becoming very popular in distributed generation, due to the need to control both the harmonic content and the power factor of the current. The Two switches of the same bridge arm tube complementary switched on and off, to complete the inverter. A Photovoltaic power generation system generally uses pulse width modulation PWM inverter to achieve, convert the rectangular wave AC to AC sine wave. For three-phase grid-connected inverter control, the control design based on synchronous rotating coordinate system is very convenient, the ABC three-phase static coordinate system is converted into synchronous rotating coordinate system by the coordinate transformation, after coordinate transformation, converted the fundamental sine variables in the three phase stationary coordinate system into synchronous rotating coordinate system DC variable. In a state space model of three phase paralleled inverters in grid-connected micro-grid based on droop control to facilitate the control design and stability analysis. This model is established in rotation framework based on modern control theory and can be very easily used in micro-grid. In traditional control methods, the control of three phase grid-connected inverter are designed in either synchronous reference domain or stationary domain. The stationary frame based control can avoid the coupling terms and also the possibility of harmonic by controlling, but suffers from the complicated design, sensitivity to the grid frequency, and resonant controllers that causes difficult for digital implementation. Therefore, PI controller is used to decouple the real and reactive power by eliminating the coupling terms between d-q axes, the control of reactive power has been widely understood and applied in rectifier, grid-connected inverters of PV and distributed power generation systems.

This paper proposes a control strategy of three-phase Grid-connected inverter. This control method responsible injection power to grid and compensation main harmonic in micro-grid bus and Power Common Coupling (PCC). To use this control method can remove dedicated compensation devices such as active power filter in PCC.

2. System Configuration

The micro-grid described in Figure 1, based on the system parameters in Table 1 and the proposed control method, is simulated in the MATLAB environment. This system contains a sine voltage source along with one DG sources, PV and WT and as well as two non-linear loads, the first of which is formed by three unbalanced single-phase diode rectifiers and the second of which is formed by one three-phase diode rectifier and acts as a source of harmonic current (Figure 1, Table 1).

![Figure 1. Studied system configuration with nonlinear loads, PV and WT.](image)

<table>
<thead>
<tr>
<th>Load/DGs</th>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photovoltaic</td>
<td>Inverter resistance</td>
<td>0.2 mΩ</td>
</tr>
<tr>
<td></td>
<td>DC-link voltage</td>
<td>675</td>
</tr>
<tr>
<td>Wind turbine</td>
<td>Inverter resistance</td>
<td>0.02 Ω</td>
</tr>
<tr>
<td></td>
<td>DC-link voltage</td>
<td>720 V</td>
</tr>
<tr>
<td>Rating of nonlinear load 1</td>
<td>RL</td>
<td>25.68 A</td>
</tr>
<tr>
<td>Rating of nonlinear load 2</td>
<td>Resistor</td>
<td>115.4 A</td>
</tr>
</tbody>
</table>
Table 2. Current and THD results.

<table>
<thead>
<tr>
<th></th>
<th>Before Compensation</th>
<th>After Propose Control Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current (A)</td>
<td>THD %</td>
</tr>
<tr>
<td>Grid</td>
<td>151.2</td>
<td>12.02</td>
</tr>
<tr>
<td>PV</td>
<td>41.99</td>
<td>16.57</td>
</tr>
<tr>
<td>WT</td>
<td>50.01</td>
<td>1.24</td>
</tr>
<tr>
<td>N-load1</td>
<td>25.86</td>
<td>6.08</td>
</tr>
<tr>
<td>N-Load2</td>
<td>115.4</td>
<td>18.66</td>
</tr>
</tbody>
</table>

Figure 2 shows a PV that has a frequency of 50 Hz. To obtain power, many PV cells are connected in different parallel and series circuits on a panel (module). The PV array is a group of a PV modules electrically connected in a parallel series to generate current and voltage\(^2\). The detail model about this DG is 100-kWand maximum power 330 sun-power SPR-305 (Figure 2).

The detail model about this DG is 9-MW wind farm DFIG and connected to the grid by AC/DA/AC converter. Figure 3 shows a WT that has a frequency of 50 Hz.

Figure 3. Schematic diagram of the wind turbine.

3. Propose Control Method

To enhance grid and micro-grid current quality, an advanced current control method for the interface converter, as shown in Figure 4, is introduced.

\[
\begin{align*}
\begin{bmatrix}
  u_d \\
  u_q
\end{bmatrix}
& =
\begin{bmatrix}
  u_A \\
  u_B \\
  u_C
\end{bmatrix} \\
\begin{bmatrix}
  i_d \\
  i_q
\end{bmatrix}
& =
\begin{bmatrix}
  i_A \\
  i_B \\
  i_C
\end{bmatrix}
\end{align*}
\]

(1)

\[
[L] = \begin{bmatrix}
\sin\alpha & \sin\left(\frac{2\pi}{3}\right) & \sin\left(\frac{4\pi}{3}\right) \\
\cos\alpha & \cos\left(\frac{2\pi}{3}\right) & \cos\left(\frac{4\pi}{3}\right) \\
\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}}
\end{bmatrix}
\]

(2)

Figure 4. Block diagram of the proposed control method.

3.1 Synchronous Reference Frame Control

The Park transformation for electrical power system analysis was extended. The application of the Park transformation to three generic three-phase quantities supplies their components in \(dq0\) coordinates\(^2\). Figure 5 shows a schematic of the SRF control.

Figure 5. General structure for synchronous rotating frame control.

In general, three-phase voltages and currents are transformed into \(dq0\) co-ordinates by matrix \([L]\) as follows:
The three-phase load currents are transformed in dq0 co-ordinates by [L].

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

Therefore, by averaging \(i_{ld}\) and \(i_{ld}\) in domain \([0 - 2\pi]\) results in components \(i_{ld}\) and \(i_{ld}\), that is:

\[
\overline{i_{ld}} = \frac{1}{2\pi} \int_0^{2\pi} i_{ld} \, dt
\] (4)

\[
\overline{i_{lq}} = \frac{1}{2\pi} \int_0^{2\pi} i_{lq} \, dt
\]

Where,

\[
i_{ld} = \sqrt{\frac{2}{3}} \left[ i_{LA} \sin (\omega t - \frac{2\pi}{3}) + i_{LB} \sin \left( \omega t - \frac{2\pi}{3} \right) \right]
\] (5)

\[
i_{lq} = \sqrt{\frac{2}{3}} \left[ i_{LA} \cos (\omega t - \frac{2\pi}{3}) + i_{LB} \cos \left( \omega t - \frac{2\pi}{3} \right) \right]
\] (6)

\[
a_{Al}^{(i)} = \frac{2}{\sqrt{3}} \overline{i_d}(t) \quad \text{and} \quad b_{Al}^{(i)} = \frac{2}{\sqrt{3}} \overline{i_q}(t)
\] (7)

Equation (7) gives the relationship between the dc component of \(i_{ld}\) and \(i_{lq}\) and the coefficients of \(i_{ld}\), the compensating objective of the grid-connected inverter.

The three-phase load currents are transformed in dq0 co-ordinates as follows:

\[
u_d = [L] \begin{bmatrix} u_A \\ u_B \\ u_C \end{bmatrix}
\] (8)

Similarly, the averages of \(u_d\) and \(u_q\) are calculated, and the coefficients of \(u_i\), are:

\[
a_{Al}^{(u)} = \frac{2}{\sqrt{3}} \overline{u_d}(t) \quad \text{and} \quad b_{Al}^{(u)} = \frac{2}{\sqrt{3}} \overline{u_q}(t)
\] (9)

Hence, the following equations can be obtained:

\[
v_d = \frac{2}{3} \left( u_A \sin (\omega t - \frac{2\pi}{3}) + u_B \sin (\omega t + \frac{2\pi}{3}) + u_C \sin (\omega t + \frac{2\pi}{3}) \right)
\] (10)

\[
v_q = \frac{2}{3} \left( u_A \cos (\omega t - \frac{2\pi}{3}) + u_B \cos (\omega t + \frac{2\pi}{3}) + u_C \cos (\omega t + \frac{2\pi}{3}) \right)
\] (11)

\[
\overline{v_0} = \frac{1}{3} (v_A + v_B + v_C)
\] (12)

The control variables then become dc values; consequently, filtering and controlling can be easily achieved. The dc-link voltage in this structure is controlled by the essential output power, which is the reference for the active current controller. Usually, the dq control methods are associated with Proportional–Integral (PI) controllers because they have a satisfactory behavior when regulating dc variables. Equation (13) gives the matrix transfer function in dq coordinates.

\[
G_{PI}^{(dq)}(s) = \begin{bmatrix} K_p + \frac{K_i}{s} & 0 \\ 0 & K_p + \frac{K_i}{s} \end{bmatrix}
\] (13)

Where \(K_p\) and \(K_i\) are the proportional and integral gain of the controller, respectively.

### 4. Simulation Results

To demonstrate the effectiveness of the proposed control strategy on grid-connected PV and WT inverters, the system in Figure 1 was simulated in MATLAB/Simulink and a sinusoidal grid voltage is assumed. In the simulation, two case studies are taken into account. Case I: Without any compensation and case II: Without compensation devices and using propose control method.

#### 4.1 Case I: Unbalanced and Distorted System Currents without using Proposed Control Method

In case 1, the resulting system waveforms are shown in Figure 4 without any compensation. The dispersed generation unit (i.e., PV and WT) are connected to the system.
through a power electronic inverter and nonlinear loads (three-phase and three single-phase diode rectifiers), which produce the distorted waveforms. The DG sources and nonlinear loads make the system current nonlinear and unbalanced (Figure 6).

Figure 6. System, DG units and nonlinear loads current waveforms without compensation: (a) Grid currents; (b) PV currents; (c) WT currents; (d) nonlinear load 1 currents; (e) nonlinear load 2 currents.

4.2 Case II: With Using Propose Control Method

Case II, an improved power quality with the propose control method of grid connected PV inverter. The main contribution of this study is the PCC current compensation and micro-grid bus. The compensated system currents are explained in this subsection. The resulting system waveforms are shown in Figure 6. After connecting propose control method the THD has been reduced to below 3% and also the proposed control method is able to increase the inverter output current around 8 times of conventional one (Figure 7).

Figure 7. System and DG unit currents waveforms with using propose control method; (a) Grid currents; (b) PV currents.
5. Conclusion

This paper has proposed a new approach to control the interface inverter of photovoltaic in a micro-grid bus under nonlinear and unbalanced load conditions. The PV is connected to the grid by inverter, and a harmonic current is injected into the grid. The proposed control method is responsible for controlling the power injection to the grid and is also responsible for compensating for the main harmonic current in micro-grid bus and PCC. The novel method is able to increase the inverter output current around 8 times of conventional one. The simulation results demonstrated that the system current THD was reduced below 3% by the proposed method, which meets the IEEE-519 standard limits.

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7. References


