Harmonic currents Compensator Grid-Connected Inverter at the Microgrid

A. Asuhaimi Mohd Zin, A. Naderipour, M. H. Habibuddin Josep M. Guerrero

The main challenge associated with the grid-connected inverter in distributed generation (DG) systems is to maintain the harmonic contents in output current below the specified values and compensate for unbalanced loads even when the grid is subject to disturbances such as harmonic distortions and unbalanced loads. To overcome these challenges, a current control strategy for a three-phase grid-connected inverter under unbalanced and nonlinear load conditions is presented. It enables grid-connected inverter by the proposed control method to inject balanced clean currents to the grid even when the local loads are unbalanced and/or nonlinear and also compensate of the harmonic contents and control the active and reactive power. The main advantage and objective of this method is to effectively compensate for the harmonic currents content of the grid current and microgrid without using any compensation devices; such as active, passive and LCL filters.

Introduction: The main problem of microgrids (MGs) when exchanged the current with grid consider as source of harmonic distortion in Grid-Connected Inverter (GCI). Conventionally, despite the fact that it is not cost-effective, for elevating power quality problems, active power filters has been used [1]. The GCI controller is able to accomplish with unbalanced current harmonics and current of utility grid. However, compensation for the power quality problem, such as current harmonics, can be achieved through appropriate control strategies. This Letter proposes a new current compensation control method for photovoltaic (PV) GCI. The proposed control strategy consists of Synchronous Reference Frame (SRF) Phase Locked Loop (PLL) [2]. The ASRF is proposed to control power injection to the grid, and also is used for harmonic current compensation between Point of Common Coupling (PCC) and the MG.

The Proposed Control Method: To enhance grid and MG currents quality, an advanced current control method for the GCI, as shown in Figure 1, is introduced.

\[
\begin{bmatrix}
  u_d \\
  u_q \\
  u_0 \\
\end{bmatrix} = [L]egin{bmatrix}
  i_d \\
  i_q \\
  i_0 \\
\end{bmatrix} \quad \text{and} \quad \begin{bmatrix}
  i_d \\
  i_q \\
  i_0 \\
\end{bmatrix} = [L]^{-1}\begin{bmatrix}
  u_d \\
  u_q \\
  u_0 \\
\end{bmatrix}
\]

(1)

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

(2)

The phase angle of voltage and current signals set as reference current which achieves unity power factor while \(P^* = 0\). Refer to Figure 1 the current controller is under study. The Sinusoidal Pulse Width Modulation (SPWM) voltage frame guarantees. The voltage reference and design PLL synchronize inverter with grid. Hence \(P^* \) and \(Q^* \) as reference current in \(dq \) transform re-calculate as:

\[
P = V_d^* I_d^* + V_q^* I_q^* - V_g \quad \Rightarrow \quad I_d^* = \frac{P}{V_d^*}
\]

(3)

\[
Q = V_d^* I_q^* - V_q \quad \Rightarrow \quad I_q^* = \frac{Q}{V_d^*}
\]

(4)

where \(V_d \) and \(V_q \) are the grid voltage in \(dq \) transform. Furthermore the inverter is able to deliver \(P^* \) and \(Q^* \) where are reference active and reactive power, respectively. The inverter inject real power which the flow is controlled by \(I_d^* \) and \(I_q^* \) and a specified reference current \(I_{dref}^* \). When the system is fully inject reactive power \(I_{qref}^* \). The other components \(I_{dref}^* \) is extracted of the DC capacitor’s dynamics analysis. Hence the \(V_d^* \) and \(V_q^* \) of inverter gate SPWM are obtaining as following:

\[
V_d^* = K_p (I_d^* - I_d) + K_i \int (I_d^* - I_d) dt - \omega L f I_q + V_d
\]

\[
V_q^* = K_p (I_q^* - I_q) + K_i \int (I_q^* - I_q) dt - \omega L f I_d + V_q^*
\]

(5)

The SPWM modulating voltage signals are transformed from \(dq \) to \(abc \) frame. The PI controller are the main methods to control \(dq \) due to proper regulation of \(DC \) variables. Equation (6) gives the matrix transfer function in \(dq \) coordinates:

\[
G(s) = \frac{K_p + K_i}{s}
\]

(6)

where \(K_p \) and \(K_i \) are the controller’s proportional and integral gain, respectively. In order to provide the phase information of the grid voltage, which is required to generate the current reference \(i_d \) and also is designed to make the inverter synchronize with grid, The PLL technique can be used. Using a PLL system, the three current references are created, each with the error going into the controller, and the corresponding measured current can be compared. The switches of GCI are controlled by the output of PLL system. The duty cycles for the SPWM pattern is generated by modulator which is controlled by three PI units. The PLL schematic is illustrated in Figure 2.
The dq rotating frame converts back to abc stationery frame uses inverse Park's transformation Eq. 7, 8 and 9, by extracting reference signal.

\[
i_{sa} = i_d \sin(\omega t) + \cos(\omega t)
\]

\[
i_{sb} = i_d \sin(\omega t - \frac{2\pi}{3}) + \cos(\omega t - \frac{2\pi}{3})
\]

\[
i_{sc} = i_d \sin(\omega t + \frac{2\pi}{3}) + \cos(\omega t + \frac{2\pi}{3})
\] (9)

The unit of control compensation of harmonic currents uses DC quantities. The design compensation current is injected by appropriate gate plus for inverter which is transferred by gate driver controller to extract reference signal.

Simulation results: The basic MG in this letter includes the MT, the fuel cell, wind turbine and PV array which are connected to the grid by the interface inverter. The proposed control methods is applied to the PV. Furthermore, a fuel cell has an output of 50 kW and a grid-connected PV array has an output of 100 kW and also a 9 MW wind farm and 25MW MT are connected to the grid by AC/DA/AC converter. Another side of this system consists of two non-linear loads, which produced the distorted waveform. In the grid and MG the voltage is assumed sinusoidal. In the simulation, two case study are taken into account.

A. Case study I
The resulting system waveforms consist of grid, PV currents are shown in Figure 3 without any compensation devices.

B. Case study II
This case study has an improved power quality with the absence of compensation devices such as passive, active and LCL filters in the MG. Figures 4 (a) and (b) show the effective compensation values of the harmonic current for the grid and the PV. When all of the loads and DGs are connected, the Total Harmonic Distortion (THD) current without any compensation was 13.5%. As shown in Figure 4 (a), THD is reduced to 1.69% in the system with the proposed control method. The Current and THD value of study system is given in Tables 1.

Table 1: Current and THD Result

<table>
<thead>
<tr>
<th></th>
<th>Before Compensation</th>
<th>After Propose Control Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>THD %</td>
<td>Current (A)</td>
</tr>
<tr>
<td>System</td>
<td>207.6</td>
<td>1175</td>
</tr>
<tr>
<td>PV</td>
<td>250</td>
<td>339.6</td>
</tr>
</tbody>
</table>

Conclusion: This Letter proposes a new control strategy for harmonic current compensation for photovoltaic inverter between PCC and MG and also is responsible for controlling the power injection to the grid, and compensating unbalanced load. The presented simulation results show that the PCC harmonic currents due to unbalanced load, NLL and DGs are compensated to the desired value. This strategy can be used for single-phase and three-phase systems.

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References