Power Quality Improvement in Microgrid Using Active Power Conditioner
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Abstract—This paper presents a three-phase three leg Active Power Conditioner to improve power quality in micro grids based on renewable energy. A micro grid is a weak electrical grid which can be easily subject to disturbances. The Active Power Conditioner (APC) acts as an interface between renewable energy sources and the AC bus of a micro grid And uses an APC control strategy, which makes possible to inject energy in the micro grid, compensate the current harmonics and correct the power factor. The proposed control strategy allows the line current at the point of common coupling (PCC) to be balanced and sinusoidal even when the load is unbalanced. Consequently, the voltage at the PPC becomes balanced. Simulation results show the validity of the innovative control strategy.

Index Terms—Active Power Conditioner, Micro grids, Renewable Energy, Current control

I. INTRODUCTION

Nowadays we are using extensively nonlinear loads such as electric arc furnaces, electric arc welders, adjustable speed drives and switch mode power supplies has become a serious problem in electrical power systems. These loads generate a lot of harmonic currents, which are injected into the power system power electronics have created opportunities for the renewable sources to be exploited indifferent configurations. The power electronic interface allows renewable sources to be connected with the distribution grid or interconnected with other renewable and non-renewable generators, storage systems and loads in a micro grid. A micro grid is different from a main grid system which can be considered as an unlimited power so that load variations do not affect the stability of the system. On the contrary, in a micro grid, large and sudden changes in the load may result in voltage transient of large magnitudes in the AC bus. Moreover, the proliferation of switching power converters and nonlinear loads with large rated power can increase the contamination level in voltages and currents waveforms in a micro grid, forcing to improve the compensation characteristics required to satisfy more stringent harmonics standards.

A possible solution to overcome the above mentioned drawback is to use the APC as a power interface between the renewable energy sources and the AC bus of the micro grids as shown in Fig. 1.

The APC has proved to be an important alternative to compensate current and voltage disturbances in power distribution systems. Different APC topologies have been presented in the technical literature, but most of them are not adapted for microgrid applications.

![Figure 1. APC for Microgrid applications](image-url)

II. ACTIVE POWER CONDITIONER TOPOLOGY

Generally, four-wire APCs have been conceived using four leg converters [5]. This topology has proved better controllability [6] than the classical three-leg four-wire converter but the latter is preferred because of its lower number of power semiconductor devices. In this paper, it is shown that using an adequate control strategy, even with a simple three-leg four-wire system, it is possible to mitigate disturbances like voltage unbalance. The topology of the investigated APC and its
Interconnection with the microgrid is presented in Fig. 2. It consists of a three-leg four-wire voltage source inverter. In this type of applications, the VSI operates as a current controlled voltage source. In order to provide the neutral point, two capacitors are used to split the DC-link voltage and tie the neutral point to the mid-point of the two capacitors. This topology allows the current flow in both direction to the switches and capacitors.

Figure 2. APC topology

The three-phase APC current is given by:

\[ i_{fN} = i_{fA} + i_{fB} + i_{fC} \tag{4} \]

Where:
- \( i_{fA} \) the fundamental active current component;
- \( ilxk \) the addition of current harmonics;
- \( iluq \) the reactive current component.

The three-phase APC current is given by:

\[ i_{fA} + i_{lA} + i_{luq} + i_{fC} + i_{fB} = i_{x} \tag{5} \]

The APC switches generate undesirable current harmonics around the switching frequency and its multiples. Considering the switching frequency of the APC sufficiently high, these undesirable current harmonics can be filtered with the LR passive filter.

III. CONTROL OF THE APC

A. Control Strategy

There are many ways to design a control algorithm for an APC [7] [8]. Generally, the controller design is made considering that the grid voltage at the PCC is balanced. In a microgrid, the supply voltage itself can be distorted and/or unbalanced. Consequently, the controller of an APC used to improve the power quality in the microgrid has to be designed according to the weakness of this kind of grid.

The proposed control algorithm is a compensation method that makes the APC compensate the current of a non-linear load by forcing the microgrid side current to become sinusoidal and balanced (Fig. 3). The controller requires the three-phase grid current (ia, ib, ic), the three-phase voltage at the PCC (va, vb, vc) and the DC-link voltage (VDC). As shown in Fig. 3, the sinusoidal waveform and the phase of the grid current reference(ia*, ib*, ic*) comes from the line voltage thanks to a PLL.

The instantaneous load current is:

\[ i_{x} = i_{f} + i_{ld} + i_{luq} \tag{3} \]

Where:
- \( i_{f} \) the fundamental conditioner current component;
- \( i_{ld} \) the deforming component of the current.
The magnitude of the same current is obtained by passing the error signal between the DC-link voltage \(V_{DC}\) and a reference voltage \(V_{DC^*}\) through a PI controller. Using this magnitude and phase displacement of 120° and 240° respectively, the reference three-phase grid currents \(i_a^*, i_b^*,\) and \(i_c^*\) can be expressed as:

\[
i_a^* = PI \cdot \sin(\omega t) \tag{6}
\]

\[
i_b^* = PI \sin(\omega t - 2\pi/3) \tag{7}
\]

\[
i_c^* = PI \sin(\omega t - 4\pi/3) \tag{8}
\]

**B. Switching control**

As shown in Fig. 3, the hysteresis control has been used to keep the controlled current inside a defined band around the references. The status of the switches is determined according to the error. When the current is increasing and the error exceeds a certain positive value, the status of the switches changes and the current begins to decrease until the error reaches a certain negative value. Then, the switches status changes again.

Compared with linear controllers, the non-linear ones based on hysteresis strategies allow faster dynamic response and better robustness with respect to the variation of the non-linear load. A drawback of the hysteresis strategies is the switching frequency which is not constant and can generate a large side harmonics band around the switching frequency. To avoid this drawback, the switching frequency can be fixed using different solutions like variable hysteresis bandwidth [9] or modulated hysteresis [10].

**IV. SIMULATION RESULTS**

To validate the proposed control algorithm, many simulations have been run in various operating conditions using Matlab, SimPower Systems toolbox. The investigated active power conditioner has been simulated with six IGBTs controlled by the system illustrated in Fig.3. All the parameters are shown in Table 1. During all the simulations, the power coming from the renewable energy sources is considered unvarying.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC voltage (v_{abc}) [V]</td>
<td>230</td>
</tr>
<tr>
<td>DC-link voltage (V_{DC}) [V]</td>
<td>750</td>
</tr>
<tr>
<td>Inductor (L) [mH]</td>
<td>3</td>
</tr>
<tr>
<td>Capacitor (C) [μF]</td>
<td>20000</td>
</tr>
<tr>
<td>Hysteresis Band [A]</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**A. CASE STUDY 1**

During this case study load required only nonlinear load Fig shows the simulation diagram for microgrid a three-phase diode bridge rectifier with a 60 Ω resistor in series with a 0.1 mH inductor placed at the dc side. Initially grid interfacing inverter is not connected, so grid demand entirely supplied by grid alone then load current is identical to microgrid side current i.e non sinusoidal At 0.3s the APC is connected to network. Then inverter starts injecting compensating current the proposed control strategy allows the current \(i_{abcn}\) on the microgrid side to be sinusoidal Fig 5 shows the currents and supply voltage at the PCC. As can be seen, most of the current required by the load \(i_{labcn}\) is injected by the APC (renewable energies, \(i_{fabcn}\)) and the balance comes from the micro grid, \(i_{labcn}\). The current required by the load is non linear and as a THD of 28.16%. The supply current also identical to nonlinear and as a THD of 27.47%. and THD of supply voltage is 9.70%. After placing APC at 0.3s we get supply current and voltage is sinusoidal and as a THD of load current is 28.17% and THD of supply current is reduced to 3.26% and supply voltage is 1.32%.
B  CASE STUDY 2

During this case study load required linear and non linear load. Initially we place linear load, and at 0.02s we place nonlinear load. Then we place APC Fig shows supply current, load current, and conditioner current at PCC Initially current required by the load and supply current and voltage is sinusoidal. Because of linear load, After 0.02s load current and supply current is non sinusoidal and as a THD of both load current and supply current is 27.40%... But after placing the APC At 0.05s It inject compensation current in to system we get microgrid side current is sinusoidal and as a THD of load current is 28.14% and microgrid side current is 4.86%.

C  CASE STUDY 3

During this case study load required RL load and non linear load. APC is placed at 0.02s Load is composed by non linear load and three phase inductor in series with a three phase resistor requires about 3kw active power 4kvar reactive power. In this case we eliminate the harmonics and improve the power factor. Figure shows the load current and load voltage supply current and supply voltage at PCC Here Active power conditioner placed at 0.02s. After placing APC the measured power factor between load current and supply voltage is 0.58 the APC to impose a unity power between load current and supply voltage the phase of micro grid side current inverted to the phase of supply voltage at the PCC because power injected by the APC exceed the power required by the load. So remaining energy is injected in to the microgrid and compensates the current able harmonics.
V. CONCLUSIONS

In this paper, a three phase three leg APC used to improve power quality in micro grids based on renewable energy has been presented. The APC is controlled using an innovative control strategy allowing the line current at the point of common coupling to be balanced and sinusoidal even when the load is unbalanced. Active power conditioner, it simultaneously mitigate current harmonics, current unbalance and improve the power factor. Different case studies have been investigated with the APC simulated in the Matlab SimPowerSystem.

VI. REFERENCES


