Power quality improvement using renewable energy

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Abstract. This paper presents a three-phase Active Power Conditioner to improve power quality in microgrids based on renewable energy. Three hysteresis controllers are used to control the six IGBT bridge. In a microgrid which is a weak electrical grid the disturbances can be very important. The Active Power Conditioner (APC) presented in this paper acts as an interface between renewable energy sources and the AC bus of microgrid. The improved control strategy used offer the possibility to inject electrical energy from the renewable sources and on the other hand to improve the power quality in the same microgrid. This control strategy named *Extended Indirect Control Strategy* is capable to achieve better values for the following power quality indicators: THD_I (Total Harmonic Distortion), PF (Power Factor), current and voltage balancing. Simulation results show the validity of the innovative control strategy.

Key words

Active Power Conditioner, Renewable Energy, Power Quality, Microgrids, Current hysteresis control.

1. Introduction

Nowadays the advances in power electronics give us the possibility to use the renewable sources in different configurations. Using power electronics interfaces the renewable sources can be connected with distribution grid or interconnected with other renewable and non-renewable generators, storage systems and loads in microgrids [1]. A microgrid 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 microgrid, large and sudden changes in the load may result in voltage transient of large magnitudes in the AC bus. Moreover, the proliferation of non-linear load such computation technique, switching power converters can decrease the power quality indicators especially in microgrids. The power quality also in grid is affected by nonlinear loads, but in microgrids this can be very poor under mentioned conditions.

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 microgrids as shown in Fig. 1.

APC have proved to be an important alternative to compensate current and voltage disturbances in power distribution systems [2], [3]. Different APC topologies have been presented in the technical literature [4], but most of them are not adapted for microgrids applications.

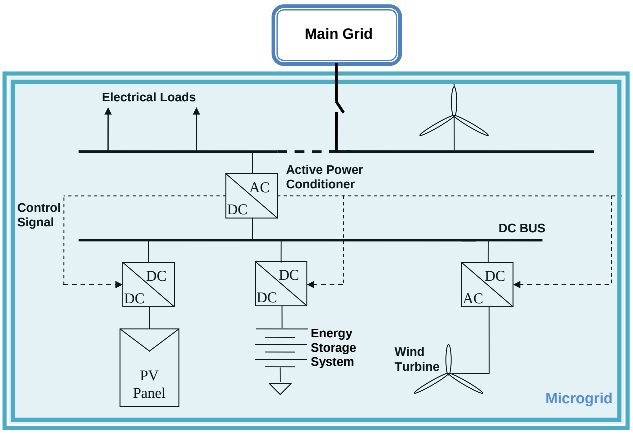

Fig. 1. APC for microgrid applications

This paper presents an APC used to improve the power quality in a microgrid. The attention will be mainly focused on the innovative control strategy, which allows injecting energy in the microgrid, compensating the current harmonics, correcting the power factor and balancing the supply voltage at the PCC (Point of Common Coupling). The validity of the control strategy has been proved through many simulation tests using SimPowerSystems from MATLAB.

2. Active Power Conditioner Topology

The most utilised topology, to manage four currents, is 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, THD and others. 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 to flow in both directions through the switches and the capacitors, causing voltage deviation between the DC capacitors.

$$i_{fa} + i_{fb} + i_{fc} = i_{fN} \tag{1}$$

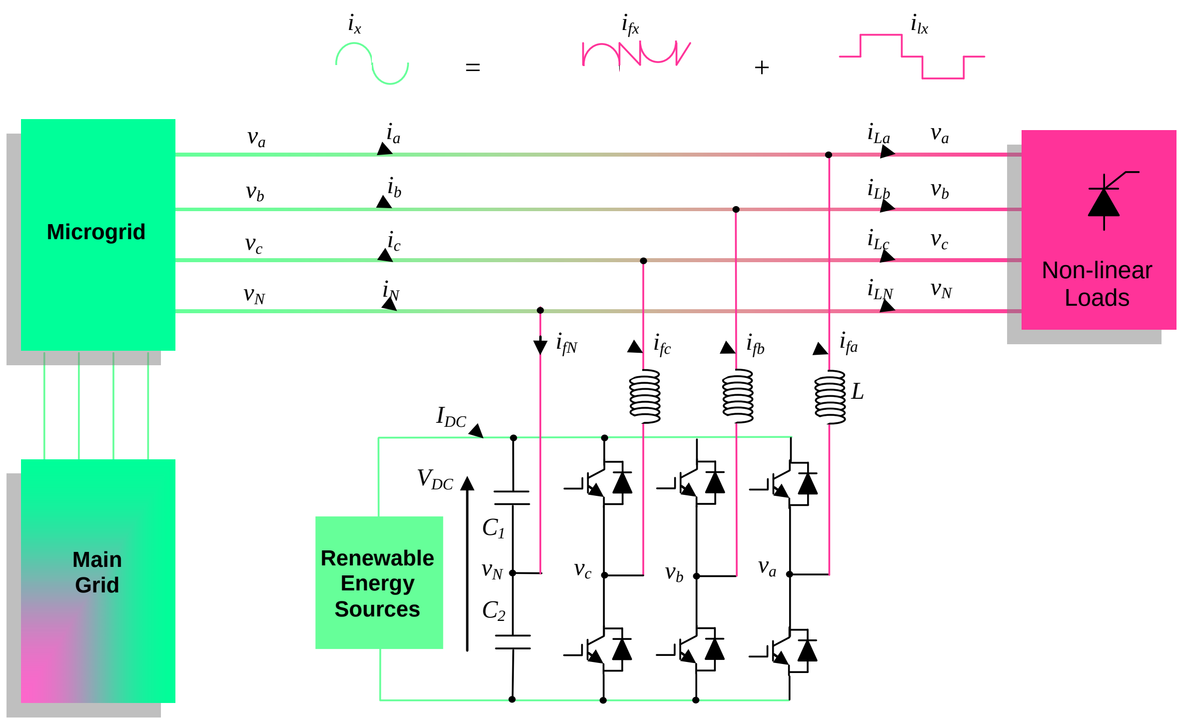

Figure 2. APF topology

where:
i_{fa}, i_{fb}, i_{fc} are phase APC currents and i_{fN} is the APC neutral current.

Therefore, the total DC voltage will oscillate not only at the switching frequency but also at the corresponding frequency of the neutral current. As shown in [2], if the current control is made by hysteresis, the above mentioned drawback can be limited with a dynamic offset level added to both limits of the hysteresis band.

For the investigated topology presented in Fig. 2, the current at (PCC) is:

$$i_x = i_{lx} + i_{fx} \tag{2}$$

where:

i_x, i_{lx}, i_{fx} *are* the microgrid side current, the load current, and the APC current respectively. The *x* index points the *a*, *b* and *c* current phases.

The instantaneous load current is:

$$i_{lx} = i^1_{lx} + i_{lxk} + i_{lxq} \tag{3}$$

where:

- i^1_{lx} the fundamental active current component;

- i_{lxk} the addition of current harmonics;

- i_{lxq} the reactive current component.

The three-phase APC current is given by:

$$i_{fx} = i^1_{fx} + \tilde{i}_{fx} \tag{4}$$

i^1_{fx} - the fundamental conditioner current component;

$\tilde{i}_{fx}$ - the deforming component of the current.

As shown in Fig. 2 the current drawn from the grid has to be sinusoidal and moreover, in phase with the voltage at PCC. Consequently, the control strategy for the APC has to be designed in order to ensure a sinusoidal wave for the grid current (i_x):

$$i^1_{lx} + i_{lxk} + i_{lxq} + i^1_{fx} + \tilde{i}_{fx} = i_x \tag{5}$$

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.

3. Control of APC

A. Control Strategy

There are many ways to design a control algorithm for an APC [7]. Generally, the controller design is made considering that the grid voltage at the P_{CC} 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 (V_{DC}). 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 magnitude of the same current is obtained by passing the error signal (ε) between the DC-link voltage (V_{DC}) and a reference voltage (V^*_{DC}) through a PI controller.

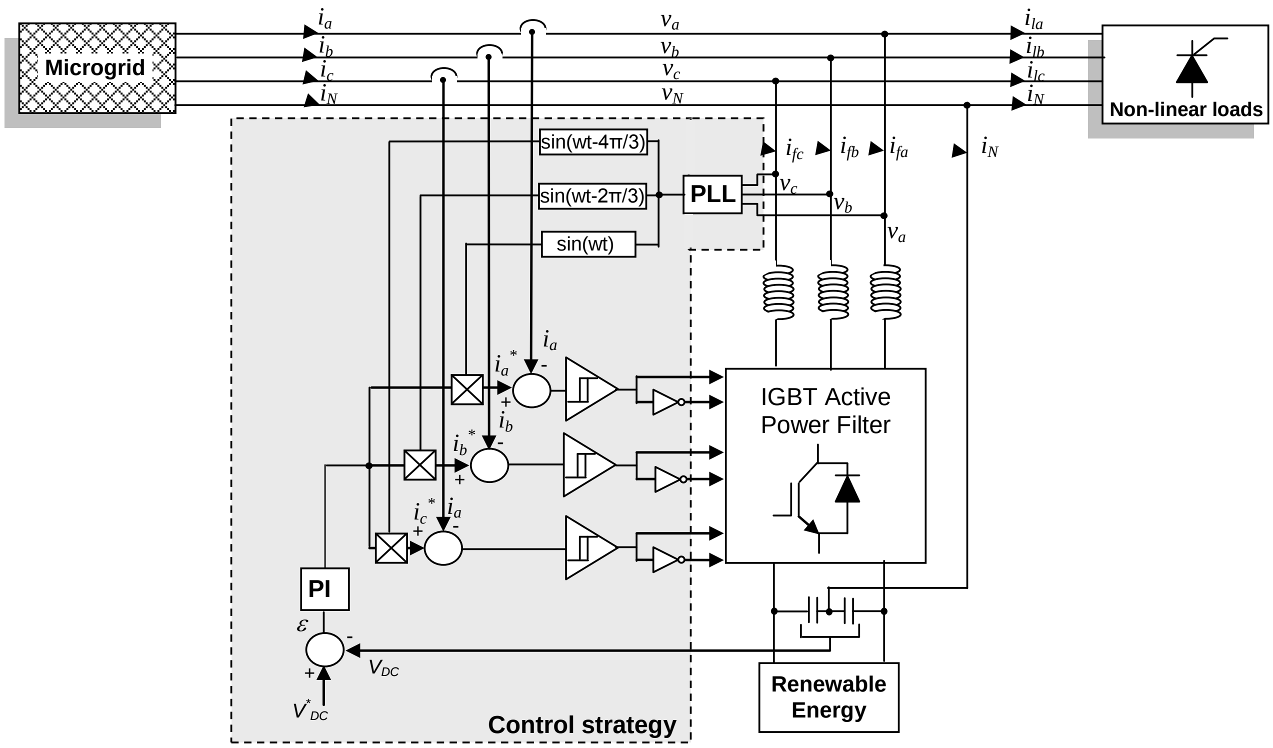

Figure 3. APC control strategy

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:

$$i_a^* = \varepsilon \cdot \sin(\omega t) \tag{6}$$

$$i_b^* = \varepsilon \cdot \sin\left(\omega t - \frac{2\pi}{3}\right) \tag{7}$$

$$i_c^* = \varepsilon \cdot \sin\left(\omega t - \frac{4\pi}{3}\right) \tag{8}$$

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 or modulated hysteresis. But this is not the object of this paper.

4. Simulation Results

To validate the proposed control algorithm, many simulations have been run in various operating conditions using Matlab, SimPowerSystems 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.

Table 1: Parameters of the APC

Parameters	**Value**
AC voltage v_{abc} [V]	230
DC-link voltage (V_{DC}) [V]	750
Inductor (L) [mH]	3,3
Capacitor (C) [μF]	20000
Hysteresis Band [A]	0.5

The simulation results are grouped and presented according to the following power quality indicators: THD (Total Harmonic Distortion), power factor.

A. The current and voltages in PCC

The light energy from the sun can be converted in electrical energy using photovoltaic panels. This energy can be added to grid by the APC. Also other renewable sources can be added in DC BUS to inject energy in Pcc.

In Fig. 4 are presented: i_S – the current from the grid which is decreasing at t=0.1s when the renewable source is starting to inject current; i_L – is the load current which have no variations; i_f – is the current through APC which at t=0.1s is increasing. This means that the current from the renewable source is added to grid current; v – is the voltage in PCC.

B. The current and voltages in PCC when is used a non-linear load

In Figure 5 are presented the current variations in Pcc when the renewable source inject the current at t=0.1s and the load is a nonlinear one: i_S – the current from the grid which is decreasing at t=0.1s when the renewable source is starting to inject current; i_L – is the load current which have no variations but is a non-sinusoidal current; i_f – is the current through APC which at t=0.1s is increasing which mean that the current from the renewable source is added to grid current; v – is the voltage in Pcc.

It can be seen that the energy from the renewable source is used and in the same time the power quality indicators can be improved.

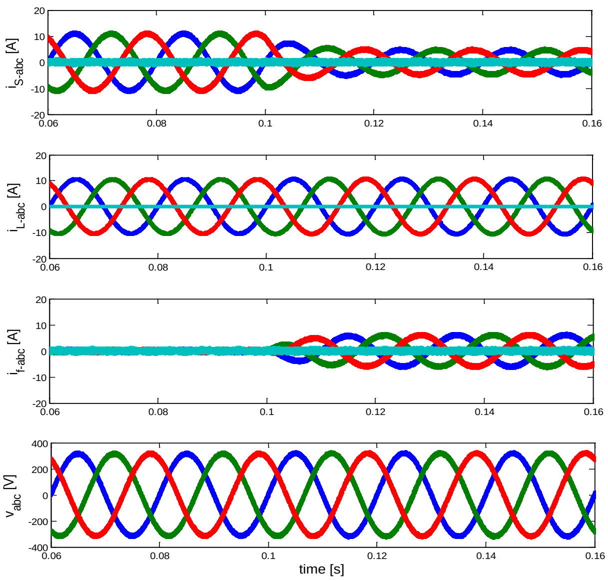

Figure 4. Currents and voltage in PCC

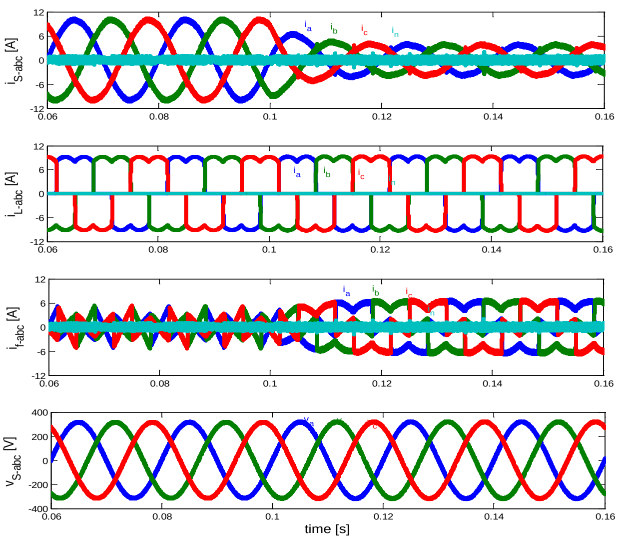

Figure 5. Currents and voltage in the PCC during harmonics compensation test

C. The current and Voltages in PCC when is used a load with a low power factor

In Figure 6 there are presented simulations results when it is simulated a load with a natural PF of 0,69.

It can observed the load voltage and current for phase a (v_{La}; i_{La}), the grid voltage and current for phase a (v_{Sa}; i_{Sa}); the APC current and voltage (v_{Fa}; i_{Fa}) and the voltage in Pcc (v_a, v_b, v_c).

Using the energy from renewable source the amplitude of grid current is reduced and the power factor is increased.

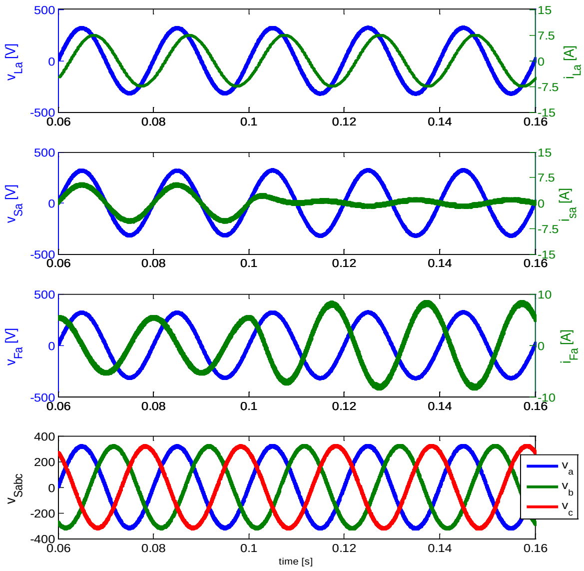

Figure 6. Currents and voltage in the PCC during power factor correction

4. Conclusion

The active power conditioner presented is capable to use energy from a renewable source and in the same time to improve the power quality indicators on grid.

The load feed by the microgrid is not affected in voltage level.

The limitation for the proposed solutions is regarding the switching frequency.

This APC can be used in a microgrid where there are interconnections between renewable sources and grid.

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