International Conference on Renewable Energies and Power Quality (ICREPQ'14)
Cordoba (Spain), 8th to 10th April, 2014
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.12, April 2014

Control strategy for an interface to improve the power quality at the connection of AC microgrids

Salvador P. Litrán, Patricio Salmerón, Jaime Prieto and Alejandro Pérez

Departamento de Ingeniería Eléctrica y Térmica
Escuela Técnica Superior de Ingeniería, University of Huelva
Ctra. de Palos de la Frontera s/n, 21819, Palos de la Frontera, Huelva, Spain
Phone: +34-959217585, Fax: +34-959217304
e-mail: salvador@uhu.es; patricio@uhu.es; jpthomas@uhu.es; aperez@uhu.es

Abstract. In this paper, a control strategy is proposed for an interface which is connected between a microgrid and main grid. The interface is based on an active power filter configuration of series connection. The proposed control strategy allows mitigating of current harmonics and reduction of voltage unbalances that may appear at the microgrid side and/or at the network side. The proposed strategy was verified by simulation. To do this, a simulation platform based on MATLAB-Simulink was developed. The interface was subjected to voltage unbalances and current harmonics produced at the microgrid side and main grid side. The results obtained demonstrate the validity of the designed interface with the proposed strategy.

Key words

Microgrids, power quality, distributed generation, harmonic compensation, unbalance voltage.

1. Introduction

Nowadays most electrical equipment are connected to the mains through a power electronic converter. The objective of this interface is to control the power injection/consumption of the electrical device, depending on whether it is a load or a source.

On the other hand, it is becoming more common to connect microgenerators to distribution network resulting in the so-called distributed generation (DG). The increase in nonlinear loads connection and penetration of distributed generation systems based on power electronics may introduce power quality issues to the distribution power system, such as harmonics, protection interferences, voltage regulation problems, etc.

Microgrids are proposed to isolate the problems associated with distributed generation. A microgrid is a local grid consisting of distributed generators, energy storage systems and dispersed loads, which can operate in either grid-connected or islanded modes [1].

Two of the most important problems in microgrids are related to harmonics and voltage unbalances. The first one is due to the connection of loads and micro-generators that use power electronic converters. The second one is due mainly to many of the equipment, which are connected to the microgrid, are low power, so they usually are single-phase, as a consequence, voltage unbalances in the side of the microgrid are produced.

To mitigate these problems of lack of quality in microgrids are proposed different solutions. Some of them are based on improving the functioning of the converters that connect equipment of DG to the network [2,3]. Other proposals are based on the use of power quality compensator [4,5] which integrate generation units with the capacity to active power filter such that two different controllers are included for the power converter, one for injection of power into the network and another for the quality improvement. On the other hand, when the microgrid is connected to the public network, it should not cause disturbances to the rest of the system, so that a connection interface between the microgrid and the main grid is necessary to avoid these issues. These interfaces are based on a configuration of series-parallel active power filter [6].

In this paper is proposed the use of a series active power filter as an interface between microgrid and main network. The active filter was controlled to compensate voltage unbalances and mitigate current harmonics. The proposed strategy was verified by simulation. To do this, a simulation platform based on MATLAB-Simulink was developed. The equipment was subjected to voltage unbalances and current harmonics produced at the microgrid side and main grid side.

2. Control strategy

The interface consist of a inverter connected in series with the system between main grid and microgrid. Fig. 1 shows the general scheme, where the main network is

https://doi.org/10.24084/repqj12.498

represented by its Thevenin equivalent and the microgrid by a set of source and nonlinear load.

The series APF consists of an inverter bridge of IGBTs. At the ac side a ripple filter is connected, which allow the high frequency components to be eliminated. Connection to the system is done with coupling transformers.

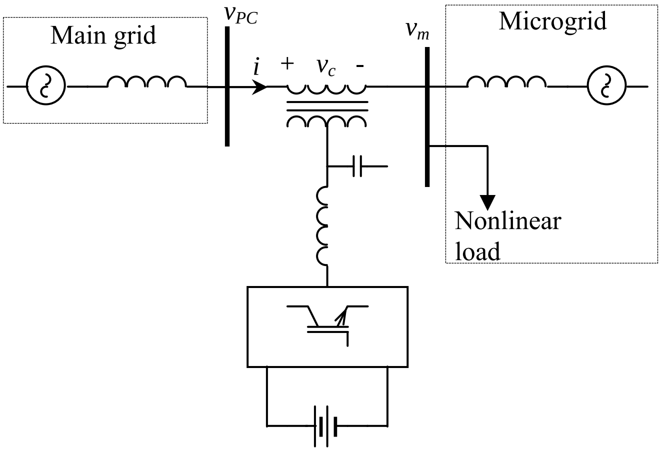

Fig. 1. Scheme of interface between utility grid and microgrid

The objective of the proposed control strategy is to avoid transferring of voltage unbalances and current harmonics from the main grid to microgrid or from microgrid to main grid. Thus, the inverter must generate a compensation voltage such that at the network side, voltage unbalances are not transmitted to the microgrid and viceversa. Furthermore, the generated harmonic currents should not be transferred between two networks. Therefore, two control loops will be designed: one to compensate voltage unbalances and another to mitigate current harmonics.

A. Voltage unbalance compensation

The direct sequence component of voltage vector of the "a" phase can be calculated by means of the following expression

$$v_a^+ = \frac{1}{\sqrt{3}}\left(v_a + a\,v_b + a^2 v_c\right) \tag{1}$$

Where v_a, v_b and v_c are the components of the voltage vector and a operator is defined as $a = e^{j2\pi/3}$, what supposes a 120° phase shift. This operator can be implemented by an all pass filter, [7].

Once (1) is applied, the Fortescue inverse transformation allows voltage vector of direct sequence component to be obtained. It is calculated by means of the expression

$$\vec{\mathbf{v}}^+ = \begin{bmatrix} v_a^+ & v_b^+ & v_c^+ \end{bmatrix}^T = \frac{1}{\sqrt{3}}\begin{bmatrix} v_a^+ & a^2\,v_a^+ & a\,v_a^+ \end{bmatrix}^T \tag{2}$$

Where, v_a^+, v_b^+ and v_c^+ are the components of the direct sequence voltage vector for each phase.

These components are obtained at the main network side ($\mathbf{v}_{PC}$) and at microgrid side ($\mathbf{v}_m$). So, the compensation voltage vector ($\mathbf{v}_c$) will be calculated by

$$\mathbf{v}_c = \mathbf{v}_{PC} - \mathbf{v}_{PC}^+ - \mathbf{v}_m + \mathbf{v}_m^+ \tag{3}$$

B. Current harmonic compensation

To mitigate the current harmonics, the inverter is controlled to present zero impedance at the fundamental frequency and high impedance at the frequencies of the load harmonics. For it, the compensation voltage will be proportional to the current harmonics

$$v_C = k\,i_h \tag{4}$$

Where k is the proportionality constant.

Fig. 2 shows the single-phase equivalent circuit of Fig. 1 for a harmonic of h order. Here, the main grid and the microgrid are represented by its Thevenin equivalent and the inverter by a controlled voltage source of v_C value. By applying Kirchhoff's voltage law and the equation (4), the current is given by

$$I_h = \frac{v_{PCh} - v_{mh}}{Z_{PCh} + Z_{mh} + k} \tag{5}$$

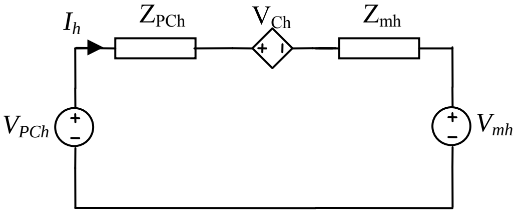

Fig. 2. Single-phase equivalent circuit of Fig. 1 for a harmonic of h order

According (5), the h order harmonic of the current can be mitigated when k has a high value, ideally k should be infinite, however, in the practice it is enough when $k >> Z_{PCh}+Z_{mh}$ to the most significant harmonics.

3. Simulation results

A model for the circuit shows in Fig. 1 was developed in MATLAB/Simulink. Main network and microgrid was modeled by its Thevenin equivalent. For the inverter model was used the SymPowerSystem library. The proposed control was applied and the system was subjected to disturbances at the network side and microgrid side. Fig. 3 shows the power system scheme. The values of the passive elements are included in Table I.

The main grid impedance is considered less than microgrid impedance. This is intended to consider the microgrid weaker than the main grid.

Table I.- Values passive elements

Main grid	R_{PC}= 1 Ω	L_{PC}= 1 mH
Microgrid	R_m= 3 Ω	L_m= 3 mH
Ripple filter	C_{rf}=50 µF	L_{rf}=10 mH

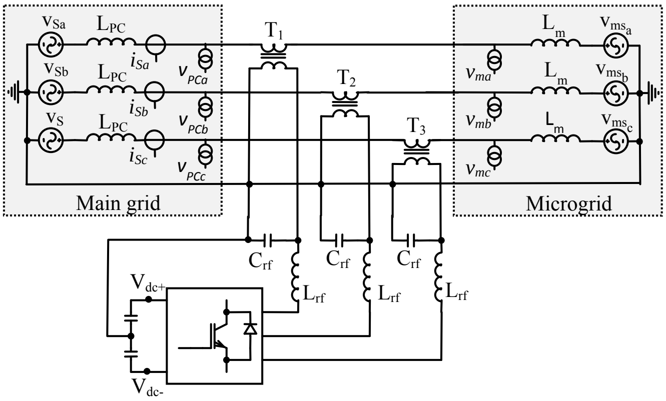

Fig. 3. Simulation circuit for the series interface

The system was subjected to different tests in two different situations. In one, the power flow is from the main grid to the microgrid, and in the other, the microgrid is what gives power to the main grid.

Among all the tests performed, in this paper are only presented the results of two different network situations:

- Test 1. The voltages at the main network side have an unbalance of 25% and further have a 5th order harmonic of 12% of the fundamental harmonic. In this case, the power flow is from the main grid to microgrid.

- Test 2. The voltages at the microgrid side have an unbalance of 25% and contain a 5th order harmonic of 12% of the fundamental harmonic. In this test, power flow is considered from the microgrid to the main grid.

A. Test 1. Disturbance at the main grid.

In the first test, the main grid voltage contains a 5th order harmonic of 12% and a negative sequence component of 25%. Fig. 4 shows the waveforms of the voltage at the point of common coupling and the current before connecting the inverter.

When the interface is connected, it is obtained the waveform of the voltages at the main grid side and at the microgrid side shown in Fig. 5. The proposed control strategy was applied to the inverter. The proportionality constant defined in (4) was fixed in 50. The unbalance factor was calculated, being its value of 5.2 %. This represents a significant reduction of voltage unbalance; however, it is not completely eliminated. It is due to the current system is unbalanced, resulting in different voltage drops across the equivalent impedances in each phase. This current unbalances cannot be compensated with a series topology, so these slight unbalance voltage that depends on the current unbalance will always be present.

On the other hand, taking into account the "a" phase, the current THD is reduced from 24.6% to 4.9%. This reduction is even higher in the other phases. Therefore, it is possible to state that the interface "isolates" the microgrid from the main grid harmonics. Table II shows the most important results.

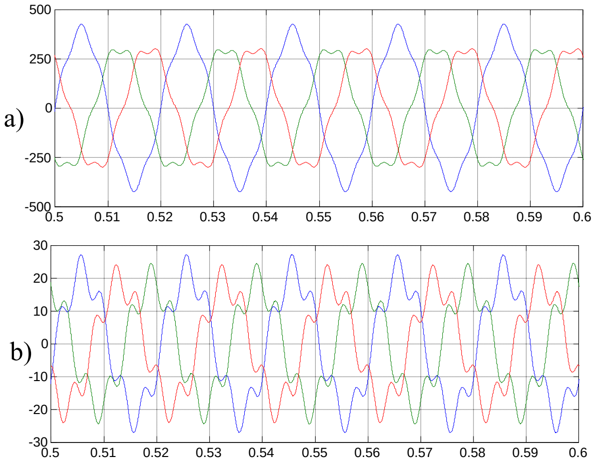

Fig. 4. Test 1, waveform voltage and current, before the interface is connected. a) Voltage $\mathbf{v}_{PC}$; b) current

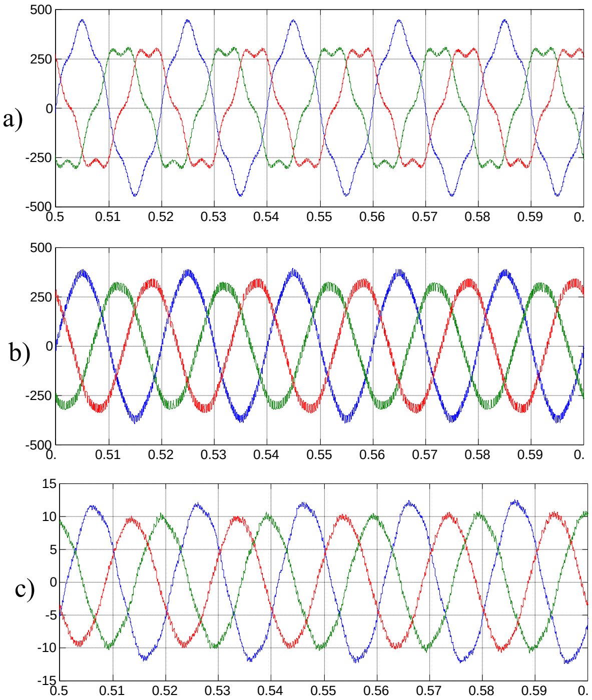

Fig. 5. Test 1, waveform voltage and current, after the interface is connected. a) Voltage $\mathbf{v}_{PC}$; b) voltage $\mathbf{v}_m$ and c) current

A similar analysis can be performed with respect to the harmonics of the voltage. The results shown in Fig. 5a and 5b illustrate how the interface "isolates" the microgrid of the voltage harmonics from the main grid.

Table II. Results obtained in test 1. (1) Without interface and (2) with interface

		VPC			Vm			I		
		a	b	c	a	b	c	a	b	c
(1)	rms (V,A)	279	216	216	279	216	216	15.5	13.5	13.5
	THD (%)	7.6	9.8	9.8	7.6	9.8	9.8	24.6	28.3	28.3
(2)	rms (V,A)	286	217	211	247	228	229	10,7	8,3	8,2
	THD (%)	9.8	13.1	13.5	3.5	5.0	5.1	4.9	3.7	3.7

B. Test 2. Disturbance at the microgrid

In this test, the voltages at the microgrid side have an unbalance of 25% and contain a 5th order harmonic of 12% of the fundamental harmonic. At the main grid side, the voltages are balanced and sinusoidal.

Fig. 6 shows the waveform before to connect the interface. Voltages and currents present a waveform no sinusoidal, with the 5th harmonic as most significant. The Table III shows the main results of rms values and THD of voltages and currents.

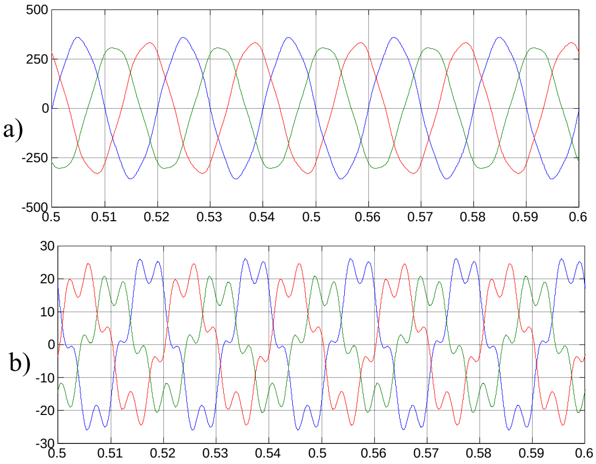

Fig. 6. Test 2, waveform voltage and current, before the interface is connected. a) Voltage $\mathbf{v}_{PC}$; b) current

After, the interface is connected to the system with the control strategy proposed. The proportionality constant was fixed in 50. The voltage and current waveforms are shown in Fig. 7. Voltage at the main grid and current are almost sinusoidal. However, the voltages at the microgrid side are strongly distorted. Therefore, the interface isolates the main grid of harmonics generated in the microgrid side.

Respect to the voltage unbalance, with the proposed control is possible to reduce it. The calculated value of unbalance factor is of 3.8 %. It is an important reduction however, as it occurred in test 1, its value is not null. This is justified by the current unbalance that causes an unbalance in the voltages due to drops in system impedances. These cannot be avoided with an interface topology of series connection.

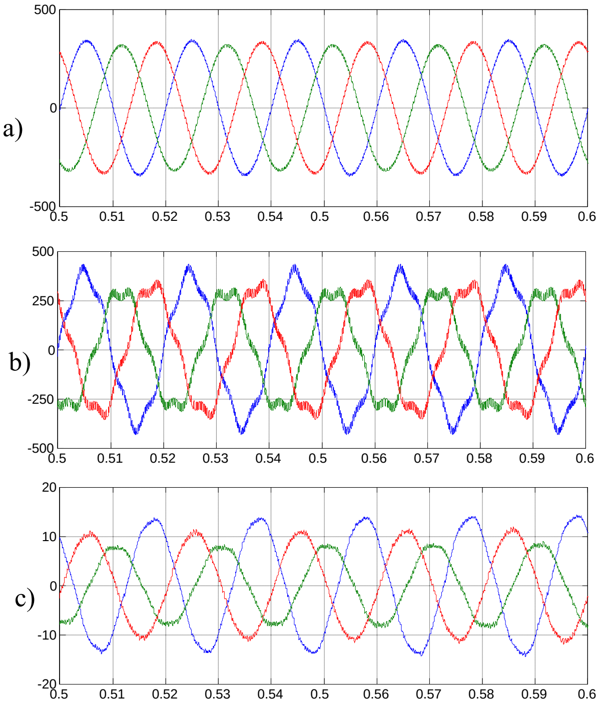

Fig. 7. Test 2, waveform voltage and current, after the interface is connected. a) Voltage $\mathbf{v}_{PC}$; b) voltage $\mathbf{v}_m$ and c) current

Table III. Results obtained in test 2. (1) Without interface and (2) with interface

		VPC			Vm			I		
		a	b	c	a	b	c	a	b	c
(1)	rms (V,A)	247	226	215	247	225	215	13.1	11.5	11.2
	THD (%)	2.9	3.2	3.2	2.9	3.2	3.2	24.6	28.3	28.1
(2)	rms (V,A)	240	225	231	268	225	208	9.3	7.6	8.2
	THD (%)	1.4	1.8	1.8	11	13	15	2.8	3.2	2.5

4. Conclusion

In this paper, the connection of an interface between a microgrid and main network is proposed. This equipment has a topology based on a series active filter configuration. In addition, a control strategy is proposed to control the inverter interface. The control objectives to be addressed were:

- Mitigation current harmonics.
- Avoid mutual transfer voltage unbalances between main grid and microgrid.

Thus, the interface must generate a compensation voltage such that at the network side, voltage unbalances are not transmitted to the microgrid and viceversa. Furthermore, the generated harmonic currents must not be transferred between two networks. Two control loops were designed: one to compensate voltage unbalances and another to mitigate current harmonics. The first one is based on calculating the direct sequence components of the voltages at the main grid side and microgrid side. The second one is based on generating a proportional voltage to current harmonics.

To verify the operation of the equipment, a simulation platform based on MATLAB/Simulink was designed. The equipment was subjected to unbalances and harmonics of voltage and current produced at the microgrid side and main network side. The simulation results demonstrate the validity of the designed interface with the proposed strategy.

References

[1] J. M. Guerrero, P. C. Loh, T-L Lee, M. Chandorkar, "Advanced control architectures for intelligent microgrids-Part II: power quality, energy storage, and A/DC microgrids," IEEE Trans. on Industrial Electronics, Vol. 60, no 4, pp-1263-1270, April 2013.

[2] R. Teorodescu, F. Blaabjerg, M. Liserre, P. C. Loh, "Proportional-resonant controllers and filters for grid-connected voltage-source converters," IEE Proc-Electr. Power Appl. Vol. 153, no 5, September 2006.

[3] F. Blaabjerg, R. Teodorescu, M. Liserre, A. V. Timbus, "Overview of control and grid synchronization for distributed power generation systems," IEEE Trans. Industrial Electronics, Vol. 53, no 3, October 2006.

[4] X. Tang, K. M. Tsang, W. L. Chan, "A power quality compensator with DG interface capability using repetitive control," IEEE Trans. On Energy Conversion, Vol. 27, no 2, June 2012.

[5] J. He, Y. W. Li, M. S. Munir, "A flexible harmonic control approach through voltage-controlled DG-grid interfacing converters," IEEE Trans. On Industrial Electronics, Vol. 59, no 1, January 2012.

[6] Y. W. Li, M. Vilathgamuwa, P. C. Loh, "A Grid-interfacing power quality compensator for three-phase three-wire microgrid applications," IEEE Trans. On Power Electronics, Vol. 21, no 4, July 2006.

[7] Salmerón P. y Litrán S. P., "A Control Strategy for Hybrid Power Filter to Compensate Four-Wires Three_Phase Systems". IEEE Transaction on Power Electronics. Vol. 25, Isue 7, pp. 1923-1931, July 2010