21th International Conference on Renewable Energies and Power Quality (ICREPQ'23)
Madrid (Spain), 24th to 26th May 2023
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.21, July 2023

Inverter Control Design for the optimal management of electrical Micro-grids

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Abstract. Nowadays, the promotion of renewable energy sources is a necessity. Technically, the increase of the renewable penetration in the power system (PS) is a challenge. One solution for this problem is the use of self-controlled microgrids (smartgrid, SG). In this work, the design of an algorithm to optimal manage the SG energy through the power inverter control in the SG is presented. In general, a SG consists of renewable energy sources, electrical loads and storage systems. In an isolated SG (no connected to the power system), a DC/AC (direct current / alternating current) converter (power inverter, PInv) is necessary to provide an alternating voltage to supply the loads. If the SG is connected to the PS, the PInv is used to inject the active power from the renewable energy sources.

Key words. Smartgrid, power inverter, simulation platform, Matlab/Simulink, power quality.

1. Introduction

The energy dependence and environmental problems are making that the governments of many countries propose energy self-sufficiency plans for homes and other types of buildings. So, these problems are reduced by promoting the integration into the PS of self-controlled installations based on renewable energy sources, SG.

However, distributed generation presents several inconveniences such as bidirectional power flow, associated to the challenge of the complexity to establish the protection systems, a discontinuous production and electrical power signal deteriorated due, among other causes, to the use of power electronic interfaces.

One way of tackling this problem is the use of SG. They allow the management of several energy sources, energy storage systems and some types of controllable loads, such as thermal or electric vehicles, through a suitable control system. This SG could operate connected to the PS and also in isolated mode, substituting the PS, if necessary. This behaviour of the SG increases its reliability.

SGs can be directly connected to the distribution grid or through a PInv that allows the SG to inject energy into the PS whether the SG production is higher than its own consumption. In addition, SG allows its own disconnection to PS, when this last one fails. In this case, the SG manages its own production and demand, [1],[2].

In this paper, the design of a control algorithm for the PInv is presented, to manage the interaction between the SG and the PS, [3]-[5]. Figure 1 shows the general scheme of a simple AC micro-grid.

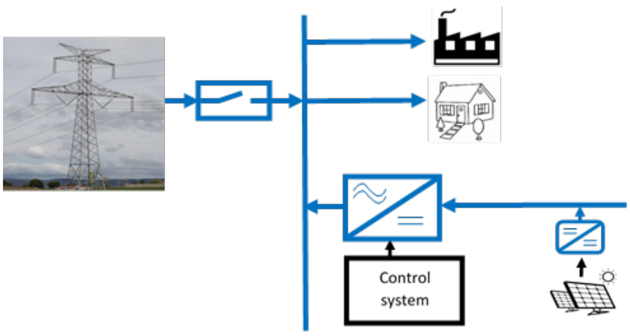


Fig.1. Micro-grid scheme without energy storage

The renewable sources are connected to DC side. The PInv is controlled to supply the AC loads and to inject the resting energy to the PS, [6]-[7]. In the grid-connected mode, the PInv could be also used as a shunt active power filter and an adequate current control would allow the improvement of the power quality in the PCC, [8]-[11].

When the power system breaks down, the PInv control system will change to operate as a voltage source to only supply the SG AC loads.

So, the target of this work is to design an optimal control algorithm for the SG PInv which improves the existing ones and integrates all the requirements indicated above. To do that, different software solutions has been used in the technical literature, [12]-[14]. In this case, an own simulation platform has been developed within Matlab-Simulink to model the SG configuration and to check the control algorithm with different kinds of loads.

In section 1, the general scheme of a SG is presented. The designed PInv control algorithm is shown in section 2. It allows the operation of the SG in isolated mode if the PS fails. In addition, in grid-connected mode, it improves the electrical power quality in the point of common connection (PCC). In section 3, some practical results are presented through a simulation platform designed within Matlab-Simulink. Different linear and non-linear electrical loads are connected, to analyse the control performance in stationary and transient conditions.

2. System description

The SG designed to prove the control algorithm includes the PInv which supplies linear and non-linear loads. The AC voltage is imposed by the PS if the SG is grid-connected or directly supplied by the PInv in isolated mode.

The SG complete scheme has been modelled using Matlab/Simulink and it is shown in figure 2. Different linear and non-linear loads ("Load" in figure 2) are connected to the general power system ("power System" in figure 2) through a connection switch. In the DC side of the PInv, the renewable energy sources are connected. The PInv AC side is connected through a reactance and a passive filter ("Inverter Power Stage in figure 2).

For the SG management, the rms value of source voltage is continuously measured. If source voltage is near the nominal value, the SG will be connected to the PS and it control the AC voltage. So, a current control will be implemented in the PInv. If the source voltage falls, the SG will be disconnected, and the AC voltage will be fixed by the Pinv through a voltage control. Figure 3 shows a flowchart of the SG management.

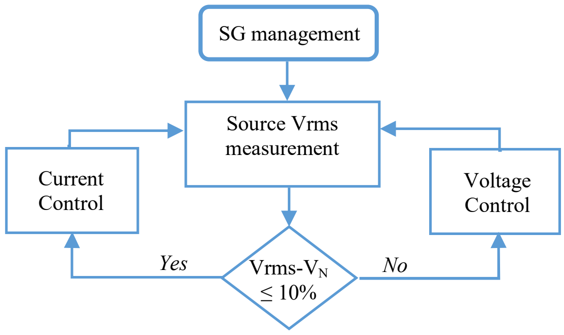


Fig.3. Control Flowchart

A. *Grid-connected scheme*

When the SG is connected to the PS, a current control of the PInv injects the renewable energy to the AC loads. If this active power is greater than the required by the loads, the resting energy is injected to the PS. In addition, the injected current can be improved to compensate harmonics and non-balanced currents produced by the AC loads. So, the designed current control will upgrade the power quality at the SG PCC. In short, the proposed current control strategy will include the injection of the active power generated by the renewable sources and the compensation of non-linear and unbalanced current introduced by the loads. In this work, sine compensation has been proposed in order to obtain balanced, sinusoidal and direct sequence current. This strategy has been proposed because it is effective, simple and easy to implement with a reduced computation time requirement.

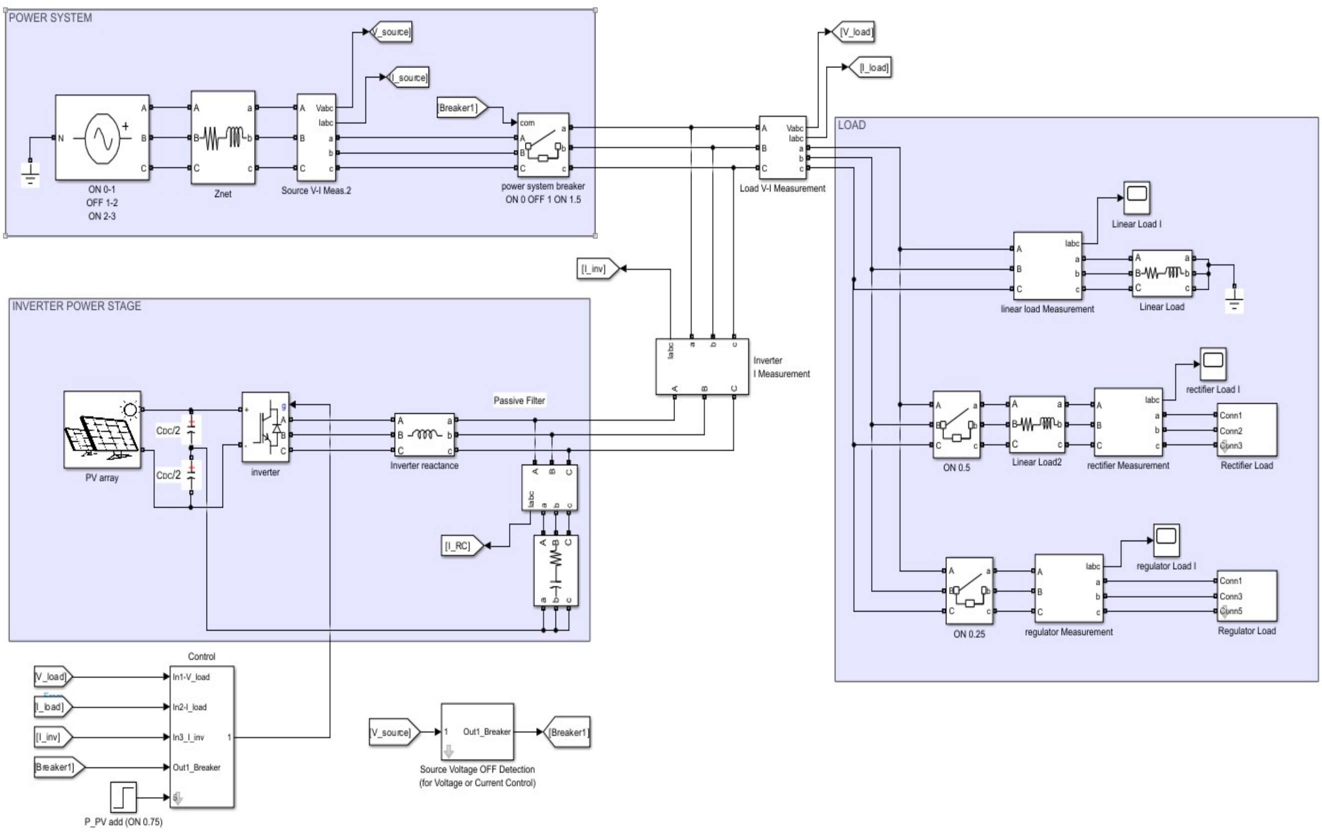


Fig.2. Micro-grid scheme without energy storage

The output current of the PInv is called i_T and it has two components. The first one, called i_{RS}, transports the active power generated by the renewable sources. The second one is called i_C, and it is the current needed to compensate the non-active power introduced by the AC loads. To determine the last one, the load active current i_a has to be calculated and PInv will supply the difference between the actual load current and its active component. The current i_a depends on the active power, P in W, and on the voltage at the PCC, and it is shown in (1):

$$i_a = \frac{P}{V_{1+}^2} v_{1+} = G_1 v_{1+} \quad (1)$$

where v_{1+} is the fundamental direct sequence voltage at the PCC in Volts and G_1 is the equivalent conductance of the load. The inverter compensation component, i_C, is the difference between the actual load current and its active component, (2).

$$i_C = i_L - G_1 v_{1+} \quad (2)$$

The proposed strategy for the current control is completed in order to get the maximum power from the renewable sources connected to the PInv DC side. The active power produced by the renewable sources, P_{RS}, is supplied in this proposal by a current i_{RS}, (3).

$$i_{RS} = \frac{P_{RS}}{v_{1+}^2} v_{1+} = G_2 v_{1+} \quad (3)$$

The total reference current for the PInv control algorithm is shown in (4).

$$i_T = i_{RS} + i_C = i_L - (G_1 - G_2) v_{1+} = i_L - G_T v_{1+} \quad (4)$$

A split capacitor between renewable sources and the inverter is used to stabilize the PInv DC voltage, C_{DC} in figure 2. This voltage must be fixed to the desired value to adequate performance of the inverter. That is achieved adding to the conductance a parameter ρ that depends on the error between the capacitor voltage and the reference. This parameter allows a proportional control to guaranty a constant voltage at DC side, (5),

$$i_T = i_L - (G_T \pm \rho) v_{1+} = i_L - K v_{1+} \quad (5)$$

where $K=G_1-G_2\pm\rho$ can be established by a PI (proportional integral) control. If the error between this reference current and the inverter output current is higher than a hysteresis band, the state of semiconductors will change to follow the reference.

B. Isolated micro-grid scheme

When the PS fails, the micro-grid can work in isolated mode. In this case, PInv control changes and an adequate voltage control will provide the voltage to supply the AC loads. The PS voltage is monitored and when its rms changes more than a percentage (10% in this work), the connection switch is activated, and the SG is disconnected from the PS. In the control block of the PInv, a voltage control is established, and the transistors triggers are calculated to follow the voltage references, (6).

$$v_T^* = v_{1+} \quad (6)$$

The passive filter in the PInv AC side is adjusted to an optimal performance in current or voltage control as presented in the next section.

3. Simulation results

In this work, a three-phase AC SG has been simulated within Matlab/Simulink, figure 2. The PS voltage is 400 V, and it falls between 1 and 2 seconds and the block of source detection forces the disconnection/connection of the SG to the PS and the change of the PInv control mode. Figure 4 shows the PS source in three seconds of simulation.

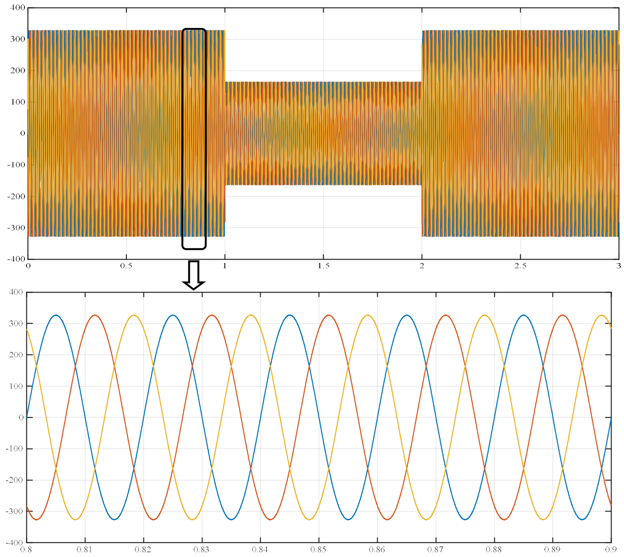


Fig.4. Power system voltages and a voltage signal zoom

The load currents are presented in figure 4. At the beginning, a linear load is only connected, and different non-linear loads are added at 0.5 s, an AC regulator and a rectifier. Figure 5 shows a detail of the total load currents and figure 6 shows the different load currents. For an easy transfer of the result to an experimental set-up in the lab, the load power values chosen in this simulation work were low, about 1 KW per phase.

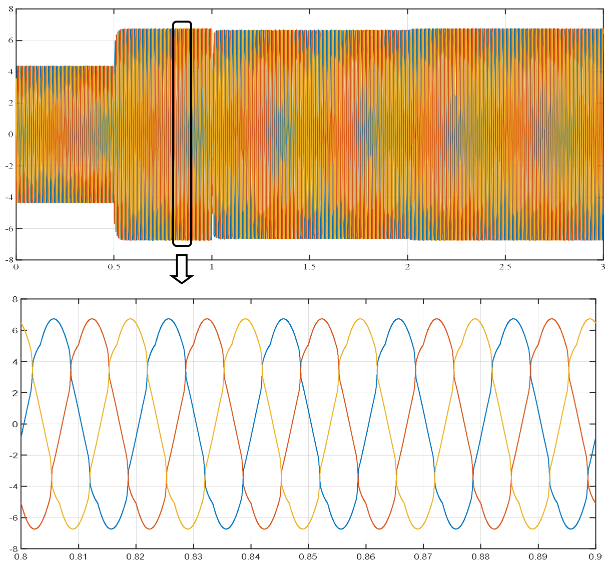
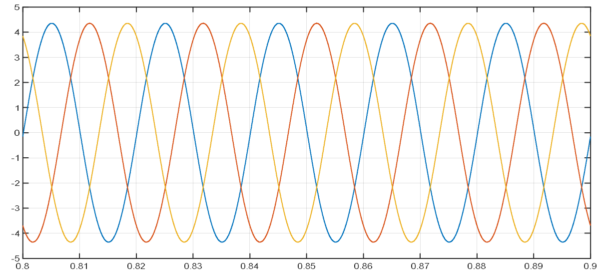


Fig.5. Load currents and a zoom



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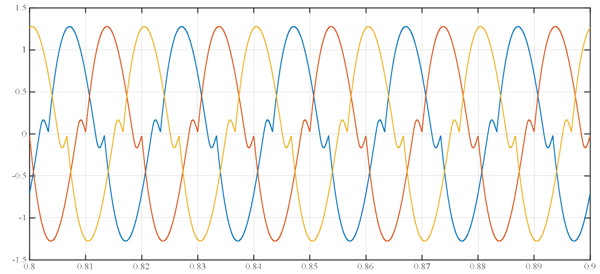

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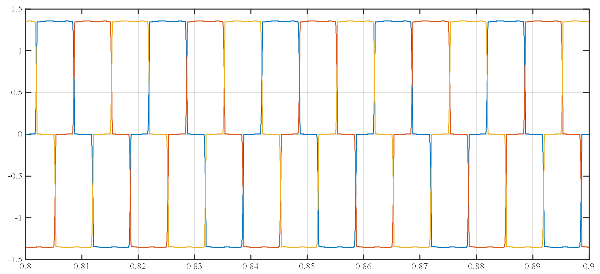


c)

Fig.6. The different load currents in the micro-grid; a) linear load, b) rectifier, c) AC regulator

If the PS is going, the PInv current control will allow the injection of the compensation currents and the PS currents will become sinusoidal. Figure 7 shows the inverter reference currents obtained by the designed control strategy.

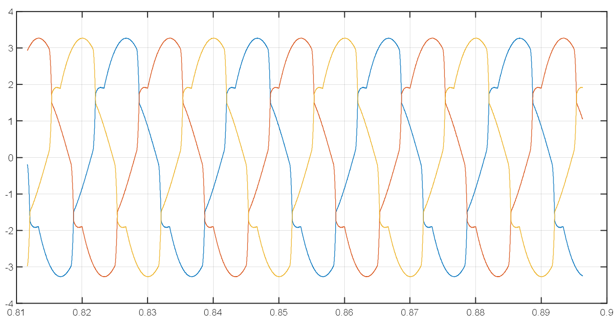
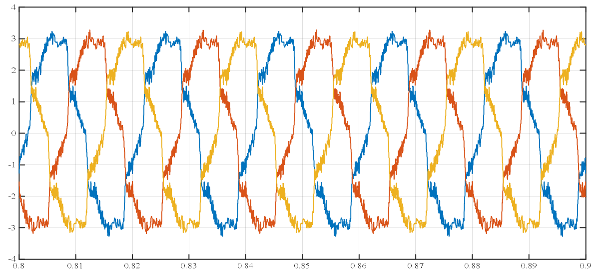


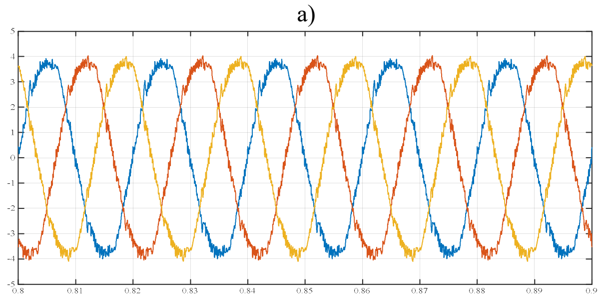
Fig.7. Inverter current references

The inverter current control is a Pulse Width Modulation control (PWM control) with a switch frequency of 20 kHz. The inverter injected currents and the source currents are presented in Figure 8. The effective harmonic compensation can be observed because source currents became sinusoidal.

To reduce some high frequency components of the inverter currents, a passive filter has been included at AC output, figure 2. The inverter output reactance is 60 mH and the passive filter includes a shunt capacitor of 30 µF. A shunt resistor of 5 Ω is added to avoid resonances for high harmonics that appear in the network. Thus, although the power inverter is an ideal converter, the efficiency of power stage is reduced about 2,5%.



a)



b)

Fig.8. Currents with lineal and non-linear load connected, a) inverter currents, b) power system currents

To analyse the transit performance of the designed control, the non-linear loads were connected in second 0.5, and the renewable source was connected in second 0.75. The harmonics are still compensated and the source currents are still sinusoidal, as it was presented in figure 8. From this time on, the PS active power is reduced as figure 9 shows, because of the renewable energy source connection.

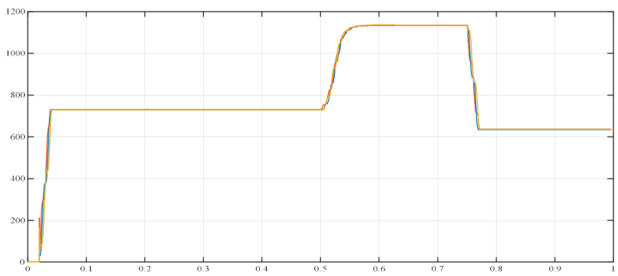


Fig.9. Power system active power

In second 1 of the simulation, the PS falls. The control strategy changes, and an inverter voltage control is now executed. So, the PInv begins to supply the voltage to SG AC load. Figure 10 shows the load voltages after the PS fail.

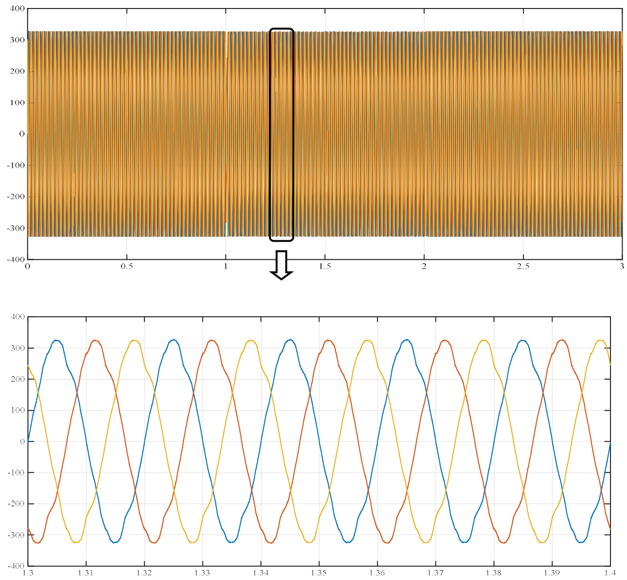


Fig.10. Micro-grid voltage and a detail when the power system is not connected

4. Conclusions

In this paper, a complete control algorithm for a power inverter in a smartgrid has been proposed, to make that the inverter acts as a source current or as a voltage source depending on the smartgrid connection to the power system. In the case that the smartgrid works in isolated mode, the control algorithm makes that the inverter produce a direct, symmetric sinusoidal three-phase 400 V voltage system to supply the smartgrid AC loads. In the case of grid-connected mode, the control algorithm makes that the inverter work as a current source and the current provided contains two components: the first one injects the active power produced by the smartgrid renewable sources to the power system and the second one compensates the harmonic and asymmetric components introduced by the smartgrid AC loads into the system.

The control algorithm has been tested in a simulation platform designed within Matlab/Simulink and the results have been presented in this paper. These results show the good performance of the control proposed.

Acknowledgement

This paper is framed in the project "Integral control system to optimize the microgrids energy demand" funded by the Spanish Ministry of Science and Innovation, call for Scientific and Technical Research and Innovation 2020-2023.

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