Microgeneration as a solution for Power Quality in Low Voltage Grids

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Abstract — The main purpose of this paper is to show that microgeneration has an important role to play, not only in the production of “clean” energy, but also in improving Power Quality in the low voltage grid. Specifically, it can improve the Total Harmonic Distortion (THD) of current and voltage, and also the power factor.

This study is based on the analysis of low voltage grids, similar in structure, where the aim is to compare the simulation results. On one hand, there’s a scenario with only conventional microgeneration (injection of active power in the grid), on the other, a scenario where there is only compensated microgeneration (injection of both active and reactive power).

I. INTRODUCTION

The growing awareness for a sustainable environment, as well as the assurance of that sustainability for coming generations took several countries (including Portugal) to sign the Kyoto Protocol, with the objective of reducing CO$_2$ emissions into the atmosphere. In the Portuguese case, it was agreed to have 39% of all produced energy coming from renewable sources by 2010 [1]. The biggest challenge ahead will be the Copenhagen Summit, where the European Commission will propose a wider and more ambitious agreement than previously signed in Kyoto. Portugal, with the continuous investment in new aerogenerators, in new hidroelectric projects and recently with the simplification of the licensing of microgeneration for private homes and companies, has made its intention of expanding renewable sources clear. Microgeneration, in the portuguese case, allows the owner (Micro-producer), to sell the produced electricity to the distribution grid through a subsidized regime[5]. With the growing decentralized production, there’s no longer a clear electrical generation, and consumers aren’t just consumers anymore, starting to have an active role in energy production. The power flow is no longer just from the typical production points to consumers, starting to take place also in the distribution grid. This new reality also brought new challenges to overcome. The increase and growing dispersion of microproduction carries some problems in the field of Power Quality, specifically the increase in THD of voltage and current, but also a decrease in the Power Factor. It’s in this framework that solutions were devised for improving Power Quality with the aid of the microgenerator itself, locally compensating reactive power. The microgenerator ceases to be part of the problem and, as Power Quality concerns, becomes part of the solution.

II. THE MICROGENERATOR

The elements of the microgenerator used to compensate reactive power are, roughly, a photovoltaic panel, followed by a boost converter and a voltage inverter. The entire microgenerator model was built using the MatLab®/Simulink® platform [1]. The panel is responsible...
for the production of active power to be injected in the grid, and the inverter has a capacitor in the input, responsible for compensating reactive energy from the respective loads. The respective scheme can be seen in Figure 1.

Because of the computational load inherent to the complexity of simulating microgenerators, these are represented by equivalent microgenerators. The inductive, capacitive and resistive parameters of each microgenerator used in simulation are calculated as a function of the number of individual microgenerators the respective equivalent represents. In the following figures, some simulations were conducted to verify the stability of the controllers, on the voltage control level, as well as the current control level (1) and (2). The correct operation of the MPPT is also verified, on the voltage and current level (3) and (4).

In order to compare the results obtained from the conventional microgenerator, a respective model was also created, which, like the previous one, represents equivalent microgenerators. This conventional microgenerator only injects active power in the grid, varying its value according to the number of equivalent microgenerators it represents[2].

III. GRID DESCRIPTION

The low voltage grid model used, like the different microgenerator models, was obtained using the MatLab®/Simulink® platform with its SimPower Systems Toolbox. The low voltage grid is made of a Medium/Low voltage transformer, a distribution line and the electrical loads, aside from the previously mentioned microgenerators.

The 400 kV transformer used in the simulation has a 30 kV voltage in the primary winding (Medium Voltage) and 410 V in the secondary winding (400 V + 2.5 %) [3].

The distribution lines are represented using the Π model.
The loads were split in two main groups: Linear and Nonlinear. The linear loads were in turn subdivided in two groups: type R, resistive charges, representing devices like heaters or light bulbs and type RL loads, representing cooling systems. The nonlinear loads can also be divided in two groups: type I rectifier loads, representing electronics like TV’s, DVD’s etc, and type II rectifier loads representing higher power devices (dishwashers, etc). The linear loads represent 15% of the total load while the nonlinear account for 85%.

The grid is composed of six cables and six loads, that represent the transformer’s six exits. The values of the load division and the cable lengths can be observed in Table I.

<table>
<thead>
<tr>
<th>Consumer Group</th>
<th>Load (%)</th>
<th>Line (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>0.05</td>
</tr>
<tr>
<td>2</td>
<td>18</td>
<td>0.125</td>
</tr>
<tr>
<td>3</td>
<td>17</td>
<td>0.200</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>0.275</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
<td>0.350</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>0.425</td>
</tr>
</tbody>
</table>

IV. SIMULATION ANALYSIS

In the simulations, two separate scenarios were addressed. In the first simulation, two cases were made. In the first, microgeneration has reactive power compensation while in the second it doesn’t (only produces active power). In both scenarios, the microgeneration accounts for 25% of the total transformer power (maximum allowed value under Portuguese law) and the load of the transformer is 15% (minimum load scenario). In the second simulation, the scenario is similar, the only difference being that the transformer’s load power is 85% (maximum load scenario). To emulate reality further, 35% of the maximum allowed values for the 5th and 7th harmonics were included, amounting to 1.8 and 1.2% respectively.

A- Minimum Load Scenario

In this situation the low voltage grid will supply energy to the medium voltage grid, because active power production from microgeneration surpasses the LV grid consumption, the rest being injected in the MV grid. In figures (6), (7), one can observe the current and voltage THD. In the voltage THD, an improvement of around 10% is observed in the scenario involving compensation. Regarding the current THD, improvements are extremely significant, since the value with compensation is 10% of the value without it. Considerable improvements are also observed in the Power Factor. The scenario with compensated microgeneration produces all the consumed reactive power, so the Power Factor approaches the unit (8).

Regarding the transited currents, as well as the voltage in the loads, no significant differences were found between both situations (9), (10).

In (11) one can observe the active and reactive power produced by the microgenerators (reactive in the case of compensation).

Legend:
- Phase A, Unloaded Grid
- Phase B, Unloaded Grid
- Phase C, Unloaded Grid
- Phase A, Loaded Grid
- Phase B, Loaded Grid
- Phase C, Loaded Grid
- Active Power, Compensated Microgeneration
- Reactive Power, Compensated Microgeneration
- Active Power, Conventional Microgeneration
- Reactive Power, Conventional Microgeneration

![Voltage THD](Picture 6 – Voltage THD of minimum load scenario.)
Picture 7 – Voltage THD of minimum load scenario.

Picture 8 – Power Factor of minimum load scenario.

Picture 9 – Voltage of minimum load scenario.

Picture 10 – Currents of minimum load scenario.
This scenario shows a situation of high consumption, so production from microgeneration isn’t enough to satisfy the entire LV grid. In this situation we face an “energy consuming” grid.

In figure (12) the voltage THD is shown. It can be seen that, in some more distant loads, the voltage THD can be 30% higher in for conventional microgeneration relative to compensated one.

In terms of the current THD it is still much lower when compensation is present, about 15% of the value without compensation (13).

Regarding the Power Factor, one can also verify an improvement in this scenario since like in the previous situation, the consumed reactive power, in the case of compensated microgeneration is produced, locally, by the microgenerators (14).

About the voltage, no relevant differences can be found.

Concerning the currents, the compensated microgeneration scenario requests less current from the MV grid since in this case only active power is needed, while in the conventional microgeneration one has to add the consumed reactive power. (15) (16) [4].

The power produced by microgeneration can be observed in (14), where the reactive production can clearly be seen (in some cases its superior to the active power itself).
Current THD of maximum load scenario.

Power Factor of maximum load scenario.

Voltage of maximum load scenario.
V. CONCLUSION

From the analysis conducted, we can conclude that the introduction of microgeneration with reactive power compensation improves the different point in question (except the voltage level at the loads), when compared with conventional microgeneration.

The improvements are verified in both situations: Minimum load scenario and Maximum load scenario.

REFERENCES

[1] Frade, P. A Microgeração como solução reparadora da Qualidade de Energia Elétrica, MSc thesis in Electrical and Computer Engineering, Instituto Superior Técnico Technical University of Lisbon, October 2009


