Island Grid Operation in Contingency

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Abstract—The use of microgeneration, namely photovoltaic in industrial low voltage networks is increasingly, as more and more companies are under pressure to reduce their energy bill and consequently their environmental footprint. However, nowadays the maximum power point that control these micro-photovoltaic plants are not programmed to work in island, they are only programmed to work with low voltage industrial network connected to the distribution network. In emergency, the industrial low voltage network must remain in an island situation, at the least disturbance the microgeneration will be out of service. With different tests, it is concluded that all microgeneration works correctly whenever there are no major disturbances of the frequency and voltage of the network. Whenever there are large fluctuations of these variables, Photovoltaic power plants are out of service. In short, photovoltaic microgeneration is not ready to work in island operation.

Index Terms—Microgeneration, Photovoltaic Systems, Diesel Generators, Synchronous Machine, Low Voltage Networks

I. INTRODUCTION

Since 2015, the Portuguese companies are covered by the decree-law 71/2008, which regulates the Energy Consumption Management System, as one of the measures of the National Action Plan for Energy Efficiency. This diploma aims to provide energy efficiency and monitor energy consumption of intensive consumers of energy facilities (CIE). In this degree is defined as CIE a company that annually consume a higher amount of energy above 500 tep / year. All the companies covered by this law and which are of this annual limit consider reducing their energy bill in a preventive way, avoiding expenditures on energy efficiency audits, and consequently avoiding fines in case of default.[1]

In order to supply electrical power failures in emergency situations, there are various types of solution, namely UPS (Uninterruptible Power Supply System) and diesel generators. Commercially available UPSs are designed to ensure System, for a short period of time, however comparing with the load power of an industry would require multiple UPSs, even then it might not be feasible because there are loads (Voltage, power angle, active power) and that a battery cannot suppress. This type of UPS presents some disadvantages namely, discharge pattern in a battery regime, a harmonic component that is introduced in the low voltage network and may affect other equipment. [2]

On the other hand, there are other types of UPS capable of satisfying power requirements of an industry, where the combination of supercapacitors and discharge acid batteries can ensure a factory load for very short periods. According presented in the article "Battery / Supercapacitors Combination in Uninterruptible Power Supply (UPS)". A UPS with 500kVA would require 2226 elements of lead-acid batteries with 12V voltage, knowing that these batteries have a relatively short service life, there would be costs associated with maintenance of this relatively expensive equipment. [3]

The objective of this article is to evaluate the network in question, when it is operating in island. Thus, it is intended to evaluate the transient behavior of the network, as well as the elements of generation, analyzing for what state of operation the network evolves. In order to carry out an evaluation of the network, the value of the effective voltage and current of the generator, voltage and current at the microgeneration plant, as well as the frequency of the network, waveforms and power transits. In order to be able to study this low voltage network, it is placed on some conditions and then analyzes how it evolves. Knowing the maximum values and voltages, current and frequency, where these quantities may fluctuate when the network is placed in a vacuum, as a way to ensure and its users.

II. MODEL OF LOW VOLTAGE GRID

In order to analyze the impact of microgeneration in island network, it is essential to simulate the low voltage network, representing loads connected to the network. This simulation is performed in the program MATLAB / Simulink.

This type of simulation is computationally heavy and can become overly slow because it involves a large number of cables and electrical loads, as well as the reading of many values voltage and current as well as power calculations. It has been confirmed that this same network follows the low voltage rules and meets the conductors well dimensioned through the simulation tests.
• Transformer
The most common voltage levels in the MV network of the national grid are 10, 15 and 30kV. In BT, the voltage level used is 230V (per phase), 400V (composite). Most transformers allow you to set the output voltage between ± 2x2.5%. The operating frequency is very close to 50Hz. There is a wide range of transformers with different rated power ratings, which usually range from 25 to 2500kVA. In this project, we consider a power of 630kVA, as it is similar to the transformer placed in the industry under study.

![Transformer equivalent in T model](Image)

Table 1 - Parameters of three-phase network transformer

<table>
<thead>
<tr>
<th>Parameters of three-phase network transformer</th>
<th>Circuit</th>
<th>Aparent Power (VA)</th>
<th>Active Power (W)</th>
<th>Reactive Power (VAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Magnetization</td>
<td>Secondary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>----------------</td>
<td>-------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R₁ (pu)</td>
<td>X₁ (pu)</td>
<td>R₂ (pu)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.007</td>
<td>0.022</td>
<td>0.007</td>
<td>0.022</td>
<td></td>
</tr>
</tbody>
</table>

- Sizing of cables
Analyzing the type of cable used in the industrial installation under study, it was verified to be LVV type. This type of cable is characterized by a conductive core made of multi-stranded copper, with polyvinyl chloride (PVC) insulation and PVC sheathing sheath and PVC outer sheath, having a nominal voltage of 0.6 / 1kV and a test voltage of 3.5kV, belonging to class 2 of the multi-wire type. This cable is approved by the standards NP2365, IEC502 [4]. This type of cable is perfectly adapted to the transport and distribution of electrical energy in industrial installations. Then, the calculations were made to determine resistance and reactance of each cable, and to put their values in the simulation.

The corrected current $I_z$ will allow to calculate section of the cable to be installed. The constant $K_p$ represents the coefficient of temperature, it is considered $K_p = 1$ because it is the worst case under study. On the other hand, $K_p$ is related to the number of cables that share the same cable path. In this case $K_p = 0.72$ is used, because through the low voltage technical rules, this is the value found for the most crowded cable path of installation. These constants are explained in IEC 60228. [4]

Table 2 - Load Power from sections

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Aparent Power (VA)</th>
<th>Active Power (W)</th>
<th>Reactive Power (VAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load 1</td>
<td>23717</td>
<td>18996</td>
<td>14200</td>
</tr>
<tr>
<td>Load 2</td>
<td>172500</td>
<td>138000</td>
<td>103500</td>
</tr>
<tr>
<td>Load 3</td>
<td>332508</td>
<td>266010</td>
<td>199500</td>
</tr>
</tbody>
</table>

Table 3 - Currents from loads

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Service Current $I_s$ (A)</th>
<th>Nominal Current $I_n$ (A)</th>
<th>Corrected Current $I_z$ (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load 1</td>
<td>34.27</td>
<td>40</td>
<td>55.56</td>
</tr>
<tr>
<td>Load 2</td>
<td>248</td>
<td>250</td>
<td>347.22</td>
</tr>
<tr>
<td>Load 3</td>
<td>479</td>
<td>500</td>
<td>694.44</td>
</tr>
<tr>
<td>Generator</td>
<td>1444/2=722</td>
<td>885</td>
<td>1229</td>
</tr>
</tbody>
</table>

Table 4 - Section from cables

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Section Cable Fase (mm²)</th>
<th>Section Cable Neutro (mm²)</th>
<th>Section Cable Terra (mm²)</th>
<th>Designation Cable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load 1</td>
<td>10</td>
<td>10</td>
<td>70</td>
<td>3x240+120+T70</td>
</tr>
<tr>
<td>Load 2</td>
<td>240</td>
<td>120</td>
<td>70</td>
<td>3x240+120+T70</td>
</tr>
<tr>
<td>Load 3</td>
<td>240</td>
<td>120</td>
<td>70</td>
<td>3x240+120+T70</td>
</tr>
<tr>
<td>Generator</td>
<td>630</td>
<td>240</td>
<td>-</td>
<td>3x630+240</td>
</tr>
</tbody>
</table>

Table 5 - Impedance from cables

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Section (mm²)</th>
<th>l(m)</th>
<th>R (Ω)</th>
<th>L (H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load 1</td>
<td>10</td>
<td>10</td>
<td>0.0192</td>
<td>2.4 e⁶</td>
</tr>
<tr>
<td>Load 2</td>
<td>240</td>
<td>20</td>
<td>0.0016</td>
<td>4.8 e⁶</td>
</tr>
<tr>
<td>Load 3</td>
<td>240</td>
<td>10</td>
<td>0.00080</td>
<td>2.4 e⁶</td>
</tr>
<tr>
<td>Generator</td>
<td>630x2</td>
<td>50</td>
<td>0.00076</td>
<td>6 e⁶</td>
</tr>
</tbody>
</table>

• Voltage Drop
For a correct parameterization of the network it was necessary to verify that it complied with the Technical Rules of Low Voltage Installations. Thus, by means of the formulas 2.11 and 2.12, it has been verified that the dimensioned cables comply with the technical rules. Where $\rho = 0.020\Omega\text{mm}^2 / \text{m}$, $\lambda = 0.00008\Omega / \text{m}$, $\varphi$ represents the angle of delay of the current against the voltage $(\cos(\varphi) = 0.8)$ and $I_s$ represents the service current of the section under analysis. [5]
\[\Delta U[\%] = \frac{230}{100} \left( \frac{l}{s} \cos(\varphi)I_s + \lambda l \sin(\varphi)I_s \right) \quad (2.11)\]

\[\Delta U[\%] < 1.5\% \quad (2.12)\]

<table>
<thead>
<tr>
<th>Circuit</th>
<th>(\Delta U) of branch [%]</th>
<th>(\Delta U) total [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load 1</td>
<td>0.246</td>
<td>0.27</td>
</tr>
<tr>
<td>Load 2</td>
<td>0.248</td>
<td>0.28</td>
</tr>
<tr>
<td>Load 3</td>
<td>0.239</td>
<td>0.27</td>
</tr>
<tr>
<td>Generator</td>
<td>0.027</td>
<td>-</td>
</tr>
</tbody>
</table>

All cables are correct dimensions, any one violate the rule of drop voltage. So grid are ok to simulate.

- **Load**

  Only 40% of the whole network presents elasticity zero \((\varepsilon = 0)\). Because, electronic devices has voltage control in DC side, so active power will be constant and current increase. To simulate this type of load, we will use the eq. (2.13, 2.14 and 2.15), active power is power in single phase, as reactive power too. It was considered a faithful representation of the network giving priority to the development of this system to exemplify the load, since the use of passive loads of type (RL) would not represent faithfully the network soon the behavior of the generator and the photovoltaic micro-power plant would not be reliable

\[I = \sqrt{\frac{p^2 + Q^2}{V^2}} \quad (2.13)\]

\[i(t) = \sqrt{2} \cdot I \cdot \sin(\omega t + \varphi_i) \quad (2.14)\]

\[\varphi_i = \tan^{-1} \left( \frac{Q}{P} \right) \quad (2.15)\]

- **Microgeneration**

  The value of microgeneration power may oscillate with several factors (temperature, irradiance...), however, its value shall not exceed 25\% of the power of the transformer. A maximum power of the photovoltaic power plant is 157.5kW [6].

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Power of photovoltaic power plant (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load 1</td>
<td>2010</td>
</tr>
<tr>
<td>Load 2</td>
<td>50000</td>
</tr>
<tr>
<td>Load 3</td>
<td>104962</td>
</tr>
</tbody>
</table>

Self-excited synchronous generators are the primary source of energy in case of emergencies in industries. The stability of electric power depends on many related factors, however, voltage and frequency are the main ones. Stable food sources are all those that return to their original state after being exposed to disturbances. Thus, the voltage and frequency must return to their nominal values within a regulated time interval, if they do not converge to their expected values, the system must be switched off.

The system frequency regulator consists of the controller, the actuator and engine delay.

This system receives as input the speed of rotation of the machine and as output the value of mechanical power that the diesel engine provides through the shaft to the electric generator.

The voltage regulator model is based on IEEE practice for synchronous machines. The base model is the IEEE AC5A, where the scheme is described below [10].
Modeling the dynamic behavior of the synchronous generator is quite complex due to the movement of the rotor windings relative to the induction windings of the three phases, thus the magnetic coupling coefficient continuously changes with the position of the rotor. Thus, the synchronous machine can be described by differential equations, with mutual inductance values, whose solution is not always easy to find.

In order to create a model of a synchronous generator, independently of time it is necessary to express the stator and rotor variables in separate coordinate systems, based on the Park transformation. Induction circuits in the direct (d) and quadrature (q) axes are obtained by linearization of the voltage equations in the three phases abc in coordinates dq [8].

\[
\begin{align*}
\psi_{ds} &= \int \left( u_{ds} + \frac{R_s}{L_{md}} (\psi_{md} - \psi_{ds}) + \omega_r \psi_{qs} \right) dt \quad (3.16) \\
\psi_{qs} &= \int \left( u_{qs} + \frac{R_s}{L_{mq}} (\psi_{mq} - \psi_{qs}) + \omega_r \psi_{ds} \right) dt \quad (3.17) \\
\psi'_f &= \int \left( u'_f + \frac{R'_f}{L'_{af}} (\psi_{md} - \psi'_f) \right) dt \quad (3.18) \\
\psi'_{pd} &= \int \left( u'_{pd} + \frac{R'_{pd}}{L'_{apd}} (\psi_{md} - \psi'_{pd}) \right) dt \quad (3.19) \\
\psi'_{pq} &= \int \left( \frac{R'_{pd}}{L'_{apq}} (\psi_{md} - \psi'_{pd}) \right) dt \quad (3.20)
\end{align*}
\]

Figure 6 - Scheme distribution parameters of synchronous machine

\[
\begin{align*}
\psi_{md} &= L_{md} (i_{ds} + i'_{pd} + i'_f) \\
\psi_{mq} &= L_{md} (i_{qs} + i'_{pq}) \\
i_{ds} &= \frac{\psi_{ds} - \psi_{md}}{L_{os}} \\
i_{qs} &= \frac{\psi_{qs} - \psi_{mq}}{L_{os}} \\
i'_f &= \frac{\psi'_f - \psi_{md}}{L'_{af}} \\
i'_{pd} &= \frac{\psi'_{pd} - \psi_{md}}{L'_{apd}} \\
i'_{pq} &= \frac{\psi'_{pq} - \psi_{md}}{L'_{apq}}
\end{align*}
\]
Through these equations we can have model of synchronous machine, and we can simulate the behavior of machine. And we will test the grid with this all variables.

IV. SIMULATIONS

- Network test under stationary operating conditions

This test is characterized by the operation of the network within the stationary conditions. The electric power of the medium voltage distribution network fails and the generator starts when this fault is detected, this generator starts with a delay of 0.03s, which means that critical loads that cannot have this discontinuity should be backed up by UPS, so that during this short period of time they can ensure the operation of them. This test was carried out under full load and in typical microgeneration, is \( S_{\text{load}} = 528.8 \text{kVA} \) \( S_{\text{microgeneration}} = 41.4 \text{kVA} \).

During the start-up period of the generator the photovoltaic power plant also begins to operate, therefore the connection of the generator to the grid leads to a transient voltage drop that is not significant, leading to a transient current increase. It is visualized that the voltage drop is not lower. At 10% of the rated voltage during a range of less than 0.10s, the current also does not exceed 10% (Figure 9). The rated current during the same interval, thus ensuring operation, de according NP50160.

The microgeneration will be help the generator, as it assures a part of the production of the electrical power, so the generator is no longer subject to such a large load. Thus, it is visible in Figure 10 that the power requested from the generator after a transient state is lower, as would theoretically be expected.

- Network test with load 10% nominal load and maximum microgeneration

The objective of this test is to represent a limiting situation where the power of the microgeneration exceeds the load power, causing the current in the generator to reverse the direction and the synchronous machine increase speed. However, control systems do not allow this to occur. When the current inverts the direction to the terminals of the generator, the emergency system of the same one realizes an emergency cut, putting the net to operate exclusively with microgeneration. However, microgeneration is not ready to operate island, so after a few seconds an overvoltage occurs in the network, which will cause microgeneration to shut down.

At \( t = 0.27s \), the emergency system disconnect the generator connection to the grid, because current invert direction. However grid has another production unit, the photovoltaic power plant. Therefore this unit cannot work in island, and cannot control frequency or voltage. So, the voltage will increase and inverters will cut the photovoltaic power plant. We
can see this in figure 11.

- Network test with start-up of an asynchronous machine

![Figure 11 - Voltage in generator](image)

Table 8 - Parameters Asynchronous machine

<table>
<thead>
<tr>
<th>Power (VA)</th>
<th>Voltage (V)</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>37300</td>
<td>400</td>
<td>50</td>
</tr>
</tbody>
</table>

It was considered of interest to simulate the direct starting of an asynchronous machine since it is a phenomenon that creates great disturbance in the network and it is important to verify that the microgeneration can help or not to start the machine by reducing the disturbance of the network.

![Figure 12 - Current in the starting of asynchronous machine](image)

From the moment the main voltage drops below 207 V [7], the maximum power followers are programmed to cut the microgeneration, when there are phenomena in the network that reduce the mains voltage, they perform the Integral cut-off of the photovoltaic power plant for safety reasons. So only generator will produce power to asynchronous machine starting.

V. CONCLUSION AND FUTURE WORK

- Conclusion

The objective of this work was to analyze the behavior of the plant network when they are operating in island.

It is verified by the test of the system in a stationary situation that this emergency system operates in a profitable manner, whenever there are no major disturbances in the low voltage network as in test number two and number three. Whenever the frequency or voltage is disturbed the maximum power followers are programmed to use these variables as control variables. Whenever they leave the nominal values the controllers cut the photovoltaic power plant.

For test number two, where the microgeneration power is higher than the load power. It would be expected that generator will be off, because there is no need for it to start operating, that microgeneration is ensured production, because the balance of power would be possible. However, photovoltaic panels are not ready to operate in island, so they do not have a voltage controller, they can only connect or disconnect the grid; they cannot, in case of overvoltage, try to reduce the power injected as a way to reduce the voltage to the default value. This way of operating is no longer advantageous, nowadays it is necessary that these equipment in case of overvoltage can control it and try to return it to its nominal value, the integral cutting of a power station of this power is not advisable to balance the network.

Through simulation three, once again, there is a fallibility of the photovoltaic power plant in case of voltage disturbance. The simple, starting of a machine with power inferior to the power of generation will cause the microgeneration to cut.

Maximum power followers that control the production of the photovoltaic power plant maximizing the power to be injected into the network in real time, monitoring the network voltage and the frequency at the point of connection. They are not prepared to control the voltage and frequency of the network, in case of disturbance converge these quantities to their nominal values causing, therefore, great problems when the power of the power station is considerable.

However, the maximum power follower has a memory of ten minutes, at the end of this period if it verifies that the voltage and the frequency stabilized in its reference value, it will reconnect returning the power plant to go into production [9].

In short, through this dissertation it is clear that the followers of maximum power are not prepared to work in any island whatever the situation. The voltage and the frequency in a network do not always have a constant value, depending on the
disturbances that the network suffers the same will change, so controlling an element of production “ON / OFF” is not the best way because when you switch off, Implies a load power that is not satisfied, thus creates problems at the level of the network stability.

- Future Work

In the future it will be important to carry out further studies in the island operation operation of photovoltaic micro-power plants, as it will be important to create a system that allows maximum power followers to know if they are working connected to the distribution network or if they are working in emergency mode they must be connected to the generator. Only in this way can there be a complete knowledge about the state of the network.

Abandoning design used in low voltage networks with microgeneration, where each generation component knows the data collected in its terminals, but evolving to an interconnection model among them so that image taken over the network is more reliable, thus allowing to maximize power injected in the Renewable sources at the expense of fossil sources, using the generator only in case of large fluctuations in frequency or voltage, allowing these quantities to converge to their nominal values.

However, all new paradigms need some maturation and many essays to be available to the public.

REFERENCES

   [Acess in March 2017]


