# Storage of Energy and Voltage Regulator in Electric Grids with Distributed Generation through Renewable Energies

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*Abstract* —**Global warming is a worldwide environmental threat. Concerning the global warming, international targets were established, which include the increasing of renewable energies. Therefore, we have been observing an increase penetration of photovoltaics technology in low voltage grids. This type of distributed generation can cause problems in the Electrical Power Quality. More specifically, voltage rise above the limit defined by NP EN 50160. Usually, this problem occurs if the solar inverter is located at the end of a feeder. The most commonly solution is to temporary turn off the solar inverter, so that the RMS voltage value can return to a safe range.**

**Microgeneration's technology is expensive and the solution of turn of the microgerator brings an inefficient behaviour, causing a decrease in the microproducer's income.**

**The main objective of this study is to propose a solution for this problem. The approach used in this study involves a storage system combined with decentralized regulation, based on a local closed-loop controller for reactive power. Also, with this system it will be possible to offer other services to the distribution grid operators, such as helping the mitigation of sag.**

**In order to perform this work it was necessary to build the microgeneration model with storage and the different elements that are present in a low voltage grid (e.g, the transformer of medium voltage/low voltage, low voltage distribution lines and electric loads). The performance simulations of the system were done using Matlab/Simulink software.**

**Different trials were run to analyse of the viability of the proposed solution. The different voltage profiles, power flows on the electric grid, well as, currents of the microgeneration model and state of charge of storage system were measured.**

***Keywords* — Microgeneration, NP EN 50160, Overvoltage, Storage, Sag, Electrical Power Quality...**

## I. Introduction

Global warming is a worldwide environmental threat. Several countries have established international targets, which include the increasing use of renewable energies. In addition, we have been watching a substantial price reduction of photovoltaic (PV) modules.
Therefore, an accelerated growing of the penetration of PV technology in low voltage has been observed. However, the increasing use of distributed generation (DG) comes with a cost regarding the Electrical Power Quality (EPQ). Overvoltage is one of the main problems and the prime subject of this paper. Overvoltage normally occurs during summer days, when it is high PV generation and low load periods, especially if the solar inverter is located at the end of a feeder. In Europe, overvoltage is charactered by a RMS value of voltage above 253 V, NP EN 50160. For the scenario presented were created different solutions, such as:

1) Allow the DGs to absorb reactive power, which creates high currents, losses on the distribution line and a reduction of the active power;
2) Increase the conductors size by reducing line impedance which is an efficient solution but very expensive for the grid operator;
3) Consume the energy excess by adding resistive loads to DGs, that will consume the extra power;
4) Curtail the power of DG units;
5) Reduce the secondary LV transformer voltage, adjusting the tap of the transformer. However, this causes significant energy loss because it is necessary to use an electronic converter, and this solution is not reliable;
6) Most common solution is to turn off the solar inverter when the voltage exceeds the standard maximum limit (NP EN 50160);
8) Store the power surplus for later use.

The solution described in this paper and developed in ( [1]), is a system that combines 1) and 7). For 1) the system computes a phase shift and adds it to the output current from the solar inverter (normally in phase with the voltage at that point). The phase shift on the current will decrease the active power and increase the reactive power which will have the voltage locally decreased. However, most of the times, this decrease is not enough. Therefore, it is included a storage system that will act when the reduction created by the phase shift is insufficient (limitations from the conventional inverter).

This paper is organized as follows. In Section II, the LV system under study is presented. In Section III the microgeneration simplified model. Section IV the design model of the solution proposed. The different trials of the system are shown in Section V and finally, the conclusions are stated in Section VI.

## II. LV Grid Model

The example LV distribution grid model used in this study is based on a real LV grid located in Sintra, Portugal, ( [2]).

A 630 KVA Dyn oil-immersed power transformer [3] is used to supply 18 electric loads and a rural equivalent load, figure 1. Each line of the feeder has 6 electric loads and they are monophasic. The power distribution, number of PV models per electric load, and the type of distribution lines are all presented in table 1 and 2.

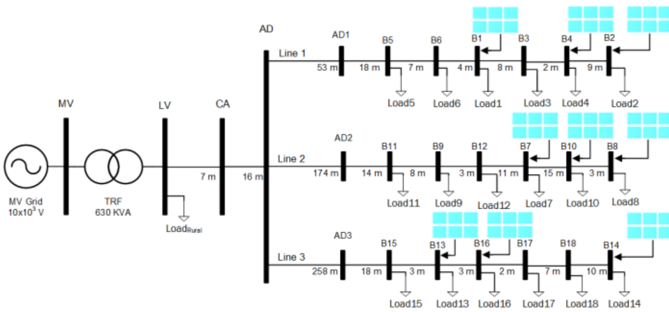


Figure 1: Distribution feeder configuration.

To compute the total power for each load, a coincidence factor, $C_{si}$, has to be taken in consideration. $C_{si}$ is a ratio of the simultaneous maximum demand of a group of electrical consumers:

$$C_{si} = 0{,}2 + \frac{0{,}8}{\sqrt{n_i}} \qquad \text{(II.1)}$$

Each electrical load is a group of electrical consumers, in which $n_i$ is the number of electrical consumers in a group. Each consumer (residence) as a contracted power of 6,9x10$^3$ VA, $S_i$. Therefore, the power consumed, $S_C$, for each load is given by:

$$S_C = S_i C_{si} n_i \qquad \text{(II.2)}$$

Table i: Summary of The Grid Characteristic [4] [5] [6].

| LV Grid characteristics | | |
|---|---|---|
| Transformer rated power | | 6,9x10$^3$ VA |
| Maximum distance | Line 1 | 124 m |
| | Line 2 | 251 m |
| | Line3 | 324 m |
| Cable types | | LSVV 1x380, LSVAV 3x185+95, LSVAV 2x16 mm$^2$ (underground) |

Table ii: Summary of the Electric loads characteristics.

| | Electric Loads Characteristics | | | | | |
|---|---|---|---|---|---|---|
| Phase | R | | S | | T | |
| Load | 1/7/13 | 2/8/14 | 3/9/15 | 4/10/16 | 5/11/17 | 6/12 /18 |
| $n_i$ | 3 | 4 | 2 | 1 | 1 | 1 |
| $C_{si}$ | 0,66 | 0,6 | 0,765 | 1 | 1 | 1 |
| $S_C$ [kVA] | 13,68 | 16,56 | 10,57 | 6,9 | 6,9 | 6,9 |
| Nº of DGs | 2 | 3 | 0 | 1 | 0 | 0 |

## III. Microgeneration Model

This section the modulation of the microgeneration's system with storage on software Matlab/Simulink and assumptions made about it.

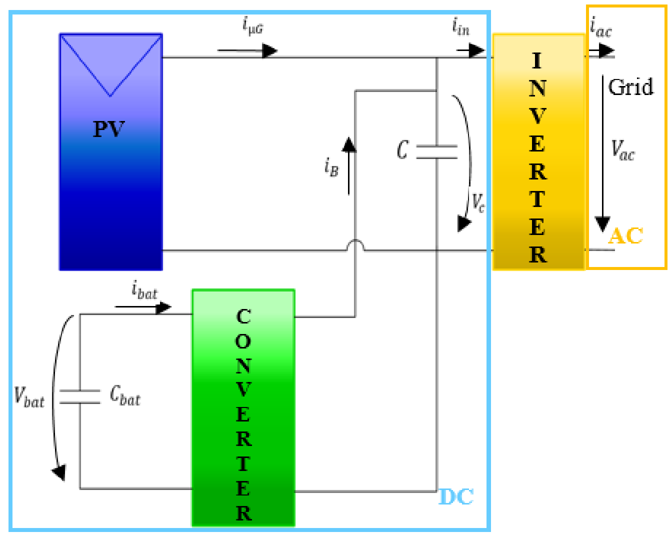


Figure 2 : Simplified microgenerator model.

### A. PV

The PV operates at the maximum power point (MPP) under all conditions.

The current provided by the PV is given by (III.1), where $P_{pv}$ is the active power of the PV and $V_c$ is the voltage on the capacitor of the converter. In this model we use a controlled current source and an approximation of 1$^{st}$ order to the delay, $T_{d1}$ .

$$P_{pv} = V_c i_{\mu G} \Leftrightarrow i_{\mu G} = \frac{P_{pv}}{V_c} e^{-sT_{d1}} \qquad \text{(III.1)}$$

### B. Inverter

To simplify, the inverter is only modulated for the two fundamental components, which are (i) the average value of the variable from the continuous side, and (ii) the RMS value from the fundamental harmonics of the alternating side.

The inverter is modulated by two controlled current sources. The first one is a DC, and the second one is an AC. It represents the conversion of the energy from DC to AC side and vice-versa. The DC current, $i_{in}$, is controlled by equation (III.3), in which $\eta_i$ represents the efficiency of the inverter, $V_{ac}(t)$ and $i_{ac}(t)$ are the fundamental harmonics of the voltage and current on the grid.

$$P_{ac} = \eta_i P_{in} \Leftrightarrow V_{ac}(t) i_{ac}(t) = \eta_i V_c i_{in} \qquad \text{(III.2)}$$

$$i_{in}(t)=\frac{V_{ac}(t)i_{ac}(t)}{\eta_i V_c} \qquad \text{(III.3)}$$

The output current of the inverter remains to be computed. First of all, the inverter generates an AC output current $i_{ac}$(t) in phase with the AC grid voltage, $V_{ac}(t)$. It is considered that $V_{ac}(t)$ is the referential in time, meaning that the phase is 0. Then, $i_{ac}(t)$ is given by (III.4), where $I_{ac}$ is the RMS value of $i_{ac}(t)$ and it can be obtain by (III.5). If the $i_{ac}(t)$ is in phase with $V_{ac}(t)$, then, disregarding the harmonics $\cos\phi$ will be equal to one.

$$i_{ac}(t)=\sqrt{2}I_{ac_{ef}}\sin(\omega t) \qquad \text{(III.4)}$$

$$P_{ac}=I_{ac_{ef}}V_{ac_{ef}}\cos\phi \Leftrightarrow I_{ac_{ef}}=\frac{P_{ac}}{V_{ac_{ef}}\cos\phi} \qquad \text{(III.5)}$$

*C. Sizing Capacitor and Converter*

The capacitor sizing is given by (III.6), where $\Delta V_{DC}$ is the ripple voltage and $f$ the frequency of the grid.

$$C\Delta V_{DC}\times V_c=\frac{P_{ac}}{\omega}\Leftrightarrow C=\frac{P_{ac}}{2\pi f\Delta V_{DC}\times V_c} \qquad \text{(III.6)}$$

This type of converter, a DC-DC Buck Boost, is once again, represented by a DC controlled current source.

The charge and discharge of the battery was regulated by a controlled current source (III.8), and $\eta_B$ represents the efficiency of the converter.

$$\eta_B V_{Bat}I_{Bat}=i_B V_C \qquad \text{(III.7)}$$

$$I_{Bat}=\frac{V_C i_B}{\eta_B V_{Bat}} \qquad \text{(III.8)}$$

The current $i_B$ must be controlled to maintain the capacitor voltage, $V_c$. So, the Kirshhoff's current law is applied to the node that connects $i_{\mu G}, i_B, i_{in}$ (III.9).

$$C\frac{dV_c}{dt}=i_{\mu G}+i_B-i_{in} \qquad \text{(III.9)}$$

It is also considered a delay, $T_d$, applied to the current $i_B$ . This is a 3rd order control system, figure 3.

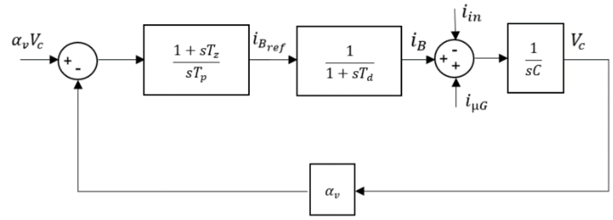

Figure 3 : Control system.

Appling the criterion ${b_k}^2=2b_{k-1}b_{k+1}$ to the polynom we can have the values of $T_z$ and $T_p$ (III.10).

$$\begin{cases} {T_z}^2=\dfrac{2CT_p}{\alpha_v} \\ (CT_p)^2=2T_zC\dfrac{T_pT_d}{\alpha_v}\end{cases}\Leftrightarrow\begin{cases} T_z=4T_d \\ T_p=\dfrac{8{T_d}^2}{C}\end{cases}\Leftrightarrow$$

$$\Leftrightarrow\begin{cases} K_i=\dfrac{1}{T_p}=\dfrac{C}{8{T_d}^2} \\ K_p=\dfrac{T_z}{T_p}=\dfrac{C}{2T_d}\end{cases} \qquad \text{(III.10)}$$

$T_d$ is 10 $ms$, $\alpha_v$ equals 1 then, $K_i$ and $K_p$ are 7,07 e 0,28.

*D. Storage System*

The average hours of sun, $h$, per year in Portugal for the PV production are 4 hours per day. More specifically, 6 hours in the summer and 2 hours in the winter. Then, the storage system must be charged during 4 hours and considering that there is not consume during that time. Therefore, the energy per day will be given by:

$$E_{bat}=P_{inst}h \qquad \text{(III.11)}$$

$P_{inst}$ is the power installed so, $E_{bat}=14{,}4\ kWh/day$ .

For this system was chosen an acid lead battery because it has the characteristics needed for the system and it is the least expensive. This battery has 12 V and charges at the current of 37,5 A during 4 hours. Therefore, to size the battery it is necessary to know the total voltage for an energy of 14,4 kWh/day, (III.12) and (III.13).

$$E_{bat}=V_{bat}I_{bat}h \qquad \text{(III.12)}$$

$$V_{bat}=\frac{P_{inst}}{I_{bat}}=\frac{3600}{37{,}5}=96\ V \qquad \text{(III.13)}$$

After determining that $V_{bat}$ is 96 V was concluded that 7 batteries in series are required.

For the implementation of the model in the software it was decided to represent the batteries by a capacitor. So, knowing (III.14) and (III.15), $C_{bat}$ was computed using (III.16).

$$Q_{bat} = C_{bat}V_{bat} \tag{III.14}$$

$$\Delta Q_{bat} = C_{bat}\Delta V_{bat} \tag{III.15}$$

$$C_{bat} = \frac{\Delta Q_{bat}}{\Delta V_{bat}} = \frac{I_{bat}h}{V_{Bat_{max}} - V_{Bat_{min}}} \tag{III.16}$$

Security limits were created for the battery, and these parameters will be used in the proposed solution.

$$V_{Bat_{máx[100\%]}} = 7\times 14{,}4 = 100{,}8\ V \tag{III.17}$$

$$V_{Bat_{min[0\%]}} = 7\times 12 = 84\ V \tag{III.18}$$

Then $\Delta V_{Bat_{máx}} = 100{,}8 - 84 = 16{,}8\ V$, therefore $20\%\Delta V_{Bat_{máx}} = 3{,}36\ V$ and $5\%\Delta V_{Bat_{máx}} = 0{,}84\ V$. Now it is possible to compute the limits:

$$SOC_{max} = V_{Bat_{máx[100\%]}} - 5\%\Delta V_{Bat_{máx}} = 99{,}96\ V \tag{III.19}$$

$$SOC_{80\%} = V_{Bat_{máx[100\%]}} - 20\%\Delta V_{Bat_{máx}} = 97{,}44\ V \tag{III.20}$$

$$SOC_{20\%} = V_{Bat_{min[0\%]}} + 20\%\Delta V_{Bat_{máx}} = 87{,}36\ V \tag{III.21}$$

$$SOC_{min} = V_{Bat_{min[0\%]}} + 10\%\Delta V_{Bat_{máx}} = 84{,}84\ V \tag{III.22}$$

The limits that were computed are present in figure 8.

## IV. Solution Model

The solution is divided in 3 parts. The first part identifies the scenario (Overvoltage, Sag or Normal State). The second one, which is a decentralized regulation, applies the phase shift to the system (and is independent from the others). Finally, the third part, decides which will be the $P_{pv}$ and $P_{ac}$ for the different scenarios.

### A. *Decentralized regulation for mitigation of overvoltage*

As described before, the first part of the solution is a closed--loop controller that computes a phase angle for the micro generator output current in relation to the voltage at the connection point. This, should be set in order to mitigate overvoltage.

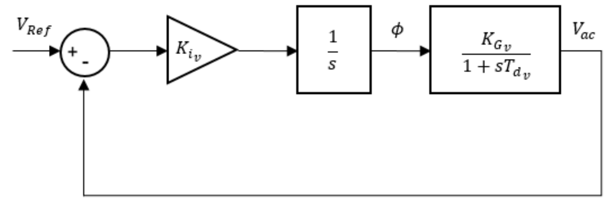


Figure 4 : Close-loop controller.

The following system (figure 4) function is regulated for a reference RMS voltage value. It creates a process control of closed loop. The system receives the RMS voltage value from the micro generator terminals and compares it with the reference value (252). The system calculates the difference between these two values resulting in an error. If the error of the comparison has a negative value it means that the micro generator voltage is higher than the reference value, therefore, there is an overvoltage.

In the control closed loop, it is used an integral compensator gain $K_{i_v}$ to compute ϕ. The use of a value proportional, ϕ, to the integration of the error, has the advantage of ensuring the follow-up reference (zero deviation) while the value of the phase does not saturate (limitations of the micro generator).

To estimate the gain $K_{i_v}$, first it is considered that the microgenerator is represented by a model consisting of an incremental gain and a delay represented by a time constant. From [1] we know that the value of $V_{ac}$ is given by (IV.1).

$$V_{ac} \approx \frac{V_{Ref}}{2} + \sqrt{\frac{{V_{Ref}}^2}{4} + P_{pv}R_{eq}\left(1 - \frac{X_{eq}}{R_{eq}}tan\phi\right)} \tag{IV.1}$$

To obtain the $K_{G_v}$ we have to derivate $V_{ac}$ in order to ϕ:

$$K_{G_v} \approx \frac{dV_{ac}}{d\phi} \approx \frac{1}{2}\frac{-\frac{P_{pv}X_{eq}}{(cos\phi)^2}}{\sqrt{\frac{{V_{Ref}}^2}{4} + P_{pv}R_{eq}\left(1 - \frac{X_{eq}}{R_{eq}}tan\phi\right)}} \tag{IV.2}$$

If the values of $P_{ac}$ and ϕ are changed, we can obtain a 3D surface plot, figure 5.

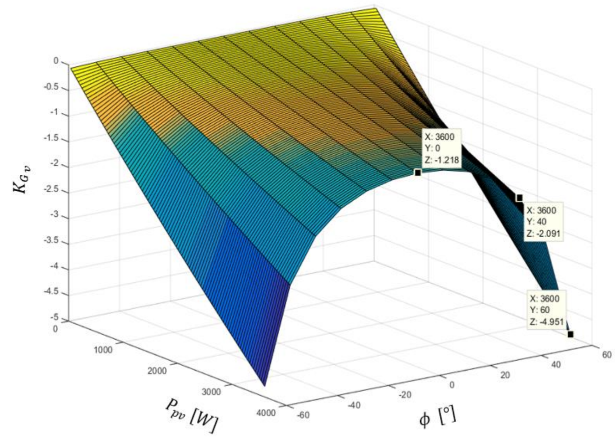


Figure 5: Surface plot of $K_{G_v}$

Then, to have the values for all the variables of the system we need to resolve the transfer function of the close-loop controller:

$$\frac{V_{ac}}{V_{Ref}} = \frac{\frac{K_{i_v}}{s}\frac{K_{G_v}}{sT_{d_v}}}{1+\frac{K_{i_v}}{s}\frac{K_{G_v}}{1+sT_{d_v}}} = \tag{IV.3}$$

$$= \frac{K_{i_v}K_{G_v}}{s^2T_{d_v}+s+K_{i_v}K_{G_v}} = \frac{\frac{K_{i_v}K_{G_v}}{T_{d_v}}}{s^2+\frac{s}{T_{d_v}}+\frac{K_{i_v}K_{G_v}}{T_{d_v}}}$$

We can see that (IV.3) has the form of 2nd order system, given by $\frac{{\omega_n}^2}{s^2+2\xi\omega_n s+{\omega_n}^2}$:

$$2\xi\omega_n = \frac{1}{T_{d_v}} \Leftrightarrow \omega_n = \frac{1}{2\xi T_{d_v}} \tag{IV.4}$$

$${\omega_n}^2 = \frac{K_{i_v}K_{G_v}}{T_{d_v}} \tag{IV.5}$$

Then, the value of $K_{i_v}$ is obtained:

$$K_{i_v} = \frac{1}{4\xi^2 K_{G_v} T_{d_v}} \tag{IV.6}$$

As the phase shift for the conventional microgenerator needs to be between -37º and 37º, which means a power factor of -0,80 to 0,80, it was chosen a value $K_{G_v}$ equal to -1,86. $\xi = \frac{\sqrt{2}}{2}$ and $T_{d_v} = 30\ ms$, then $K_{i_v} = -0{,}9$.

With this we have a decrease in the voltage. However, as showed in [1], for the grid in study, 37º only decreases 1 V. Thus, we can compute a bigger phase shift if we change the semiconductors of the micro generator, which means more costs. To avoid this, we add a storage system that, although it brings also more costs, we can offer more services and then try to compensate.

### *B. The detection system*

This system has the finality to analyse which is the scenario of the grid. There are two problems from EPQ that have interest for the system: overvoltage and sag.

1) Overvoltage is characterized, as described before, when the RMS value of the grid exceeds 253 V. However, in this problem we use a $V_{lim_{máx}}$ of 252 V.

2) A Sag consist on a momentary decrease of the normal voltage level, normally is caused by faults on the transmission or distribution network; faults in consumer's installation; connection of heavy loads and star-up of large motors. This is characterized by having a duration less than 60 seconds and a deep $\Delta U_{\%}$,(IV.7), between 10% (207 V) and 60 %. So we have a $V_{lim_{min}}$ of 208.

$$\Delta U_{\%} = \frac{U_N - U_r}{U_N} \tag{IV.7}$$

3) when the voltage is between the secure range, the system receives the grid price in order to evaluate if the microproductor should sell the energy or storage it.

Then, the differentiator variable in this detection system is the RMS voltage value from the micro generator terminals.
The $V_{ac_{Ref}}$ is 230 V.
So, the RMS voltage value from the micro generator terminals is measured, compared through a subtractor with $V_{ac_{Ref}}$, this results in an error that will have 3 value options to command the system.
Having acquired the error values, we use two relays to compare them with the desired reference values. Then the output values from both are summed and the final value will command the function of supervision. The block system is presented in Figure 6.

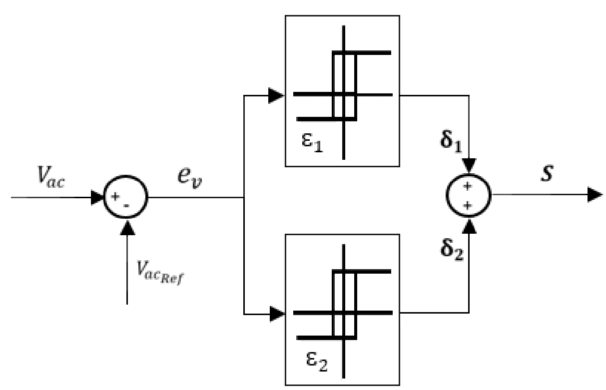


Figure 6 : Command system.

The comparator's system has 3 levels and it is built with 2 relays, each one has a bandwidth $\varepsilon_1$ and $\varepsilon_2$. The possible combinations are given on table 3.

Table 3 : Possible Combinations.

| $\delta_1$ | $\delta_2$ | S | Scenario |
|---|---|---|---|
| 0,5 | 0,5 | 1 | Overvoltage |
| 0,5 | -0,5 | 0 | Normal |
| -0,5 | -0,5 | -1 | Sag |

If the error is above or equal to 22, then the S's value should be 1 (Figure 7). $\varepsilon_1$ has a value of 2. In other hand, if the value of the error is equal or above -22 then the S's value should be -1. $\varepsilon_1$ has a value of -2. All the other scenarios should be equal 0.

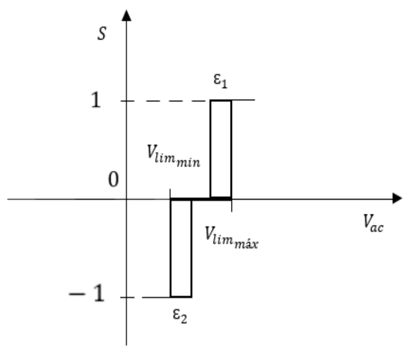


Figure 7: Figure that represent the limits of hysteresis.

### C. Supervision Function

This function's role is to decide the values for $P_{pv}$ and $P_{ac}$ and further using them to control de battery (whether it should charge or discharge). This system is not linear and it is based on user defined functions, with Matlab functions from Matlab/Simulink.

The decisions of the proposed system in this paper are based on the conditions showed in flowchart, figure 8.

This system decides if the battery will storage or inject energy in the grid as well if the PV needs to decrease his power. For the system, there were 3 assumptions:

- Any decrease or increase of power must be made slowly, in a progressively manner. Two delays were added in the output, that along with the close-loop of the output will originate the input. The delay blocks are used for the output values be the new input of the function in the next step.
- It was also despised the influence of energy injection or consume in the grid that could influence the frequency values.
- This solution works for any type of remuneration that the country has for this kind of technology. For the different trials, it was considered that the price of energy is different in some hours of the day.

As described before, there will be three different scenarios, three different value of S.

<u>Overvoltage (S=1):</u>

The system receives the value of ϕ, if this variable is at his maximum value then the system, verifies if the battery is already completely charged or not. Then, if not, the PV injects power in the battery; if the battery is already full then the PV's power must be decreased in order to decrease the voltage at connection point.

<u>Sag (S= - 1):</u>

In this case, the system must inject all the power that we can in order to rise the voltage in the connection point. As described before, a sag, most of times occurs during 1 second so, we can inject more power than the inverter normally injects. Therefore, if the battery can be discharged, both the battery and the PV will inject energy into the grid. If the battery cannot be discharged (due to security reasons) only the PV will inject power into the grid.

<u>Normal State (S=0):</u>

The system receives the energy price in the grid. If the energy price is high, then the PV injects power in the grid and if PV power is less than 3600 W and the battery can discharge then both inject power in the grid. If the energy price is low and the battery can be charged both the PV and the grid charge the battery (which means the system is buying energy).

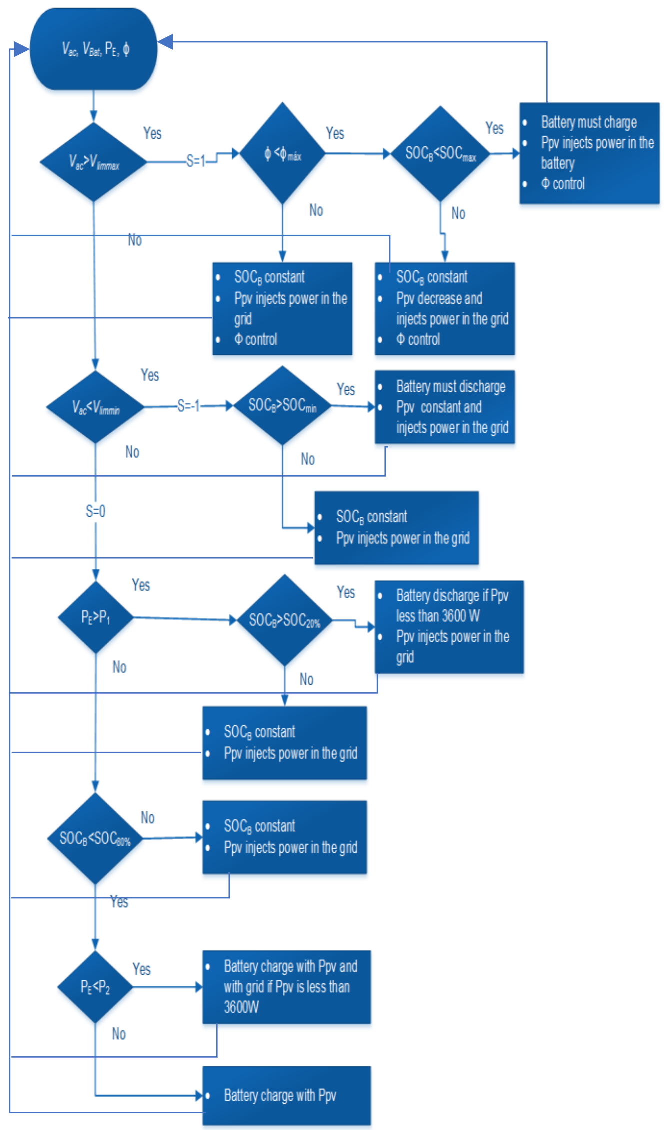


Figure 8 : Flux gram of the solution.

In the next section there made trials to show the system behaviour to the different scenarios.

## V. Results

There were made different trials in [1]. However, in this paper it's only showed the most relevant ones.

1) Trial when we have a few consumptions from the electric loads (2% from the power of the transformer).

2) When all the microgenerators in the LV grid are installed and an overvoltage occurs.

3) One conventional microgenerator is replaced by one with the solution and it tries to mitigate the sag. In this, the state of charge of the battery is low. The maximum phase shift is 37º.

4) Two conventional microgenerators are replaced by two with solutions. The storage system is fully charged. Again, the maximum phase shift is 37º.

### *1) Off-peak (when demand for electricity is lowest, 2% of the transformer).*

The simulation of the grid was made for the lowest demand. The grid simulated (figure 1) did not have any microgeneration. All the lines of the grid were studied, however it will only be presented line 3 because, for the case in study, it is the most important one. The end of the line 3 it is the point with the highest probability to occur overvoltage.

Table 4: Active and Reactive Power in the Grid

| | CA | | | B13 | B14 |
|---|---|---|---|---|---|
| | Phase R | Phase S | Phase T | | |
| **P (kW)** | 2,29 | 1,33 | 1,06 | 0,34 | 0,42 |
| **Q (kvar)** | 1,71 | 0,994 | 0,79 | 0,26 | 0,31 |

In table 4 it is possible to observe that the demand is indeed very low. Therefore, the voltage does not have a big decrease over the line (figure 9).

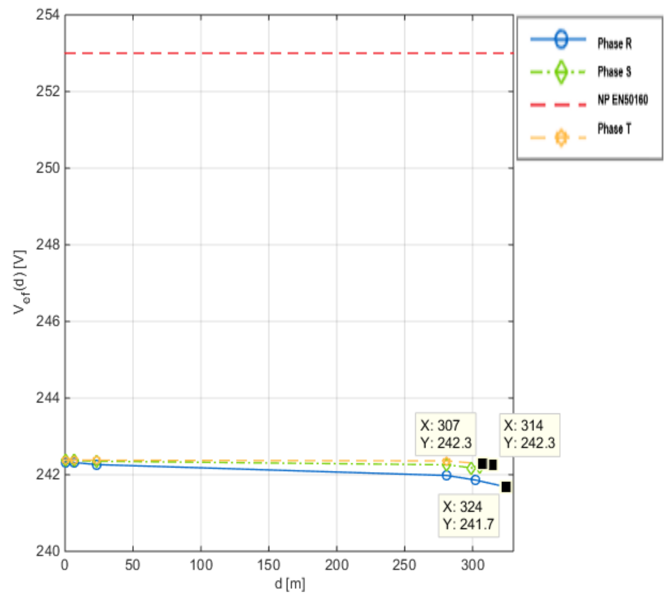


Figure 9: RMS voltage on the line 3 of the grid.

### *2) Low demand, All the microgeneration installed*

In this trial, the demand is still low over the LV grid has all the microgeranation installed (figure 1) which means that the power will flow in the oppsite direction that normaly does (table 5 ). Therefore in the end of the line we have a overvoltage.

Table 5 : Active and Reactive Power in the Grid

| | CA | | | B13 | B14 |
|---|---|---|---|---|---|
| | Phase R | Phase S | Phase T | | |
| **P (kW)** | −49,4 | −9,4 | 1,1 | −6,8 | −10,3 |
| **Q (kvar)** | 1,5 | 0,9 | 0,8 | 0,2 | 0,2 |

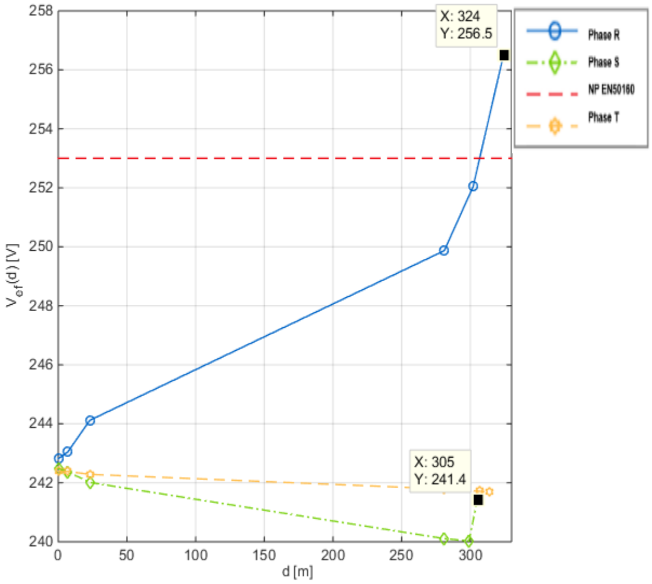


Figure 10 : RMS voltage on the line 3 of the grid.

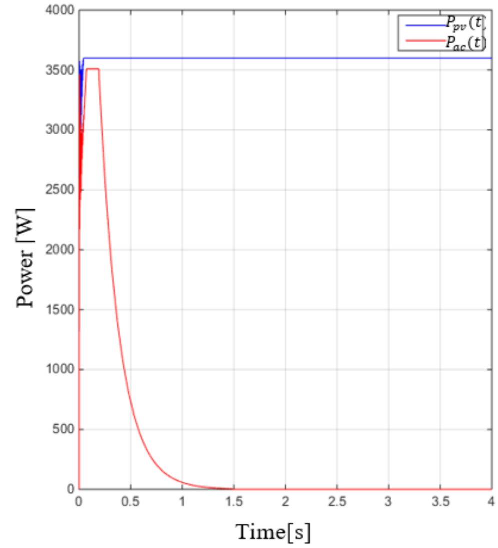


Figure 12 : Power of the inverter and PV

*3) Replacement of the microgenerator in order to mitigate the overvoltage. 1 unit replaced*

*-Storage system empty*

It is replaced one conventional microgenerator for a microgenerator with the solution proposed in this paper in each line of the grid. The microgenerator that is replaced it is on B14, B8, B2. In this trial the storage system is empty.

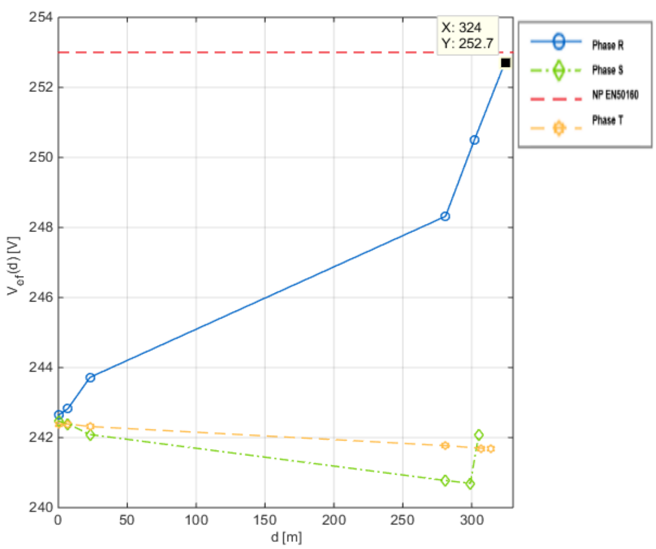


Figure 11 : Rms voltage on the line 3 of the grid

The Overvoltage is mitigated however, is close to the limit established by NP EN50160. After 0,25 seconds the shift is maximum and the battery begin to charge.

*Storage system is fully charged*

The Overvoltage is mitigated however the PV decreases till zero (figure 14). Therefore, to mitigate overvoltage there is the need to have a storage system.

Table 6 : Active and Reactive Power in the Grid.

| | CA | | | B13 | B14 |
|---|---|---|---|---|---|
| | Phase R | Phase S | Phase T | | |
| **P (kW)** | −41,99 | −9,4 | 1,05 | −6,7 | −6,65 |
| **Q (kvar)** | 3,48 | 0,9 | 0,8 | 0,16 | 0,2 |

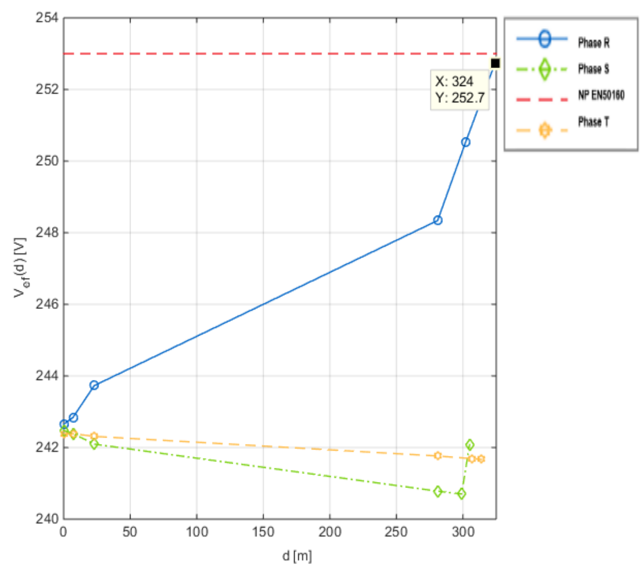


Figure 13 : RMS voltage on the line 3 of the grid.

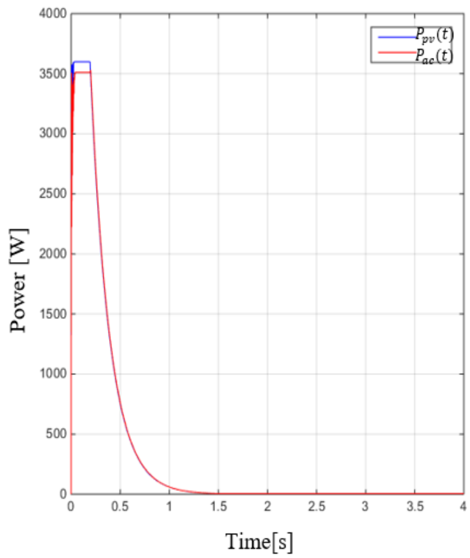


Figure 14: Power of the inverter and PV.

In both cases, trial 3. The overvoltage is mitigated; however, it is close to the limit.

*4) Replacement of the microgenerator in order to mitigate the overvoltage. 2 units replaced*

The microgeneratores replaced are from B14, B8, B2. In this trial the storage system is fully charged in both units.

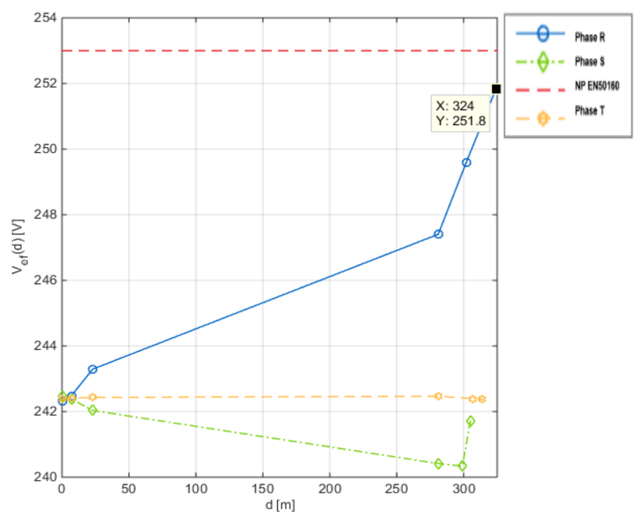


Figure 15: RMS voltage on the line 3 of the grid.

If we compare the figure 13 and figure 15, this last scenario can achieve with a higher succeed the mitigation of the overvoltage. Also, the PV's power has to decrease however, it does not go to zero.

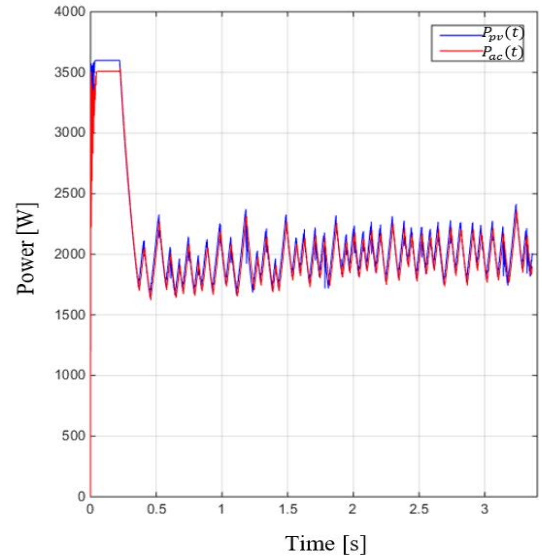


Figure 16 : RMS voltage on the line 3 of the grid.

## VI. Conclusions

A simplified model of the microgenerator along with the LV network was made in order to evaluate the systems performance. The network as simulated under a various number of different scenarios by changing the load's power and the presence of different microgeration groups. The performed tests verified the occurrence of an overvoltage under the presence of lower consumption of the electric loads and with the maximum installation power of microgeneration working on its full power.

When the solution is merged into the network and the overvoltage occurs, the regulation through phase shift of the inverter's current is enough to reduce 1 V. However, if the necessary reduction is higher than 1 V, the storage system is obliged to take action. The storage system proved itself to be effective on reducing the overvoltage if the battery is allowed to charge.

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