Impact and solutions to cope with high penetration scenarios of photovoltaic micro generation embedded in low voltage distribution networks

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Abstract

Nowadays, due to the increasing PV injection into the Low Voltage distribution networks, overvoltage and power quality issues are more likely to occur in a more and more bidirectional operating grid. This paper portrays three distinct overvoltage mitigation techniques: Active Power Curtailment, Reactive Power Support and a Hybrid Methodology. Tests are performed in different situations with total and partial PV curtailment percentages. Test results of a 55 bus LV network with 85 prosumers are further presented.

Keywords: Distributed generation, photovoltaic, overvoltage, reactive power, active power curtailment, overvoltage mitigation techniques

1. Framework

Environmental awareness has been one of the hot topics discussed lately by all the active legislators around the world. It seems due to our unprecedent and irrational consumption patterns that planet Earth regeneration capacity has been affected and we approach a point of no return, with unthinkable consequences for all of us.

Facing this, it is obvious that we must reduce fuel fossil consumption and that we must embrace, more than ever, renewable generation sources, which allows us to diminish carbon emissions to the atmosphere and possibly reduce climate change.

It is in this perspective that microgeneration concept has been gaining strength and forging its own path. Nowadays, it is difficult not to observe the numerous photovoltaic systems installed in our rooftops, reducing our dependency on the distribution network.

We should be able to act in a two-fold criteria: supply and demand. Everyone knows and acknowledges that we are irrational in what its related with energy efficiency use. We are using more resources than we can produce. Besides that, the source of production must shift from fuel fossils to renewable generation, where solar energy arises as a prominent area.

The low voltage network has been facing several changes shifting from a unilateral to a bilateral grid. Even legislations are evolving with the appearance of the prosumer concept, a client which can consume the energy he has produced locally, in his rooftop for instance.

These means that nowadays, with the addition of distributed generation concept, we can have more local production than consumption, which inverts the energy flow starting near the end user towards an injection in the LV grid.

This fact leads us to the reason this study was conducted: overvoltage issues in a high photovoltaic penetration scenario in the distribution network.

To cope with these overvoltage issues this study tests three different techniques: Active Power Curtailment, Reactive Power support and a Hybrid strategy.

2. Load Flow Three-Phase Algorithm

An unbalanced three-phase power flow program based on Backward/Forward Sweep (BFS) Algorithm was chosen, resorting to Power summation methodology. [1]

The proposed technique consists mainly in three steps: The Backward sweep, in which the power flow is calculated in each load node and in between branches, starting from the end nodes to the closest ones to the feeder. In order to calculate power values, the computed bus voltages are needed, therefore an iterative process must be implemented to attain the final voltages solution. Behind the equations used in the modeling for a three-phase LV distribution network Kirchhoff's Laws are found.

Using as reference the imposed voltage at the feeder, the phase voltages are initially assigned a predefined value, on the buses with load or with microgeneration. The power in each branch is calculated through the individual sum of each load or generator.

The following step is the Forward sweep, that computes the updated voltages in each load node and the voltage drop in between branches, based in Ohm's Law. This step takes place in the opposite direction, starting near the source to the end buses, using the previously complex powers. [2]

At last, it evaluates the convergence of the methodology. Hereby, the new obtained voltages are compared to the previous ones and if the difference is greater than a predefined value, the entire process should be repeated until convergence is reached. [3]

The chosen BFS Power Flow Algorithm was modified considering load elasticity concept, using a constant current load that adjusts dynamically its resistance whilst the load voltage fluctuates [4]. This way it is possible to the neutral voltages calculation due the utilization of a [4∗4] matrix structure – phases A, B, C and neutral (N) - which can be interesting in unbalanced networks assessment.

3. Case-Study Definition

This study is based in an unbalanced three-phase low voltage distribution grid. A single line diagram of the test radial LV distribution network is presented in the following Figure 1:

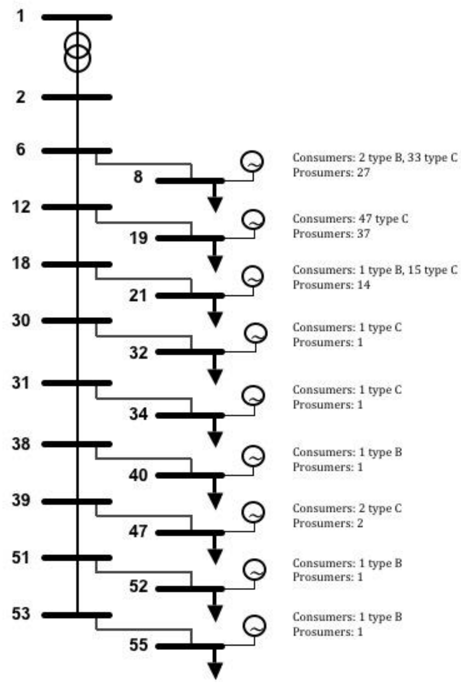

Figure 1 - Single line diagram of the LV distribution network at study

The network is composed by 55 buses. Most of them are simple load nodes, requiring energy from the grid. On the other hand, 9 busbars have prosumers connected to the grid, reaching a total number of 85 prosumers distributed in phases A, B and C. Each prosumer connected to the distribution grid is equipped with a PV generator system totaling 3.68 kWp (peak power).

Regarding consumption, the test network is composed by 105 residential customers, divided into two distinct groups – 5 Type B and 100 Type C clients. The specific load curves are presented in the study.

All the used data was collected in ERSE website, referring to the year of 2015.

In the following Figure 2, it is possible to get an overview of the studied distribution network and to analyze both generation and load curves.

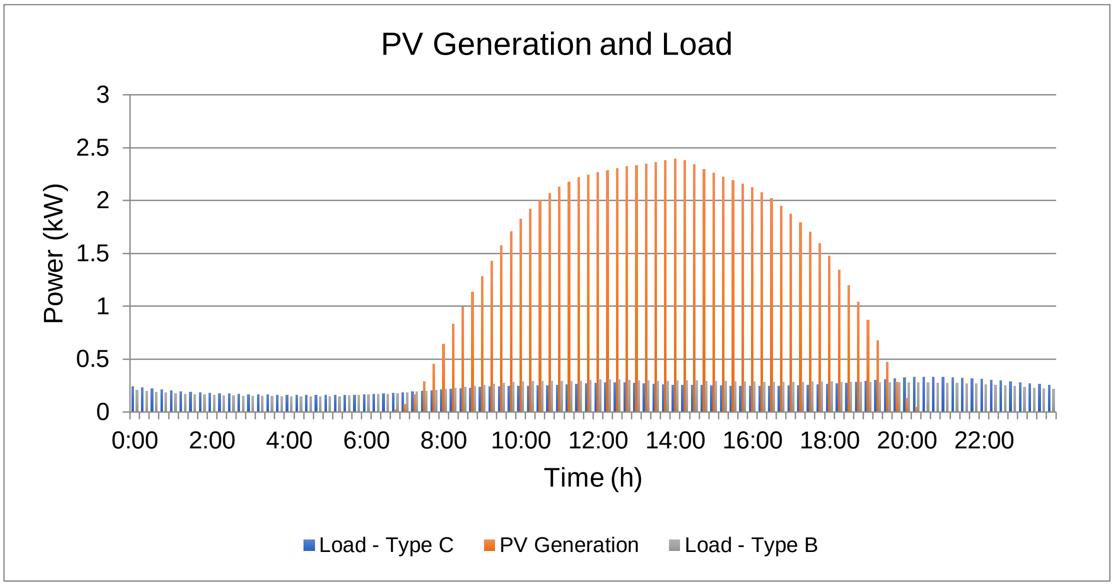

Figure 2- Load and generation Profile on a typical Summer day

Throughout the study, three distinct strategies are tested and results are presented. The simulations focused on busbar 19, the one with a higher number of clients connected to all phases, in addition to an uneven distribution across phases and further away from the transformer. All these situations combined, end in an extremely unbalanced node, registering the highest voltages.

4. Simulation and Analysis

The presented study offers three different solutions to mitigate overvoltage issues in a distribution network:

4.1 Active Power Curtailment

Once microgeneration integration in the network takes place, the equivalent load is reduced and the voltage on that specific busbar tend to increase, eventually causing overvoltage issues or reversing power flow typical direction.

Active Power Curtailment appears to tackle these situations. Whenever voltage profile surpasses 1,1 pu, active power curtailment is enabled and disconnects the specified PV set from the problematic busbar. This happens continuously through the whole grid, until voltage profile returns to the normal operation voltage range.

This technique was tested with two different curtailment percentages, revealing its benefits and disadvantages: with a full and a partial PV curtailment.

In the following Figure 3, it is possible to observe bus 19 voltage profile, focusing Phase A. Both energy curtailments percentages are illustrated, a full cut off and a 75% cut off.

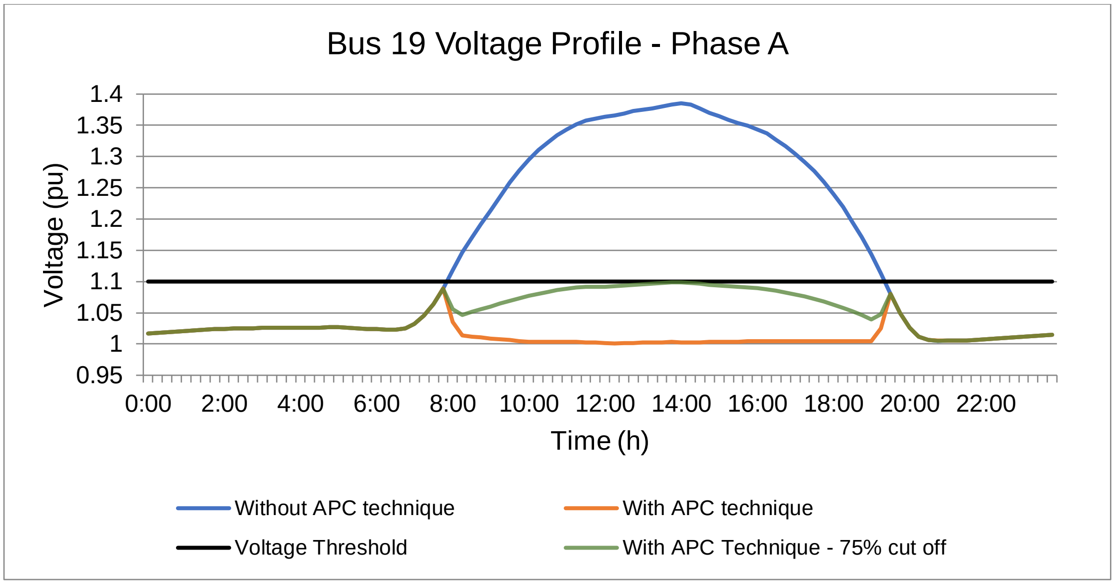

Figure 3- Bus 19 voltage profile in three distinct situations: Without APC technique, using fully APC technique and partially APC strategy (100% and 75%), on a typical summer day

As we can observe through the above figure 3, a full energy cut off, although it tackles all overvoltage cases and reinstates the normal operation grid status, ends with a high clean energy waste and reduces the potential producers' profits. On the other way, a concrete energy curtailment results in a much efficient proposal to cope with overvoltage issues.

4.2 <u>Reactive Power Support</u>

Photovoltaic energy results from the direct sun radiation transformation into electricity. PV modules generate electricity in direct current whereas our electricity power system works under an alternate current. Inverters appeared with the scope to transform direct current into alternate current.

Smart inverters may also help in the power quality along the lines and reducing power losses, through the absorption of reactive power.

Looking at the following Figure 4, it is possible to observe that although proving itself as a not much effective methodology, since does not eradicate overvoltage issue, the proposed technique is able to smooth the voltage profile, reducing its voltage in a such problematic busbar in the network.

This merely marginal enhancement in the low voltage network is due to a high R/X associated to the distribution grid, which operates with lower voltages and higher resistance and losses throughout the grid cables. [5]

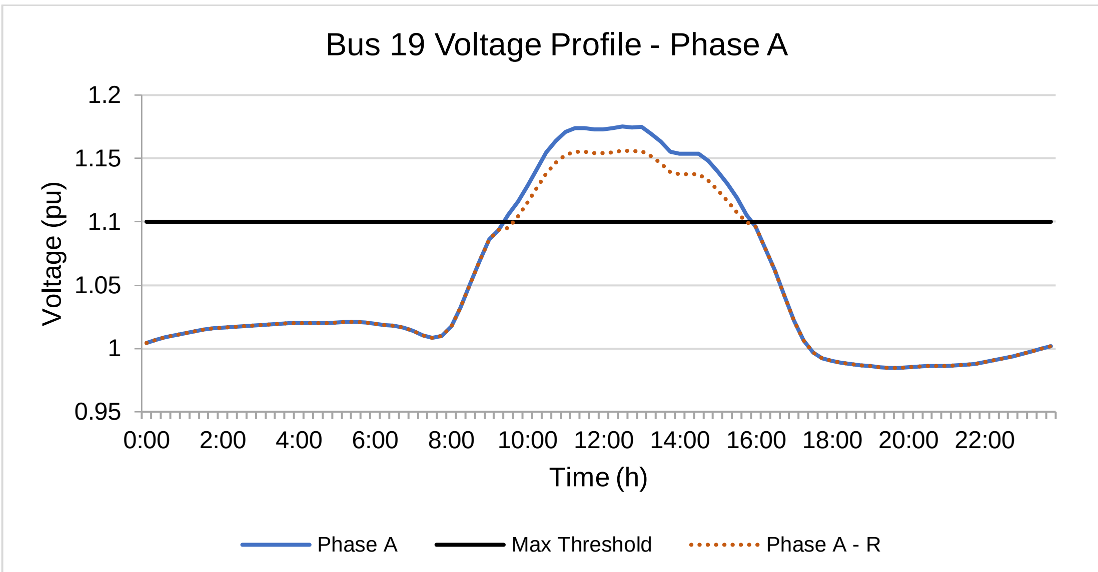

Figure 4- Bus 19 voltage profile with PV integration in the LV grid and with Reactive Power support technique in a typical winter day

4.3 <u>Hybrid Technique</u>

At last, the Hybrid Technique appears, which combines the strengths of the previous studied methodologies.

Once microgeneration appears and penetrates the grid, overvoltage issues are likely to occur. Whenever voltage values in a specific busbar along the line trespasses 1.1 pu, reactive power support technique tackles and smooths the problematic busbar. If this reveals itself not enough, Active power curtailment takes place. The desired fraction of active power that is curtailed is previously chosen in order to maximize profits, to exploit clean energy use and allowing its penetration into the low voltage grid. The ultimate technique, with a curtailment of only 32% of the produced energy is illustrated in Figure 5.

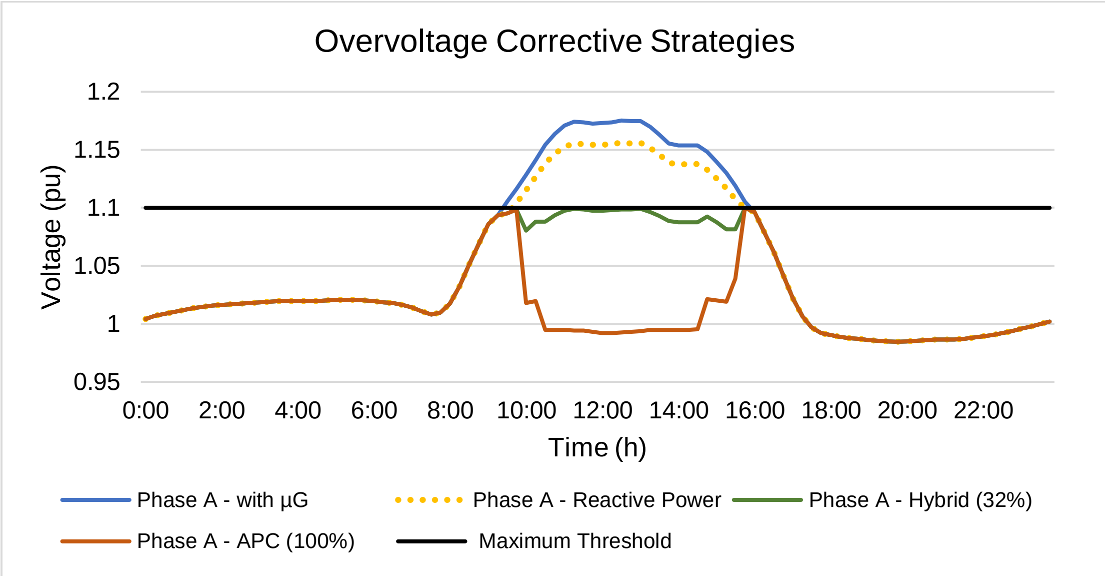

Figure 5 -Bus 19 voltage profile with µG integration, reactive power support and APC technique

An analysis to the previous studied techniques is hereby presented.

The most efficient methodology is the one which presents the best balance between a high PV injection into the LV network with none or a marginal associated rate of overvoltage issues.

Table 1 presents a summary of the obtained curtailment results, representing the precise percentage of PV energy curtailment for each strategy, preventing undesired overvoltage cases, during the studied seasons.

Table 1 - Summary of the obtained results of the strategies that involve curtailment processes

PV Curtailment		
Season	**APC (%)**	**Hybrid (%)**
Winter	45	32
Summer	75	70

5. Conclusion

This study proposes three distinct corrective strategies to tackle overvoltage issues, using Active Power Curtailment technique, with different levels of curtailment, and a Reactive Power Support Technique, with a smart PV inverter contribution. At last, a Hybrid solution is proposed to keep voltage profile values between the acceptable legal range, merging the two previous methodologies.

Comparing the results, it is clear to state that a higher curtailment is needed during summer facing winter situations. Taking into account that during summer, due to a higher radiation, reaching the PV modules and higher temperatures, there is a consequent increase in the most problematic network nodes. Naturally, in these cases, the PV curtailment must be harsher than in Winter.

Looking between APC and the Hybrid technique, due to the Reactive power support action in the later methodology, the precise PV curtailment is more reduced facing the APC method.

The hybrid methodology proves itself as the most efficient strategy to tackle overvoltage issues in a low voltage grid experiencing a high penetration scenario, ensuring power quality, the normal operation of the grid and increasing the hosting capacity. Moreover, from the producer point of view, increases his profits and maximizes renewable energy integration in the network.

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