DEVELOPMENT OF A TOOL FOR CALCULATING THE EFFECTS OF PV-SYSTEMS CONNECTED TO A LOW VOLTAGE GRID

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ABSTRACT

In this paper, a prediction tool for problems caused by small photovoltaic systems is proposed. This tool accounts for the usual stability troubles generated by these systems when connected to a low voltage grid. The voltage fluctuation due to changeable insolation, the inversion of the power flow due to generated but non-demanded energy and the increase of short-circuit capacity due to the large number of connected generation systems are the problems considered in the proposed tool. This is intended to be useful for utility companies in order to give them criteria to decide whether a certain PV unit or group is suitable for a local LV grid. Besides, this kind of installations produce a high harmonic injection, because of the final inverter needed. That leads to more distortions on the grid and further problems.

INTRODUCTION

The increasing introduction of small power generation systems such as the photovoltaic ones to the grid is provoking stability problems in the network where they are connected.
As this autonomous generation is unpredictable and dependant on weather conditions and their connection to the grid is currently more and more promoted in order to achieve a green empowerment scenario, the need for studying the consequences of this fact is getting more and more necessary.
Namely, voltage variation, reverse power flow and the increasing of short-circuit capacity are the most common instances. Other undesirable effects caused by the formers are protections and fuse malfunctioning as well as harmonic injection implied by the use of converters.
Scientific community has made lots of efforts in order to predict possible harmonic resonances due to the injection at several frequencies, but not that much has been devoted on considering other effects. The proposed tool considers and foresees them all. Because the PV panels are a technology that causes problems in other fields, not just in the harmonic issue, a tool taking them all into account is needed.
Spanish utilities complain that lots of speculation is being made with PV system, because they are highly good remunerated. Because of all the problems and instabilities that can cause to the grid, new ways of calculation need to be established. In this field is where this tool is being developed for, for helping the utilities to predict the possible problems that a mass introduction of these systems can cause in a particular LV grid.

CONCERNS

Utilities are worried about the previously mentioned effects on the network caused by PV generation units. Here comes a brief description of the main ones, which are the ones the utilities are more worried about because can lead to more problems in their grids.

Voltage variation

PV generation works on the LV network in an inverse way as it was designed for. Instead of consuming, it introduces power to the network and, to do so, the voltage at the point of connection is increased. This can help somehow to compensate the voltage drop when a big load is connected, but can lead to quick voltage variations in the whole network when the PV generator is continuously connected and disconnected.
Because nobody can guarantee that a PV generator will never fail in producing (especially because it partially depends on weather conditions), the difference in voltage with or without the unit should be considered.
If several PV units were to be connected in the same area, this problem could be increased and its effects multiplied because more and more power is being introduced to the LV grid.
As well, if the installation is big and injects lot of power to the network, the voltage can not only be increased but it can also be higher than the allowed limits. Then it causes problems not only in the point of connection but also in the whole area where this network is spread and the customers connected to it.

Reverse power flow

A LV network is supposed to bring energy to the final consumer, but it has not been designed to work the other way round. If more power generation were to be connected in a LV grid than the power that is actually consumed at that point, a reverse power flow should be expected. That

means that, globally, the LV network would introduce power to the MV grid where it comes from, instead of consuming it.
Since several protection devices work regarding the direction in which the power flows, this could lead them not to operate properly. Besides, when the power flow is inverted, the voltage at the end is higher than the voltage at the beginning. That is not desired at all.

Increased short circuit capacity

As PV units are power generators, when a fault occurs, the short circuit current is increased. This leads to an increase in short circuit power and therefore, makes it more violent.
That is so, because they act as power injections. If a short circuit occurs in a certain point where PV panels are near, they will add more power to the short circuit and, therefore, the short circuit will have worse consequences.
When protection devices are regulated against short circuits, they are not thought for this new capacity and if the short circuit current is much higher, it may lead to malfunctioning of the short circuit protections.

Operation default of protections in substations

When lots of PV units are connected along a LV line and a fault occurs at the end of it, these PV units give part of the short circuit current that flows. That makes less current flow from the substation and therefore, it may be difficult or even impossible for the protections there to distinguish between a short circuit and a usual overloading process.
That can be dangerous if a real fault occurs, because the protection devices would not be working when supposed to, and, therefore, it can lead to bad consequences.

Harmonics

One other big problem of PV installations are harmonic injections. Harmonics, though, are commented below in another chapter, because they are not a problem of distributed generation but of power electronics in general.
This may induce problems when isolating the fault and as a consequence, large short circuit effects.

TOOL EXPLANATION

In order to assure a good operation of the network and control the possible effects that in the worst case, such generation could cause, a tool has been developed in the Electrical Engineering Department of the Polytechnic University of Catalonia. This program should be able to tackle all this problems.
The first thing to be decided was the programming interface which would be used. Because of its ease in programming, its powerful mathematic library and dynamic help, the MATLAB interface was selected. It allows focusing directly on what is wanted to be programmed rather than in programming details. It has also very powerful graphical libraries, which permit to make useful plots of the variables, without much computing effort.

Then, some hypotheses were to be made in order to simplify the problem and make it more easily programmable and focused on the problems that were to be studied.

- When developing the tool, the Newton–Raphson algorithm was selected, because it is the quickest to converge. Moreover, it can lead to very precise solutions with very little error. Furthermore, it has been widely used over the years for other Load Flow software developers, and it has proved its accuracy and efficiency.
- First of all, LV networks in Spain tend to have a tree configuration, that is to say, they do not constitute a mesh. That fact strongly simplifies the algorithm used in the drawing tool.
- Besides, in LV networks all nodes are PQ nodes, which make the Newton–Raphson algorithm much easier.
- Last but not least, PV generators were modelled as simple negative loads, because their behaviour on the grid is like this: they do not behave as though they could regulate the voltage in the node they are connected, they simply inject some power to the grid.
- Lines were modelled as long lines, because in further versions of the program a harmonic module is bound to be incorporated. In order to make the calculations more precise, the long line model gives much more accuracy to the results, especially at high frequencies.

All these were taken into account and, therefore, it was much simpler to develop the tool. All networks do not comply with this hypothesis, but most of the LV grids in Spain do, and this tool has been thought to be working with them.

EXAMPLES

So all this can be easily understood, an example has been calculated with the so far developed tool.
The following network is a typical LV network from a Spanish neighbourhood. There is one main LV line and it splits into several others, so all consumptions can be satisfied.

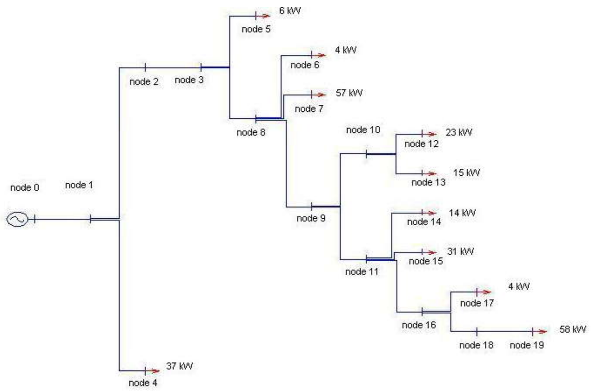

Figure 1: Network to be calculated.

Up to 10 clients hang on this line, all of them in a rural area, so they could be quite interested in installing PV generators in their facilities.

If the usual Load Flow is calculated in these conditions, the network behaviour can be analyzed. This is the worst case of all, where all clients consume all their rated power at the same time, which is very unlikely to happen.

The figure below shows the results of these calculations.

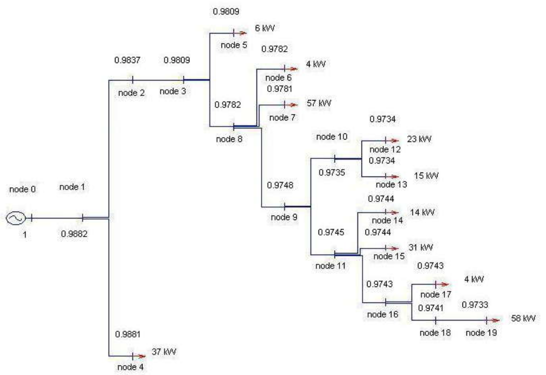

Figure 2: Results of the Load Flow calculations.

It can be seen that the lowest voltage is 0.9733 pu, that is to say, there is only a voltage drop of less than 3%. The voltage profile, from node 0 to node 19 is as follows. It was predictable, that it would be steadily falling.

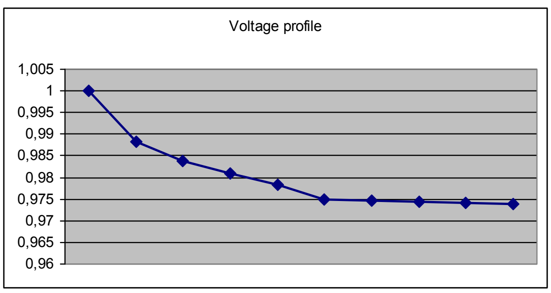

Figure 3: Voltage profile.

Table 1: Current flow between nodes.

I_{BA} (A)	Node A	Node B
367,7	0	1
54,0	4	1
313,7	2	1
313,7	2	3
304,9	8	3
214,9	9	8
158,5	9	11
91,9	11	16
85,9	18	16
85,9	19	18
5,9	17	16
45,9	15	9
20,7	14	9
56,3	9	10
22,2	13	10
34,1	12	10
5,9	6	8
84,1	7	8
8,8	5	3

This results show that the total amount of power supplied to the network is obviously coming from the main source. That will change drastically when PV inverters are installed. Imagine now, that all clients in this area are interested in installing a series of PV 20 kW rated power systems. That would lead to a total of 200kW installed PV power, which is almost 80% of the total power consumption.
What should the utility do? Should it allow such amount of power to be installed? That all clients would be interested in such PV generators seems rare, but taking into account that more and more people are asking for it and the fact that some of the projects now being led in Spain have over 1MW rated power; it makes everything much more believable.
Making these calculations, the results obtained are as follows:

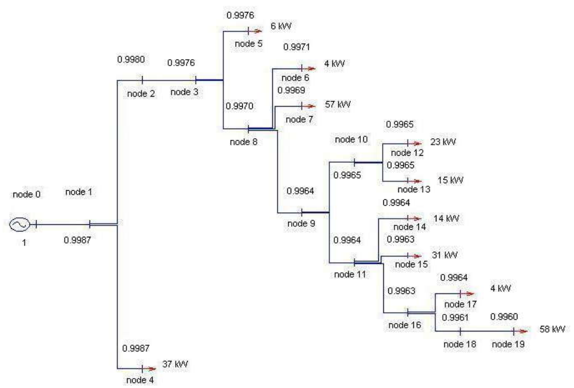

Figure 4: Results of the Load Flow with PV panels.

As can be seen now, the lowest voltage is 0.9960, which means that there is a maximum voltage drop of less than 1%. Now the voltage profile from node 0 to 19 is continuously falling again, but just by chance.

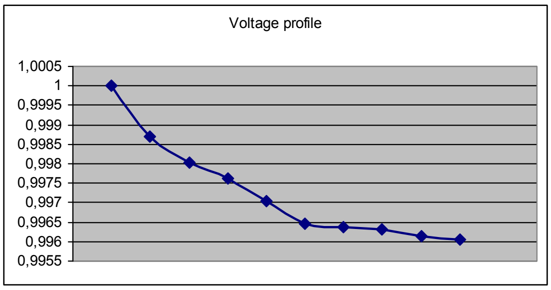

Figure 5: Voltage profile.

That is so, because we can find some examples in the same grid, where the voltage is higher at the end of the line than it is at the beginning. This means that the line is actually working the other way round, returning power to the network instead of consuming from it. Here comes the voltage profile, from node 0 to node 6.

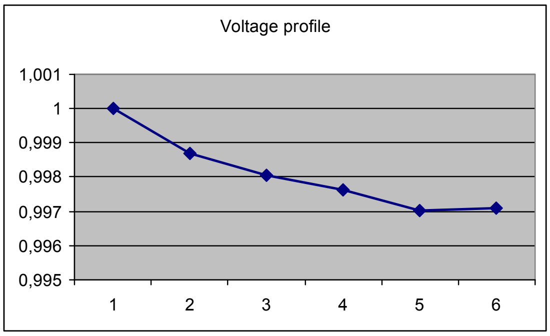

Figure 6: Voltage profile from nodes 0 to 6.

In this case, where so many PV generation units have been installed, the current flows from one node to the other result as follows:

Table 2: Current flows.

I_{BA} (A)	Node A	Node B
42,0	0	1
4,3	4	1
46,4	2	1
46,4	2	3
66,6	8	3
36,2	9	8
39,1	9	11
31,9	11	16
55,0	18	16
55,0	19	18
23,2	17	16
15,9	15	11
8,7	14	11
2,9	9	10
7,2	13	10
4,3	12	10
23,2	6	8
53,6	7	8
20,3	5	3

As it can be seen, the difference between now and the previous scenario is huge. Currents have been drastically reduced and even some lines (lines with grey background) are now working the other way round to which they are supposed to. That is the “reverse power flow” problem.

If the total amount of solar energy produced were to be higher than the total amount consumed, the reverse power flow could appear in the whole system, that is to say, the transformer before node 0 would be injecting power to the network instead of consuming from it.

FURTHER WORK

The hereby presented tool is just a first version and is still under development. Short circuit calculations and automatic search for the worst case is still to be implemented. Already, some ideas came up for a second version tough, with more modules included and further possible calculations to do.

The first kind of calculations that are thought to be made are harmonic calculations. As known, PV inverters, as other types of inverters, introduce harmonic currents in the grid. These currents at frequencies higher than 50Hz induce problems in the network, such as voltage distortion all throughout the grid, and possible resonances appearance in whatsoever node of the system.

These calculations could be easily introduced, as the main Newton–Raphson module has already been developed. That would make it possible to predict whether some kinds of inverters are more suitable than others for this technology and which are not. Furthermore, it could predict bandwidth in which can a certain resonance can be expected to appear at any point of the network.

Other calculations that may be introduced in further versions of this tool are reliability calculations. The more elements introduced in a network, the less reliable it is. If some part of this network is strongly dependant on PV generation, which are the new reliability indices? Apart from that, these indices change, because in case this PV generation is available at a certain point in time, it can be seen as an additional source of power, so parts of the network could even work if the grid were disconnected from the main grid.

HARMONIC CALCULATIONS

As said before, harmonic calculations can be part of the new enhancements of the tool. By means of them, more effects caused by the connection of new electronic equipment to the grid could be analysed.

Advantages of harmonic calculations

The effects of harmonics are well known:

- Saturation of equipment
- Resonances with the rest of the grid
- High voltage distortion
- Malfunctioning of equipment

In LV grids, the amount of harmonic injections is high, due to the high levels of Power Electronics that have lately been installed in domestic equipment.
Besides, an injection at a certain point in the network can cause problems anywhere else in the grid. That is so because the harmonic injections spread and travel along the grid.
For all of these, if a full calculation could be carried out, all of those problems should appear and solutions and possible countermeasures would be taken into account.

Disadvantages of harmonic calculations

However, some problems regarding these kinds of calculations must also be considered.
Non linear loads are very difficult to model because they behave very differently depending on the voltage applied. That means that the harmonic injection that the manufacturer gives in certain voltage conditions may not be the final injection of that very same load in other conditions. When harmonic injections appear in a grid, the voltage wave is also affected (because of the impedance of the grid elements). Therefore, it is very difficult to predict what injections a particular load will have, when not even the final voltage wave is known. Only some estimations can be supposed.
That means that harmonic calculations can be very complex if a very accurate calculation is desired, because the problem becomes iterative; supposing a final voltage, we can calculate the injections, and then the final voltages again. This circle should be repeated until the final convergence.
However, if the hypothesis that the final voltages may not differ a lot from the desired ones (as it should be in a power system) and the voltage distortion is always kept under the norm limits can be assumed, one may also consider that the voltage injection would not vary much from the initial estimated one.
Besides, when the frequency is increased, all parameters of a power system are affected. Capacitors and inductance increase their effects, so a more accurate value of them should be used. In many occasions, only estimations of that parameters are known, especially regarding the uncertainty in which most of them are estimated.
That means that, if the initial value has some errors, those will be magnified when calculations in higher frequencies are made. That would lead to errors in the results.

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