INCREASE PHOTO VOLTAIC HOSTING CAPACITY USING DATADRIVEN NETWORK MODELING

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ABSTRACT

It is frequently admitted that the rate of photo voltaic (PV) peak power must not exceed 20% to 30% of the maximum power consumed on a given LV feeder. As a result, the PV hosting capacity remains quite low, or the DSO takes the risk of voltage issue if he decides to exceed. RESA, the Belgian DSO and Odit-e, a French startup have tested a new way to at least double the PV hosting capacity of network feeders. An experimentation was made in an area already overequipped with PV and subject to voltage issues. Results show that it has been possible to tackle existing voltage issues efficiently and to identify a significant additional hosting capacity.

INTRODUCTION

Currently the DSOs have no relevant information on the load flow at the level of LV distribution Grid.
This implies the following consequences:

- A poor knowledge of the connection topology of DSO's customers.
- A distribution of LV loads of customers that is not adequate or in any case not properly optimized.
- Relatively large imbalances in both consumption and renewable production, inducing significant overvoltage phenomena (figure 1).

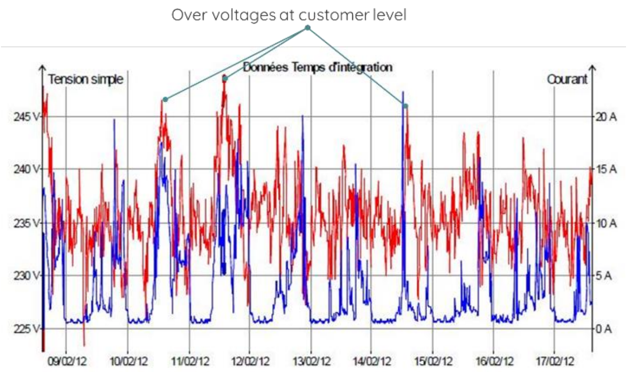

Figure 1 Overvoltages

- In some of the case, the sunshine conditions cause over voltages on the LV grid that are so great that they cause an increase of the supply voltage at the DSO's customers, leading to the shutdown of the inverters of the photovoltaic producers (loss of production).
- This lack of knowledge also implies a decrease in the efficiency of the LV distribution grid (increase in technical losses).
- It does not allow effective actions in the context of extension of the LV grid for the connection of new customers.
- It significantly limits the introduction of renewable production (photovoltaic panels) into the LV distribution grid and above all their optimal operation.

CHAMPS DE BEYNE FIELD CASE

The field case described here presents the following figures:

- 630 kVA MV/LV substation, 120 customers
- 35% of prosumers producing, 5,5 kWp averaged
- 13% of prosumers complaining about inverters disconnection

Figure 2 - Champs de Beyne

SOLUTION

Build an empiric model of the network

The classical method of studying electrical networks consists of integrating the parameters of the studied network (lengths and sections of cables, topology) into a theoretical model including precise cable models. Subsequently, and in order to perform a load flow calculation, this method proposes to link the different models through physical equations (Ohm's law).
This method, however, neglects the reality of the complexity of the low voltage network: the topology is poorly known, the impedances can be very far from the theoretical values, and many parameters are not considered (grounding of the cables, mutual inductance between phases). In practice, these methods do not make it possible to reproduce the states of the networks measured in the field by simulation. The reliability of the extrapolations obtained by these methods is insufficient and this leads to systematically taking large margins of safety in the operation of these networks.

Odit-e uses only real data measured on the network to modelize the low voltage network. Basically, smart meter data are used, but in the case of the experimentation, smart meters were not deployed at that time, therefore we used:

- Active power at MV/LV substation level for each feeder
- One voltage measurement along each feeder.

For the training stage, the machine learning algorithms request on month of recorded data and then build a digital twin of the network that behaves as the real one.

Odit-e doesn’t use any information regarding the physical network like length and cross section of the network, customer connectivity as this information is often difficult to obtain and tainted with mistakes…
On the opposite Odit-e can provide an accurate map of the network based on the smart meter data.

In the long run, the Odit-e solution aims to assimilate a large amount of data from smart meters, and to draw a map showing the critical areas: areas at risk of congestion, voltage excursions, zones with a loss rate too high, areas to rebalance, or a map of the remaining margin for PV installation.

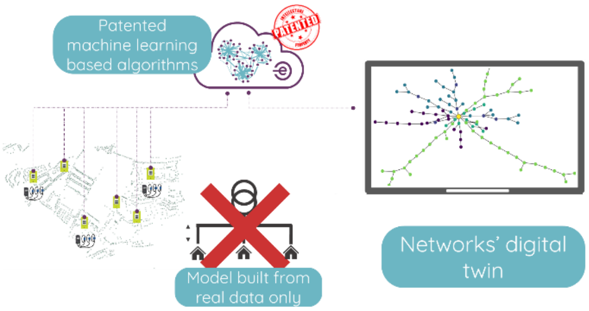

Figure 3 - Odit-e empiric model

Network preparation to PV production hosting

Photo-voltaic insertion is among other limited by network imbalances. The measurements done during the experimentation will confirm strong imbalance on both production and consumption.

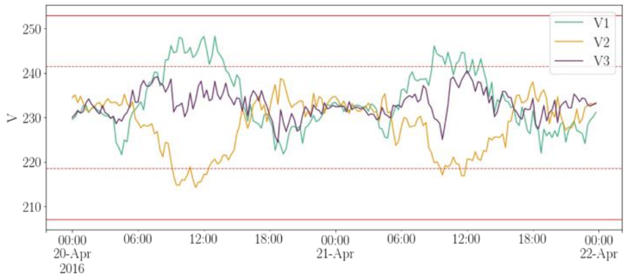

Figure 4 - Initial Voltages unbalances on feeder 3

The first step is to rebalance the loads and legacy PV productions for each Low Voltage feeder among the three phases. To do so, Odit-e provided a rebalancing scheme based on the network’s model and on subscribed power for each customer. At that time smart meters were not installed on this area, therefore we assumed that each customer contributes to the global consumption proportionally to his subscribed power.

Customer	Production	Regular phase	Target phase
Rue X, 3	Yes	2	3
Rue X, 7	Yes	2	3
Rue X, 5		3	2
Rue X, 16	Yes	2	1
Rue X, 25	Yes	2	1
Rue X, 2		1	2

Figure 5 - Rebalancing scheme for Blue feeder

Impact prediction

The second step is to estimate the impact on voltages and currents of the evolution of loads and/or productions.
Since the empiric model is directly built from field measurements, it recreates the real behavior of the network. The predictions obtained are therefore much more precise than those obtained by conventional

methods.

To perform impact studies, the second step is to isolate, in a power signal, the part due to the photovoltaic production and the part due to the consumption. The method developed by Odit-e uses the difference obtained between predictions made on various sunny days. The results, although still perfectible, allows to obtain a relevant separation.

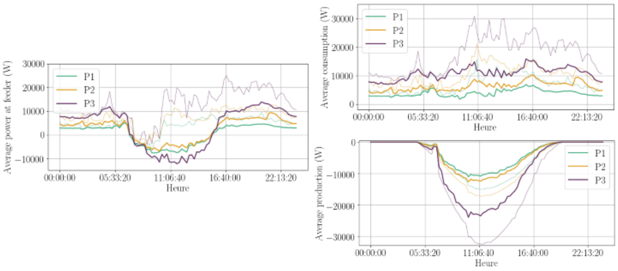

Figure 6 - Separation of the global power curve (left) into a consumption curve (top right) and a production curve (bottom right)

EXPERIMENTATION RÉSULTS

The principles described above have led to an experiment on the Champ de Beyne area. In the initial situation, this area was already very largely equipped with PV solar installations, with a peak power installed per feeder of the same order of magnitude as the maximum power consumed. The first phase of the experiment consisted of a measurement campaign to achieve model learning. Four three-phase voltage measurements were arranged towards the ends of the considered feeders, as well as power measurements on each feeder/phase in the MV/LV substation. Local sunshine was also recorded from the meteorological website.

Measurements were collected between March and May 2016, every 15 minutes, and allowed us to build the empirical model of the network.

It was then possible to precisely identify the power produced by phase and by feeder. (The Odit-e model uses the peak powers actually injected into the network which may be significantly different from the peak powers known to the DSO. Indeed, given the panel orientations and installation methods that are rarely optimal, the actual peak powers are much lower than the nominal peak powers. The Odit-e algorithm returns a distribution of the nominal peak powers, while keeping for the rest of the calculations the real peak powers). To maximize the PV capacity, a rebalancing was proposed and physically carried out. On this network, a customer who is both producer and consumer has only a single point of connection to the network. Consequently, for the same customer, the phase change of his production must have been accompanied by the same phase change for his consumption.

A review of the rebalancing was then carried out, based on the measurements recorded after the operation. The impact of rebalancing is shown in Figure 7.

		Blue feeder		
		Ph A	Ph B	Ph C
PV Installed Peak power (kWp)	Before	16	18	34
	After	21	24	23
Average consumption (kW)	Before	6,4	7,4	11,3
	After	12,3	11,6	9,3

Figure 7 – Impact of the rebalancing action

The network has thus been relatively well balanced, which is a first condition to limit voltage excursions. Figures 3 and 4 show the impact of the imbalance on the voltage at the end of the network on the blue feeder. They correspond to the average daily profile over approximately one month of measurement with, for each phase, the average value (bold lines) and the min/max values (thin lines).

The effectiveness of rebalancing is obvious: while the maximum difference between max and min voltage was more than 30 volts before rebalancing, it is only 18 volts after rebalancing.

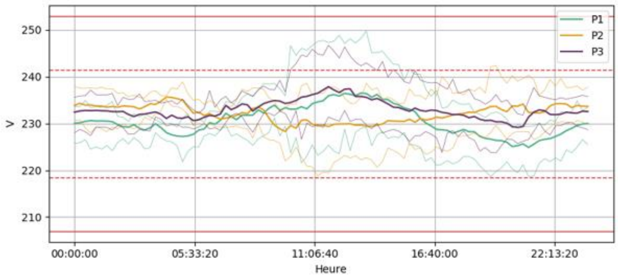

Figure 8 – Voltages before rebalancing

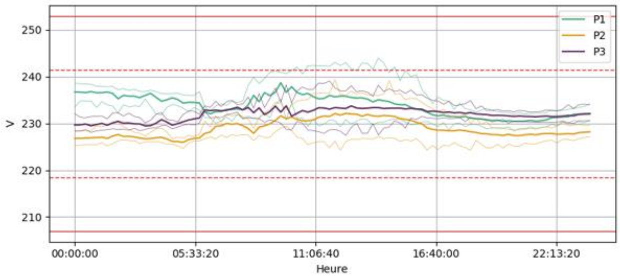

Figure 9 – Voltages after rebalancing

The third phase consisted in estimating what peak power could still be added per feeder and phase. The empirical model easily simulates the addition of new PV generators. To maximize the insertion of PV on the feeder, two constraints must be respected simultaneously:

- This addition must be done in a balanced way to limit voltage excursions between phases
- The sum of the peak power must remain compatible with the sizing of the feeder.

Concerning the blue feeder, our model made it possible to draw a sensitivity diagram (figure 10). This diagram shows the maximum peak power the feeder can accept in respect with the corresponding imbalance. Below the yellow area, the maximum voltage remains below the 5% overvoltage threshold, and below the 10% overvoltage threshold for the red area.

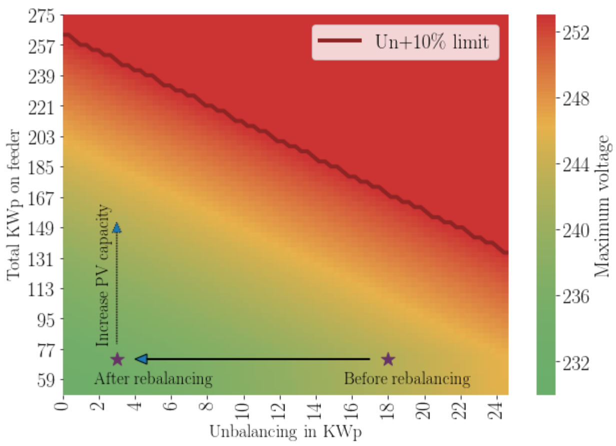

Figure 10 – PV hosting capacity according to imbalance

It is assumed that the additional peak power is uniformly added over the total length of the line. If the power were to be added at the end of the line, a new simulation would be necessary and would lead to a smaller capacity.
Finally, on this specific network, our empirical model shows that it is possible to set up 160kWp of PV production without reaching Un+5% at the end of the line. This estimation takes into account the existing loads, and assumes that production is perfectly balanced along the line.
It is also important to note that the voltage fluctuations related to the MV network and considered at the substation are those that have been observed during the learning period. It could be possible that the MV network had remained exceptionally stable. If higher voltages fluctuations would occur in the MV network, it would lead to a smaller PV hosting capacity.
Another important factor was not discussed here: the position of the transformer tap changer. In our case, we had previously identified and used the most appropriate position to conduct the experiment.

Validation of the model

The use of the empirical model suggests a significant potential for increasing the PV capacity of LV networks. This potential is far beyond what the commonly used rules would indicate. We therefore sought to validate the reliability of the simulations built with our model. Of course, it was not possible for us to experience an increase in PV production beyond the capacity already installed, but we were able to test our simulations by checking the impact of the rebalancing we had recommended.
The model was trained between March and May, based on phase/feeder currents at the substation and voltages at the end of the feeder. We verified that, after rebalancing and in the middle of summer, our model allowed the calculation of remote voltages with an accuracy better than 2 volts (~1%) based on the measurement of phase/feeder currents alone.
The next step will be to use only the data from smart meters that are being deployed in this area. During the training, the meters will provide power and voltage data for about 1 month in a 15' time interval. This will allow the creation of a model that can be used for simulation purposes in planning, for example, or to feed a SCADA with real time voltage estimation.

CONCLUSION AND PERSPECTIVES

Technical solutions exist to fill this lack of information on load flow in the LV distribution grid and especially to significantly increase the efficiency of LV grid.

- The introduction of LV monitoring directly on the LV boards in the distribution substations allows for a thorough knowledge of the load distribution (production and consumption), as well as reliable way of detecting imbalance problems and quantifying them at the level of the grid served by the MV/LV substation.
- The use of Smart Meter at the customers allows to have reliable measurements of consumption and production in the LV distribution grid, which can be used for the study of optimal grid topologies to be applied in the framework of extension of the LV grid.
- The introduction of Smart Meter technologies in the LV grid is also a reliable and fairly simple way to quantify and locate technical losses.
- The use of Smart Meters in combination with appropriate algorithms enables a simple and effective rebalancing of LV customers loads to the distribution grid level directly via the DSO maintenance teams.

The combined use of the technical solutions mentioned above with load balancing algorithms doubles the number of renewable productions that de the DSO can optimally introduce into its LV distribution grid, in complete safety.