New planning tool for Low Voltage photovoltaic connection – large scale experimentation

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Abstract

The current deployment of photovoltaic (PV) productions, which can affect voltage profiles or create congestions in low voltage (LV) networks, requires accurate planning studies. However, state of the art network simulation tools are not adapted to LV networks specificities: these tools require an extensive knowledge of LV networks characteristics, such as network topology, cables lengths and sections, which are largely unknown, inaccurate or outdated.

To work around this problem, Odit-e has developed an innovative way to digitize LV networks, where the network model is entirely built from smart meters data. The resulting model can be used to precisely estimate the impact of any change in power, including new productions, and is the core of Odit-e innovative planning tool.

To validate this tool in an operational environment, Odit-e, funded by ADEME through the Utilit-e project, has partnered with Gazélec, a French DSO, to perform a large-scale experimentation in the whole city of Péronne (7500 inhabitants).

This project has been awarded by the Solar Impulse foundation as one of 1000 solutions that can protect the environment in a profitable way.

1. Introduction

Gazélec is a French DSO that operates in the city of Péronne (7500 inhabitants) and manages electricity distribution as well as water and gas distribution. Gazélec has deployed an innovative multi fluid metering solution provided by NES for the electrical metering and Kouz Conseil for the multi fluid dongles.

Photovoltaic productions can affect voltage profiles or create congestions in Low Voltage networks. Therefore, the current deployment of Photovoltaic panels requires an accurate planning tool adapted to Low Voltage networks specificities.
Unfortunately, state of the art methods for network simulations relies on the collection of network characteristics that are used to build a network model. This is a difficult process, with questionable results, because LV networks characteristics such as topology, cables impedances, mutual impedances, or grounding scheme are often incomplete, outdated, or inaccurate, creating inaccurate models [1]. The resulting power flow simulations are incorrect, leading to photovoltaic production connections being rejected while it should not, or being accepted while it should have been rejected.
A solution would be to go on field to complete, update and correct the network characteristics, but that would be extremely time consuming.
To provide DSOs with an effective planning tool, without requiring such effort and investment, Odit-e has developed an innovative method to digitize the LV network directly from smart meters data. Collected data is automatically processed to build the network topology and digital twin, reflecting the actual network behaviour.

The obtained digital twin had already been used to compute network hosting capacity maps [2][3], but this new experimentation evaluates the expected benefits for DSOs at larger scale: a whole city is included here.

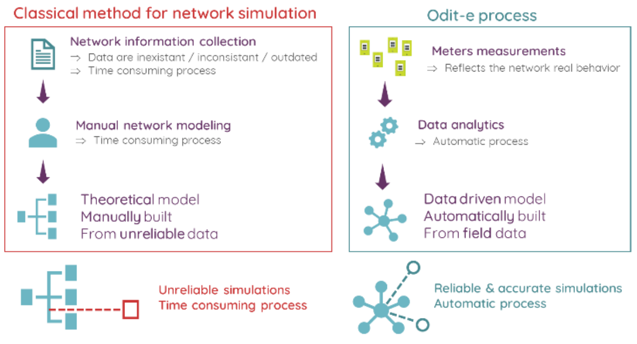

Figure 1. State of the art method & Odit-e process for network simulations

Among the challenges DSOs have to face, two very common are:

- Improving the knowledge of assets and network state (transformer load and unbalance, voltage map, installed capacity)
- Estimate and compute the grid PV hosting capacity (accepting or refusing one or several PV connection requests)

While the first challenge is currently being addressed in the Utilit-e project, and will be the subject of a later paper, the present paper focuses on the second challenge.

More specifically, the proposed software support DSOs planning teams by providing answers to two day-to-day questions:

- Can I accept this request for PV connection? What is the network maximum PV hosting capacity (if PV locations are optimized)?

The two electrical constraints that are checked by the software to ensure a PV panel can be connected are the voltage map (that should be kept within legal norms) and the admissible current at the substation. Checking these constraints requires an in-depth knowledge of the network, which is made possible by Odit-e innovative digitizing method.

Later in the project, additional features (based on the same algorithms) will be added to the software, allowing to answer further questions:

- I have this demand(s) for new PV connection(s), can I accept it (them)?
- What is the maximum PV hosting capacity among this energy community (association of prosumers)?
- What measures can I take to increase the network hosting capacity?

2. Methodology

2.1. *Utilit-e context: a large-scale experimentation*

Through the Utilit-e project funded by the French agency ADEME, Odit-e has partnered with Gazélec to perform a large-scale experimentation in the whole city of Péronne (7500 inhabitants).

This experimentation will allow Odit-e to validate the solutions designed to answer these questions.

Voltages and powers from over 3500 smart meters fed by 79 substations, have been collected during few months, and are still collected while this paper is written.

This depth of data is precious, as it allowed to study the impact of the period of data collection. The objective is to build a robust planning tool whenever the data collection is performed and with the shortest period possible.

2.2. *Identification of the grid's topology*

In order to handle this significant number of meters, meters are first clustered within substations and then processed separately [4][5]. Although this hypothesis (substations can be processed independently) seems valid when the PV penetration remains low, it can be questioned for high PV penetration, and will be further investigated during the project.

These meters-to-substations associations are provided by the DSO but might be outdated or inaccurate. In this case, the association is corrected using a mean voting approach based on a custom distance between smart meters. This approach also gives a confidence in the correction per smart meters.

2.3. *Taking into account the network constraints*

2.3.1. Power constraints

Regarding power constraints: each transformer has a maximal power capacity per phase beyond which it is overloaded and will deteriorate prematurely. When the power is not measured at the station, it is still possible to compute the current load of each phase through smart meter measurements provided the phase is known.

The Odit-e software allows the inference of the phase only from smart meter measurements [4][5], thereby allowing imbalance or power excursion computations without additional sensors.

2.3.2. Voltage constraints

Regarding voltage constraints: in France, the voltage at any point in the LV distribution network needs to be within +-10% of a target value (230V for most LV networks). Inferring the network voltage state in a new load configuration (such as additional PV or switching the phase of a consumer) is usually done by performing a load flow calculation. However, in LV networks, the wires parameters and topology are not known well enough to build an accurate network model.

To overcome this problem, Odit-e solution includes the regression of a digital twin from the voltage and power time series collected by smart meters. The regression is constrained to conform to the physics of the network, so that the regressed parameters have a physical meaning. Since the digital twin is directly built from data collected on field, it reproduces the real network behaviour.

The digital twin can then be used to precisely estimate the impact on voltage of any new consumption/production, and therefore to compute the network real capacity (without relying on theorical yet inexact models).

2.4. *Optimization of the PV hosting capacity*

Two constrained optimization problems were solved:

- Maximizing the PV surface for each smart meter separately under the voltage and power constraints.
- Maximizing the PV surface for all smart meters simultaneously under the voltage and power constraints, thereby finding an optimal PV configuration for this station.

Both of these optimizations require long time series for the voltages, consumption powers and PV production.

PV panels are modelled as the product of their surface and the production of a one meter square panel, south-oriented, and with a 40 degree tilt. The time series of the 10 past years of solar production at the target area were estimated using the pvlib library [6] and past solar irradiation obtained from the CAMS service [7]. For these use cases, PV panels are considered south-oriented only. In future works, PV orientations will be considered as a variable in the optimization.

As only a few months of smart meters data were available, we regressed a probabilistic model of the voltages and powers from the available data in order to extrapolate to the 10 years of available solar irradiation data. This is done first by regressing a probabilistic model of the voltage/power time series onto the measured data. The chosen probabilistic model was a deep learning estimator with a gaussian loglikelihood loss for voltage data and a gamma loglikelihood loss for power data (so that modelled powers are positive). Ten years of voltage time series were sampled from this model.

Finally, an excursion risk for a new arbitrary PV configuration can be estimated using Monte Carlo sampling on the generated time series. The DSO can then set an acceptable excursion risk from which a specific PV configuration is accepted or refused.

Figure 2. Odit-e planning tool

3. Results

The whole experiment consists of 79 stations, but 39 stations had been removed from the analysis due to a lack of data: either because of missing data or because there were too few smart meters to regress a meaningful digital twin. From the 40 remaining stations, 5 already had excursions either in voltage or in power. In such a case, the PV hosting capacity is zero by definition of our optimization objective.

On the 35 remaining stations, PV hosting capacities ranging up to 480 kW peak had been estimated and are displayed on Figure 3. The total PV capacity for the whole city has been estimated to be 9000 kW peak. However, this number will probably increase as we collect more data and are able to run the optimization on more stations.

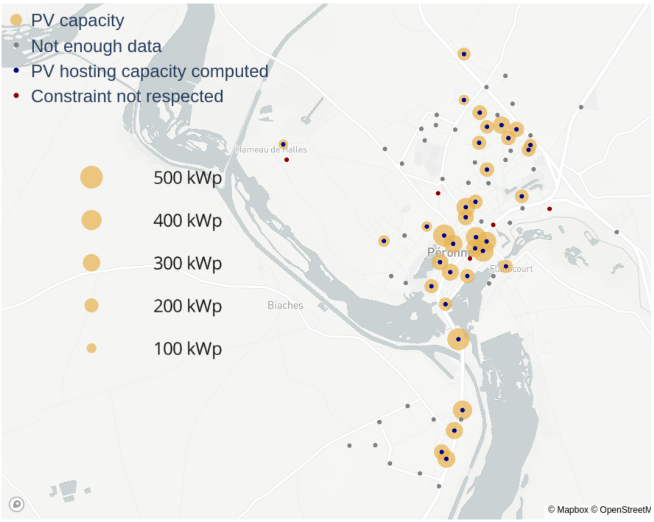

Figure 3. Optimal PV hosting capacity per substation.

The PV hosting capacity was also computed for each smart meter, each being considered independently. The result is a map showing locations where the network hosting capacity is low, and where it is important. This map can directly be used by the DSO to validate demands for new PV installations: if the request is lower that the hosting capacity of the concerned meter, the demand can be accepted. If not, the demand cannot be accepted as it is, and requires further investigation (should the network be reinforced? balanced? should the transformer tap be changed?).

This PV hosting capacity per smart meter for one substation is shown Figure 4. The map is not displayed for privacy reasons. For some clients, even a modest PV installation can bring the network close to a voltage excursion, and preventing further PV installation in the same feeder, even though these clients may have had a much larger PV capacity. For comparison, the optimal allocation of PV panel, as found when maximizing the substation total capacity, is shown Figure 5. Note that the two maps are not aligned, some clients exhibit large capacities but should not install PV if the target is to maximize the PV installation of the network as a whole. When a group of consumers would like to know how much power they could produce together (to form an energy community, for example), then the first algorithm should be used instead.

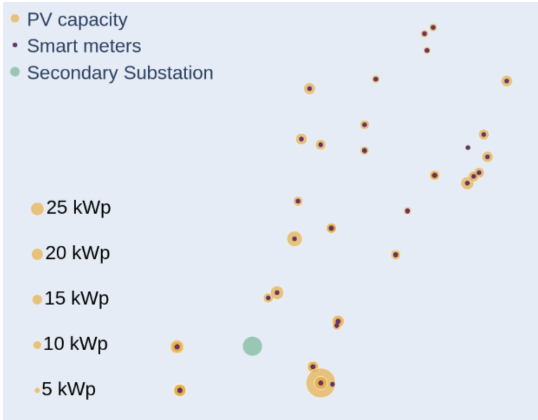

Figure 4. PV hosting capacity per smart meter. Smart meters are displayed on a blue map for privacy.

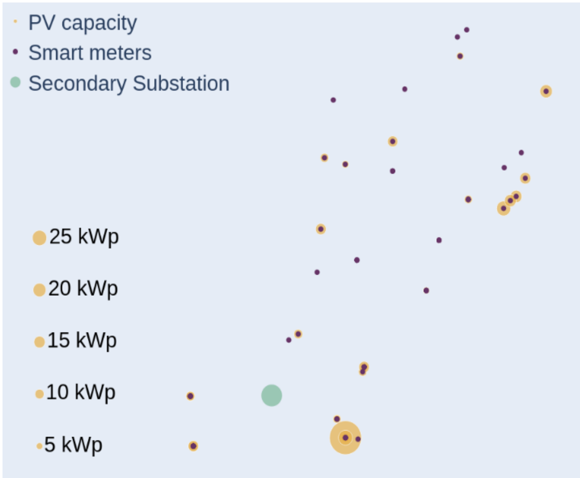

Figure 5. PV hosting capacity per smart meter when maximizing the total capacity**.**

4. Conclusion & Future Objectives of the Utilit-e project

From a technical point of view, the current analysis still suffers from the following drawbacks, which we plan to address in future publications:

- Power and voltage probabilistic models were estimated with only 8 months of data, sometimes less due to missing data. Therefore, the seasonality component of the model may be inaccurate at times of the year where no data was collected.
- The PV capacity could be computed only on a fraction of the available stations, due to a lack of data. But as more data keep being collected, we plan to establish this map over the whole network.

- The optimal PV capacity was computed for south oriented PV panels and a standard tilt. However, both larger PV capacity and more auto-consumption could be achieved by varying the tilt and azimuth orientations of the panels.
- Local constraints, such as the available surface or the orientation of the roof, could also be included.

As discussed in the introduction, the project will also be the opportunity for Odit-e to develop and validate other solutions:

- Network analysis (substations load and voltage map visualization), giving the DSO the opportunity to better manage assets and to improve the quality of distributed electricity. To further improve the estimation of substation loads, non-measured energy (from non-technical losses and non-communicating meters) will be evaluated and included in the estimation.
- Improvements proposal (to improve voltage map, substations load, or increase PV capacity): network balancing, optimization of transformer taps, reconfigurations, reinforcements…

5. References

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