IMPACT OF FLEXIBILITY ON LOW VOLTAGE NETWORKS' HOSTING CAPACITY – BELGIUM EXPERIMENTATION

Rémi Pellerej[1], Théo Trouillon[1], Clémentine Benoit[1**], Quentin Garnier[2], Alain Versyp[2]*

[1]Odit-e, 29 chemin du Vieux Chêne, 38240 Meylan,France
[2]RESA, rue Sainte-Marie 11, 4000 Liège, Belgium
**remi.pellerej@odit-e.com*
***clementine.benoit@odit-e.com*

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Abstract

To prevent photovoltaic productions from affecting voltage profiles, Distribution System Operators are currently limiting their insertion in Low Voltage networks. However, various mitigation solutions exist. This paper presents an experimentation that has been conducted jointly by Odit-e and RESA, aiming to quantify the benefits of two of these solutions (on-load tap changer and network balancing) on the network hosting capacity. The studied network had been subject to voltage excursions due to photovoltaic productions before implanting the solutions. The hosting capacity, being difficult to compute without a precise knowledge of the network characteristics, has been computed using an innovative planning tool developed by Odit-e, that only requires smart meters data. Both of the studied mitigation solutions have solved the voltage excursions, and the network hosting capacity has increased by 67%. However, random photovoltaic insertion generating huge voltage imbalances, the balancing method proved to be more appropriate while being much easier to implement, and should therefore be chosen first. Once the network is balanced, the on-load tap changer is very suitable.

1 Introduction

Hosting the vast majority of renewable productions, electrical distribution networks are the cornerstone of the energy transition. Demand for photovoltaic (PV) connections to the Low Voltage (LV) grid is skyrocketing, and new electricity uses, such as electric vehicles charging and demand response, are expanding.

To face these changes while minimizing cost, Distribution System Operators (DSO) have to conduct in-depth planning studies. But LV networks, having been disregarded for the last 60 years, are poorly known: network characteristics databases are outdated, incomplete, or inconsistent. This lack of information greatly complicates planning studies, with two main consequences. First, DSO can be brought to increase the margins they take during planning, leading to unnecessary network reinforcements, which ultimately translates into higher costs and delays. Second, some connection demands are accepted without any possibilities to check for their impact, leading to voltage issues.

Smart meters deployment provides local measurements of the LV networks, which could be very useful for the development of network models. For instance, Waeresch et al. [1], Pau et al. [2], or Ahmad et al. [3] tried to estimate the state of a network using a theoretical model and smart meter measurements. However, one needs to know very precisely the characteristics of a network (wire sections, lengths....) to create an accurate theoretical model. This information is often unknown or incorrect, leading to inaccurate models [4].
Instead of using a network model, Breker et al. [5] proposed a method based on classification methods to estimate the networks hosting capacity. It leads to better results than classical load flow estimation. But their method still needs a lot of network characteristics.

To support the energy transition, Odit-e has developed the first planning solution for LV networks that does not require any network characteristics, nor manual network modeling, while being very accurate. This planning tool has been used in this experimentation to propose a balancing scheme and compute the network hosting capacity.

2 Objective

The present experimentation has been conducted jointly by Odit-e, a young company focusing on LV networks digitization, and RESA, a Belgium DSO based in Liege.

The studied network, hosting large amount of PV productions, had been subject to voltage excursions (voltage values exceeding 230V^{+}/-10%), leading to disconnections of inverters (which security is triggered by voltage excursions).

Two actions have been implemented in order to mitigate this problem:

- Firstly, an on-load tap changer has been installed.

- Secondly, a balancing of the loads and productions has been performed.

The objective of this paper is to assess the impact of these two solutions on the voltage excursions, and to quantify their benefits in term of hosting capacity.

3 Methodology

3.1 Odit-e planning tool

State of the art methods for network simulations rely on the collection of the network characteristics in order to build a network model. This is a difficult process, with questionable results: LV networks depend on a multitude of variables, whose real values can greatly differ from their theoretical values (such as grounding or mutual impedances).

To work around this problem, Odit-e has developed an innovative way of digitalizing LV networks, which does not require any information about network characteristics: a network digital twin that is built only from metering data. Fig. 1 presents the main differences between classical LV network simulation tools and Odit-e process.

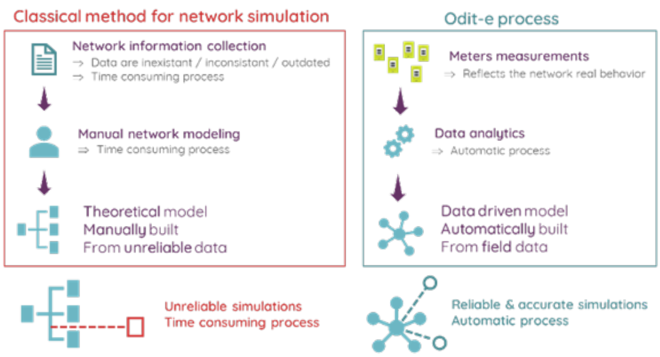

Fig. 1: Classical and Odit-e methods comparison

This digital twin estimates the voltages corresponding to a specific power consumption / production. It can therefore be used for simulation purposes: for example, the impact on voltages of the connection of a new PV panel can be precisely estimated.

In order to validate the accuracy of the digital twin, the estimated voltages have been compared to the measured ones using a 10-fold cross-validation. Concretely, the available dataset is first split in 10 subsamples. Then, the model is trained on 90% of the dataset, and the voltages are estimated for the 10% left subsample, called the validation subsample. This process is repeated until all subsamples are used once as validation subsample. As a result, the digital twin error is of 0.5 V on average for all smart meters on all validation subsamples.

This network planning tool has been used to provide a balancing scheme (which single-phased meters should be switched to which phases), and also to compute the network hosting capacity.

3.2 Computing the network hosting capacity

Once the digital twin has been created, the network hosting capacity can be computed for each meter, by maximizing the production while keeping the network state within admissible constraints. The hosting capacity therefore corresponds to an optimized allocation of PV productions.

Let's call:
- M the digital twin model.
- $\mathbf{V}$ the n-by-m voltage matrix, with n the number of time steps and m the number of smart meters, in volts.
- $\mathbf{P}$ the n-by-m load curves matrix of size, in watts.
- $\boldsymbol{\pi}$ the simulated production profile in watts, for a 1 kW peak (kWp) production. $\boldsymbol{\pi}$ is of size n.

M evaluates the LV network state such that: $M(\mathbf{P})=\mathbf{V}$. To estimate the network PV hosting capacity, we solve the following problem:

$$\hat{\mathbf{k}} = \underset{||\mathbf{k}||}{argmax}\ (M(\mathbf{P}+\mathbf{k}\boldsymbol{\pi}^{\mathbf{T}}))$$

With the following constraint:

$$230 * 0.9 < M(\mathbf{P}+\mathbf{k}\boldsymbol{\pi}^{\mathbf{T}}) < 230 * 1.1$$

where $\mathbf{k}$ is a real-valued vector of size m and correspond to the maximum of kWp that can be added for each smart meter.

4 Evaluating the benefit of flexibilities

4.1 Initial state: imbalanced network

The studied network hosts 271 kWp of PV productions, while being initially subject to voltage excursions, leading to inverter disconnections. These PV are shown in Fig. 2: each communicating meter is displayed as a dot, the four colors representing the four feeders, and orange discs being proportional to the size of installed PV productions.


Fig. 2: Location of installed PV productions – initial state

These PV productions are not evenly spread between phases: Fig. 3 shows the total amount of kWp per feeder and phase, and the total per phase for the substation. It exhibits the imbalance between phases, especially for feeders 0 and 2.

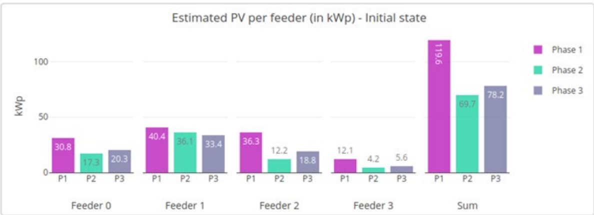

Fig. 3 Distribution of PV productions among phases and feeders – initial state

This imbalance simultaneously creates both over and under voltages: Fig. 4 shows an example of voltage profiles that had been measured on the network. The impact of PV productions on the voltage profiles is extremely clear:

- Phase 1 (green) has lot of connected productions, increasing the voltage around noon.
- Phase 2 (yellow) has very few connected productions.
- An imbalanced current is created in the neutral wire, leading to a voltage drop. This neutral voltage will increase even more the voltage on phase 1, and decrease the voltage on phase 2.

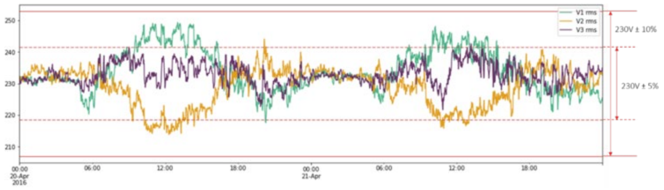

Fig. 4: Voltage profile - imbalanced example

To mitigate the voltage issues, an on-load tap changer had been installed before the beginning of the experimentation. In order to compute the network hosting capacity without flexibilities, the on-load tap changer has been virtually removed (the tap is blocked for the simulations). The total network capacity has then been estimated to **400 kWp**, and the capacity per meter is shown in Fig. 5, the meter capacity being proportional to green discs.

Fig. 5: Network hosting capacity for PV– initial state

Feeders green and red (0 and 2) are already saturated: there is no room for additional PV productions. This is due to them being extremely imbalanced, as seen Fig. 3. The two other feeders have room for additional PV connections: feeder purple (3) is short and not that loaded, while feeder orange (1) had already been balanced by Odit-e before the beginning of this experimentation.

This explains why the network is subject to voltage excursions while the total amount of production is lower than the total network capacity: these excursions are created by the imbalance.

4.2 Impact of on-load tap changer (OLTC)

In order to mitigate the voltage issues, an on-load tap changer had been installed before the beginning of the experimentation. This installation has solved the voltage excursions, and therefore the PV disconnections. The new network hosting capacity for PV has been estimated to 548 kWp, representing a 37% increase in capacity compared to the initial state.
Fig. 6 shows the new hosting capacity map obtained with the OLTC: a new capacity for PV has been created on feeders red and green.

Fig. 6: Network hosting capacity for PV– with OLTC

However, in this situation, the tap changer is limited: it can only increase or decrease all the voltages (from all feeders/phases): as described in Fig. 7, when both over and under voltage limitations are reached, there is no solution. In order to make the most of it, the network has to be balanced.

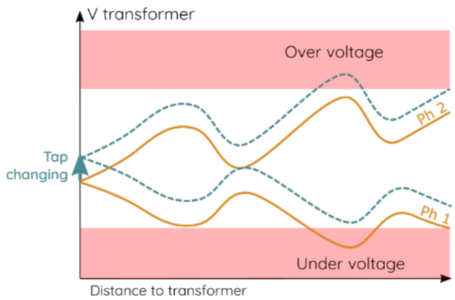

Fig. 7: Voltage profiles on two phases of the same feeder. The two voltages diverge, and the OLTC, which acts globally, cannot solve the voltage excursions.

4.3 Impact of balancing

A balancing scheme has been proposed by Odit-e and implemented by RESA: some meters where switched from one phase to another (here, consumers and producers had to be switched together). A new set of data had then been collected, in order to assess the impact of balancing on the network capacity.

Again, the OLTC has been removed by simulation in order to compute the network PV hosting capacity that results only from the balancing. It has been estimated to 568 kWp, representing a 42% increase in capacity compared to the initial state. Fig. 8 shows the PV hosting capacity map obtained with a balanced network.

Fig. 8 Network hosting capacity for PV – balanced network

The increase in network hosting capacity resulting from the balancing scheme is therefore larger than the one resulting from the on-load tap changer, while being cheaper, and much easier to implement. The balancing has also relieved the transformer: while voltage profiles are more balanced, the powers flowing in the substation are also more evenly spread between phases, reducing the peak.

It has to be noted that only single-phased meters (productions and consumptions) could be included in the balancing process: in the present experimentation, the three-phased meters would only collect the power summed over the three phases (even though the power is not evenly spread over the three phases), making the impact of balancing impossible to compute.

In this context, single phased PV present a clear benefit: they can contribute to network balancing, without requiring an intervention in the customer's installation.

4.3 Balancing and OLTC combined

Finally, the network PV hosting capacity computed with both OLTC and balanced network is 671 kWp, representing a 67% increase in capacity compared to the initial state. Fig. 9 shows the PV hosting capacity obtained with both flexibilities.

Fig. 9: Network hosting capacity for PV– balancing + OLTC

5 Outcomes and conclusions

1	The network initially hosted 271 kW peak, while being subject to voltage excursions and PV disconnections. With optimally located PV, the network could theoretically host 400 kW peak.
2	After installing the OLTC, voltage excursions have been solved and the resulting network hosting capacity is 548 kW peak (+37% compared to 1)
2bis	If the network had been balanced without installing an OLTC, the hosting capacity would have been of 568 kW peak, and the voltage excursions would have been solved (+42% compared to 1)
3	After balancing the network (with the OLTC being installed), the hosting capacity went up to 671 kW peak (+67% compared to 1)

Both solution (on-load tap changer and network balancing) where able to solve the voltage excursions and to increase the network hosting capacity.

However, considering that random installations of PV productions tend to create voltage unbalances, network balancing should be the reference solution when facing such networks issues: on-load tap changers are ineffective when unbalance is big enough that both over and under voltages happen simultaneously. In addition, network balancing is much easier and cheaper to implement. If the network hosting capacity still need to be increased after the network has been balanced, an on-load-tap-changer is perfectly suitable.

6 References

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