LOW VOLTAGE NETWORK TOPOLOGY IDENTIFICATION FOR BETTER FLEXIBILITY PLANNING – PORTUGAL EXPERIMENT

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Abstract

Low Voltage networks characteristics are poorly known. To enable smarter planning, a proper knowledge of the network topology is essential: meter-to-substation mapping, and meter-to-feeder/phase within a substation. Odit-e has developed an innovative method for topology identification based on smart meters data, avoiding the installation of any additional sensors. The method had been designed using datasets collected in various places in Europe, and is made to be robust to Low Voltage specificities. An experimentation has been conducted jointly by Odit-e and EDPD to validate this method in an operational environment. Results are promising: considering the hazards related to real data collection within various types of networks, the obtained topology is very accurate. The next step will be a large-scale validation, with thousands of meters.

1 Introduction

Hosting the vast majority of renewable productions, electrical distribution networks are the cornerstone of the energy transition. Demand for photovoltaic connections to the Low Voltage grid is skyrocketing, and new electricity usages, such as electric vehicles charging and demand response, are expanding. Dealing with these changes while minimizing cost requires in-depth planning studies.

However, Low Voltage networks have been disregarded for the last 60 years, and their characteristics are now poorly known: outdated, unreliable, or simply unknown. This lack of information is a thorn in Distribution Network Operators' side for planning: the current use of assets is unknown, and accurate simulations are difficult to implement, seriously impeding flexibilities deployment.

Topology identification is therefore an essential step towards smart network planning and flexibility development. Two approaches are currently used by DSOs:

- Using the PLC (Power Line Communication) technology: each meter communicates with a data concentrator associated with a substation. This can be used to associate each meter with a substation [1], although the accuracy is impaired by the PLC being transmittable through switch devices, transformers, and nearby cables.
- Using data collected by smart meters along with additional sensors that are installed in substations. Typically, these methods use load profiles from smart meters and from these additional sensors, and leverage the energy conservation law to associate the meters to each feeder and phase [2,3]. These methods are effective, but the cost of these additional sensors makes deployment unconceivable.

Another kind of approach is being studied: the comparison of voltage profiles, based on the idea that the more similar voltages are, the closest the meters are. These methods are promising: they only use data from existing equipment (the smart meters), and always reflects the real network topology (no matter how many changes have occurred in the network topology, no matter how much non-technical losses, and no matter the state of the network switches).

Among these methods, most use the correlations between the raw voltage profiles as an indicator of their similarities [4,5]. However, even if these methods can group the meters by phase, they are not precise enough to group the meters by substations, or by feeders. Most importantly, they have been developed with simulated data, instead of real Low Voltage data. This makes a big difference, as real voltage profiles are driven by Medium Voltage variations and similar behaviors, and are therefore all highly correlated, as shown in Fig. 3. As a result, the algorithms developed with simulated data can turn out to be totally ineffective with real data (as an example [6] claims to have tested the method proposed by [7], to no avail).

Odit-e has worked with smart meters data collected from various places in Europe in order to develop an innovative process for network-topology identification: the voltage profiles are processed in order to reveal the useful information, providing the complete network topology (meter-to-substation associations, and meter-to-feeder/phase associations [8]).

Our method is easily scalable as long as smart meters can collect and send data, and its accuracy and robustness has been proven with several proofs of concept in Europe. This paper presents the result of an experimentation conducted jointly by Odit-e and EDPD, aiming to validate the method in an operational environment.

EDP Distribution (EDPD) is the company holding the Distribution System Operator (DSO) position in the mainland Portugal. EDPD holds HV, MV and most of the LV grids; which includes more than 226 thousand km of power grids, 420 Substations, 67k secondary substations, and 6M customers.

As a DSO, the knowledge of network topology opens lots of opportunity for EDPD: identification of PLC communication issues, non-technical losses detection, and network simulations enabling.

2 Problem and Approach

The objective being the evaluation of the proposed process in an operational environment, EDPD has provided Odit-e with smart meters data, and has went on field, whenever it was required, in order to check the results provided by Odit-e.

The proposed identification of the topology is based on voltage profiles collected by smart meters. Theoretically, the closer two meters are, the closer their voltage profiles are. However, the information conveyed by voltage profiles is drown within variations due to High Voltage and Medium Voltage networks, averaging and sampling errors, three-phased network characteristics (one phase influence the other phases through the neutral wire) …

To cope with these specificities and reveal the useful information, Odit-e has developed an adapted processing of the voltage profiles. The obtained data can then be used to identify the underlying network structure.

The problem has been split into two sub-problems, that will be addressed successively (Fig. 1):

- Level 1: the meters are grouped by substations
- Level 2: the meters from each substation are grouped by feeder and phase, and ordered in trees

2.1 Level 1: meter-to-substation associations

When the PLC technology is used for communicating meters, substations are equipped with Data Transformer Controllers (DTCs), which collect smart meters data and the substation voltage profile. Therefore, both the smart meters data (voltage and power profiles), and the voltage profiles corresponding to the studied substations can be used for this level 1 topology identification.

2.2 Level 2: network tree for each substation

Once meters are associated with a substation, only the smart meters data are required to identify the network tree. The number of feeders is not required, although it can help.

The process leading to the network tree is as follow:

- Voltage profiles are first processed in order to reveal useful information (that is usually hidden in the noise created by MV/HV networks, sampling periods and averaging process).
- The similarities between these processed voltages are computed so that the meters can be clustered in groups corresponding to electric cables (one feeder / one phase).
- The cables that correspond to the same feeder are grouped together by analyzing the influences between phases.
- An arborescence is computed for each feeder (meters sequencing and branching).

3 Experimentation level 1: meter-to-substation mapping

3.1 Dataset

The dataset made available by EDPD consists of a group of meters that could belong to 5 different substations (Tab. 1).

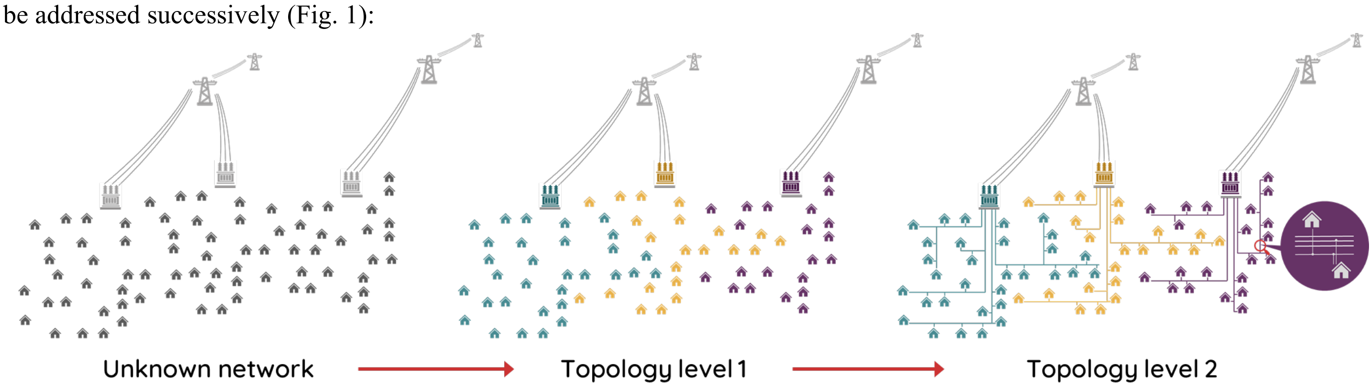

Fig. 1 Topology identification, level 1 and 2.

Tab. 1: Dataset used for the Level 1 experimentation.

Total number of consumers	842
Consumers with smart meters	602
Consumers with valid data	483

Active power and voltage profiles were transmitted for the 483 meters with valid data, along with the voltage profiles associated with the 5 substations. The data had been collected for one month, with a sampling period of 15 minutes, and the voltages were averaged over each sampling period (by opposition to instantaneous data).

3.2 Results for Meter-to-substation associations

Among the 483 meters, 435 had enough data to process. EDPD has then provided Odit-e with the true meter-to-substation associations. Among the 435 meters that could be classified, the following results were obtained (Tab. 2):

- 430 meters where associated with the right substation (99% accuracy)
- 2 meters were associated with TR116 instead of TR071
- 3 meters were associated with TR113 instead of TR050

Tab. 2: Meters-to-substations associations: confusion matrix.

TR	050	071	116	119	113
True positives [1]	113	189	127	3	3
False positives [2]	0	0	2	0	3
False negatives [3]	3	2	0	0	0

[1] Meters correctly associated with TR;
[2] Meters wrongly associated with TR;
[3] Meters that should have been associated with TR

4 Experimentation level 2: network tree for each substation

4.1 Dataset

The second dataset made available by EDPD consists of meters from 3 substations, from various areas of Portugal. There characteristics are shown in Tab. 3.

Tab. 3: Dataset used for the Level 2 experimentation.

	Meters	Three-phased meters	Type of network	Meters technology
Sub #1	215	4%	urban	PLC
Sub #2	125	6%	rural	GPRS
Sub #3	112	10%	rural	GPRS

The voltage profiles (Fig. 2) have been collected for one month, with a sampling period of 15 minutes, and the voltages being averaged over each sampling period (by opposition to instantaneous data).

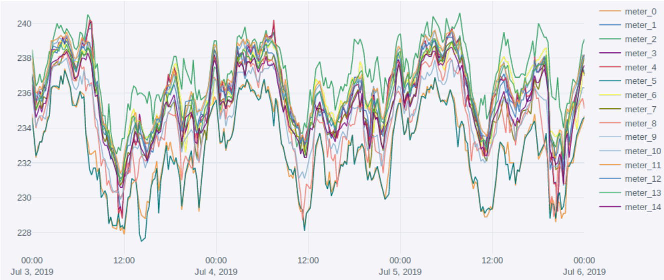

Fig. 2: Example of voltage profiles for 15 meters during three days, showing the strong similarities between data

4.2 Grouping meters by feeder and phase

The collected data is processed in order to group the meters by feeder and phase. The number of feeders (and therefore the number of groups to create) is not known.

Fig. 3 shows the effect of the data processing performed by Odit-e on the correlation between meters:

- On the left, the correlation matrix between all voltage profiles is displayed: voltage profiles are all very similar, the useful information is hidden.
- In the center, the correlation matrix between all the processed voltage profiles. Structure clearly emerges, meters can now be accurately grouped together.

Fig. 3 (right) shows the correlations between processed voltage profiles after the meters have been rearranged by feeder and phase. For this experimentation, EDPD has field-checked the true meter to feeder/phase connectivity, so that the accuracy of Odit-e's method could be assessed. Tab. 4 sums up the results for the three substations, along with the availability of the meters (missing data being part of any operational environment).

Tab. 4: Results for feeder and phase identification.

	Available meters	Available timestamps	Accuracy	
			Feeder identification	Phase identification
Sub #1	113 (215)	80%	100%	100%
Sub #2	115 (125)	51%	89%	100%
Sub #3	108 (112)	51%	100%	99%

4.3 Finding the network tree

Lastly, the network tree (Fig. 4) is recovered within each of the groups: network branching, meter sequencing, and electrical distances between meters. Unfortunately, these network trees would have been extremely time consuming to field-checked, and therefore have not been validated during the experimentation

Fig. 3 Correlation matrices between raw voltage profiles (left), processed voltage profiles (center) and the same processed voltage profiles after the meters have been rearranged by feeder and phase (right), where green lines delimit the different feeders, and black lines delimit the three phases. Correlation ranges from -1 (white) to 1 (red).

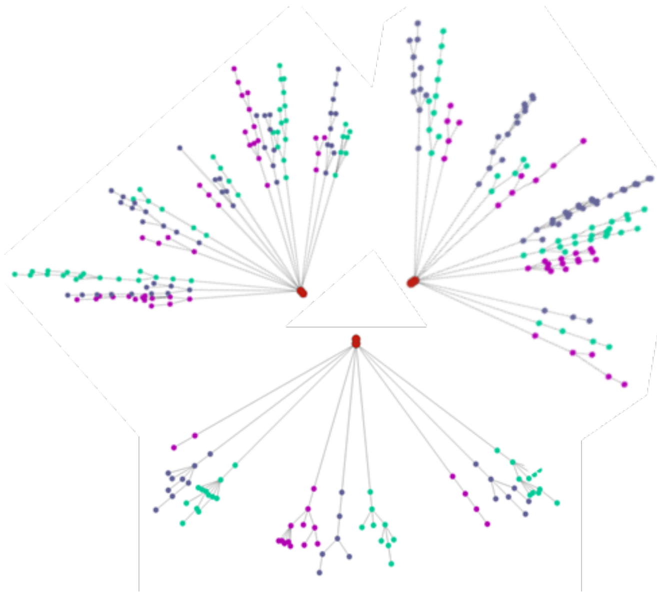

Fig. 4 Network topology tree obtained for the 3 substations

5 Outcomes and conclusions

A proper knowledge of the network topology is essential to enable smarter planning and flexibility. Unfortunately, LV networks topology is often unreliable or incomplete. Odit-e has developed a method for network topology identification that is based on smart meters data only, thus avoiding the installation of any additional sensors, or any "field checking".

To validate its efficiency, an experimentation has been conducted jointly by Odit-e and EDPD on real-world data. The method has proven successful in an operational environment, with a 99% accuracy for Meter-to-substation mapping, 99% for phase identification, and 95% for feeder identification. A large-scale deployment can now be considered.

6 References

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