SOLVING VOLTAGE CONSTRAINTS THROUGH SMART GRID PROCESS

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ABSTRACT

The French DSO (ERDF) is currently studying the opportunity reducing losses and voltage drops on LV networks through an operational process without material investment, thanks to the information provided by the new smart meter, Linky.

This article describes the process from data collection to technical solution through IT solutions including data system, Geographical Information System (GIS), and Power Flow Software.

INTRODUCTION

Linky will allow a significant modernization of the management of distribution network. Improvements are introduced in almost all aspects of the activity: knowledge of the assets and quality provided, investment decisions, maintenance and operation.

This prototype process as part of the "Linky- Réseau" program aims to design experiment and to build the industrial solutions to take full advantage of Linky. It has involved almost 300 000 smart meters in two areas of France over on around 5 000 low voltage (LV) networks.

QUALIFICATION OF ABNORMAL VOLTAGE

Linky's Data

Abnormal voltage measure by Linky is delivered to ERDF data system with a 10 minute timestamp and a customer ID. The measurement is collected every night through the hub and the traditional telecom system. Linky also provides information on the customer's phase and the low voltage (LV) network on which it is located.

SCADA's Data

The ERDF SCADA system, called ETARESO, collects into its data base indicators and electrical outputs. One of the most used indicators is the "normal scheme indicator". A normal scheme is designed for each medium voltage (MV) feeder; it is defined by the state (open or close) of each switch on it. For consistency, this indicator is also recalculated each 10 minutes.

Others data coming from the SCADA system can be useful, as the voltage and intensity measurement at the head of the MV Feeders.

Qualification process

The norm EN 50160 gives a characterization of the badly fed customer:

- During each period of one week , 95% of RMS values averaged over 10 minutes from the voltage supplied must be in the range ± 10% of the nominal voltage
- All RMS averaged over 10 minutes from the voltage supplied must be in the range +10 % / -15% of the nominal voltage.

It also defines the exceptional conditions when abnormal voltage should not be taken into account.

The ERDF reading of these exceptional conditions for this experimentation is built on the "normal scheme indicator", the TSO abnormal voltage signal and a weather signal.

Each week, the data coming from Linky and ETARESO is compiled. The number of badly fed customers for each LV networks is estimated as well as the number of abnormal voltage measurements and their average depths.

Network selection

Prioritizations are made based on the quantity and the characterization of abnormal voltage events. However, without a good Linky penetration ratio on the LV network, studies can be inconsistent. In this experimentation, only networks with at least 20 abnormal voltage measurements, 5 customers concerned and with more that 80% of the customers equipped with Linky meter were picked to be tested.

Moreover, this selection could not be done without the knowledge of ongoing works on the networks for other reasons; involving ERDF local teams in this process is essential. During this experimentation, every week, local teams have selected five to eight LV networks with voltage issues they wish to investigate.

ENHANCED SURVEILLANCE

Subscription of the load curve

By default Linky meters do not record or broadcast the customer load curves. However, for technical issues, the load curves can be collected and exploited by ERDF.

Here the subscription of the customer load curves is done after the detection of the first abnormal voltage measures. Once the subscriptions have been made, load curves are received during a short among of time.

Post Network Selection

For each LV network with new abnormal voltage issues after their customer's load curves have been subscribed, the day with the more events is picked.

Data processing

Once a couple "Day-LV network" is found, the data compilation can be launched. It has several steps which can be summarized as follow:

a) Extract Data from Linky System, GIS, SCADA system, Weather system

b) Run quality analyses to check if these data are complete or consistent.

c) Merge actions are done inside the two network's description files (LV&MV).

d) Run a power flows into the ERDF calculation engine, ERABLE. It is a combination of ERDF and DigSilent developments on a Power Factory base.

e) Analyze calculation logs and results.

f) Provide the results and networks.

CREATION OF THE ELECTRICAL MODEL

MV Voltage Drop calculation

Thanks to the voltage at the head of the MV Feeder, a power flow algorithm can estimate dynamically the MV voltage along the feeder and then to the MV/LV transformer.

Ideally all the load curves of every customer are needed. However, previous experimentations have shown that on average MV feeders another method, that we called scalability, can be as efficient with less data needed.

From a standard situation, a loss coefficient is estimated:

$$\mathrm{K_{loss}} = \frac{P_{shf} - P_{tot\_load}}{{P_{tot\_load}}^2}$$

Where

$\mathrm{P}_{shf} = static\ head\ feeder\ power$
$\mathrm{P_{MV\_load}} = subcribed\ power\ load$
$\mathrm{P_{LV\_load}} = static\ estimated\ LV\ network\ power$

Thanks to ETARESO, the intensity at the head of the MV Feeder is also known, which allows the estimation of a dynamic power $P_{dhf}(t)$:

$$\mathrm{P}_{dhf}(t) = U(t) \times I(t) \times cosphi$$
$$\mathrm{P}_{dhf}(t) = P_{tot\_load}(t) + K_{loss}\left(P_{tot\_load}(t)\right)^2$$

There is only one positive solution to this second degree equation:

$$P_{tot\_load}(t) = \frac{-1 + \sqrt{1 + 4K_{loss}P_{dhf}(t)}}{2K_{loss}}$$

However $P_{tot\_load}(t)$ has to be divided between the loads on the feeder:

$$P_{tot\_load}(t) = \sum P_{MV\_load}\,(t) + \sum P_{LV\_load}\,(t)$$

Several load curves surveys have shown that on a small area as the one concerned by a single MV feeder, the variability of loads, ν_{load}, is roughly the same and proportional to the static estimated power on network following this equation:

$$P_{tot\_load}(t) = \nu_{load}(t)\left(\sum P_{LV\_load} + 1/3 \sum P_{MV\_load}\right)$$

Each load can now be estimated dynamically:

$$P_{LV_{load}}(t) = \frac{P_{tot\_load}(t) - P_{tot\_load}}{\sum P_{LV\_load} - 1/3 \sum P_{MV\_load}} \times P_{LV\_load}$$

and

$$P_{MV_{load}}(t) = \frac{P_{tot\_load}(t) - P_{tot\_load}}{3\sum P_{LV\_load} - \sum P_{MV\_load}} \times P_{MV\_load}$$

For each timestamp, a power flow can now estimate properly the MV voltage drop at the edge of the MV/LV transformer.

LV Voltage Drop calculation

For the Non-Linky customers a random phase is applied and their load is based on a profile which is estimated thanks to the temperature of the day, their main characteristics and their consumption index.

For the Linky customers, the real load curves are used. They could be with a timestamp of 10 to 60 minutes depending on the quality asked. Their phase is also given by the meter.

At the end of the calculation, voltage at each phase of each node of the LV network is estimated, within a timestamp of 10 minutes.

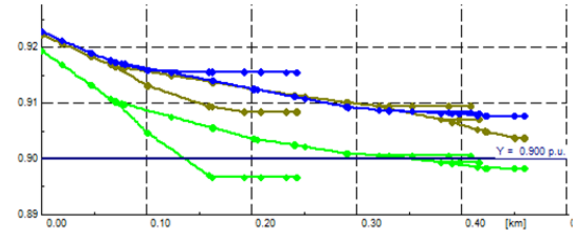

Figure 1 - Voltage drop (%) on the 3 phases of a LV feeder

Transformers' tap estimation

The MV/LV transformers used by ERDF are equipped with voltage tap which allows enhancing or reducing the voltage output by -2.5%, 0% or 2.5% of the nominal voltage. The current values of these tapes are unfortunately uncertain inside ERDF data bases.

For every LV network selected here, the closest customer to the transformer is identified and his voltage curved is collected.

By subtracting it to the MV voltage drop and the voltage drop inside the transformer estimated in the previous step, the position of the tap could be deduced by a density of probability.

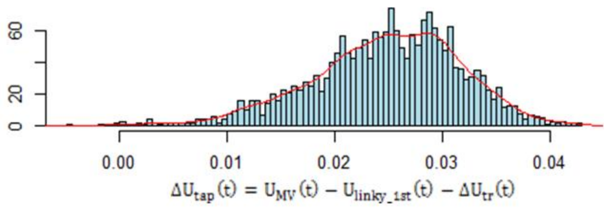

Figure 2 – Density of ΔU (%) determining the transformator tap

Reliability indicator (RLI)

Once the model is entirely built, its accuracy has to be challenged. The most effective way is first to compare the voltage measured to the calculated one.

The choice has been made to use the distance between them, customer by customer then an aggregation on the LV network.

$$RLI = Mean\left(\sqrt{(Umes(t) - Ucalc(t))^2}\right)_t$$

Where
$Umes(t)$: Voltage measured each 10min
$Ucalc(t)$: Voltage calculated each 10min

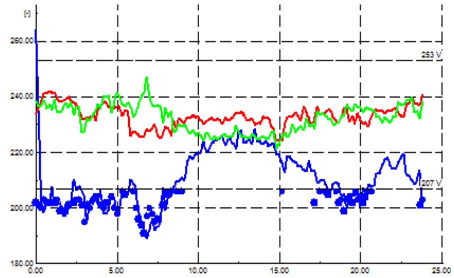

Figure 3 - Voltage Curve with a good reliability indicator

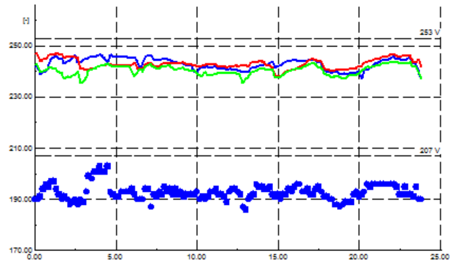

Figure 4 - Voltage Curve with a bad reliability indicator

Where

Calculated phase-neutral A Voltage
Calculated phase-neutral B Voltage
Calculated phase-neutral C Voltage
Abnormal measured phase A Voltage

The optimisation is only run for network with a reliability indicator under 30.

OPTIMISATION OF THE NETWORK

Transformers' tap switching

The transformer tap which has the smallest number of badly fed customers with real load curves, represents the new tap that should be considered and configured.

Rebalancing phases

There are several methods to rebalance phases on networks. The main difficulties are to take into account the arborescent structure of the network and the dynamic nature of the load. The one used here is a compromise between performance and results found after several iterations.

The algorithm starts with the worst fed node of the network and keeps running node by node until the voltage constraints disappears or the balance cannot be improved. After this node is targeted, in order to optimize the calculation performance, the rebalancing will be performed on only 4 critical moments of the day, the ones with the maximal voltage drop among 4 periods of 6 hours.

For each of the 4 moments, the balance of phases for each branch of the network, Bal_{branch}, is estimated using a so-called “PZ method”, following this equation:

$$Bal_{branch} = \sqrt{(S_1 - S_2)^2 + (S_2 - S_3)^2 + (S_3 - S_1)^2}$$

With for ending branches

$$S_k = \left(\sum_{customer\ i} P_{load\_curve\ ik} \times Z_{upstream\ ik} \right)_{phase\ k}$$

And then for upper branches:

$$S_k = \left(\sum_{customer\ i} P_{load\_curve\ ik} \times Z_{upstream\ ik} + \sum_{\substack{downstream \\ branche\ j}} P_{transited\ jk} \times Z_{upstream\ jk} \right)_{phase\ k}$$

Where

$P_{load\_curve\ ik}$: Consumption power of the single phase customer i connected on the phase k of the branch.

$Z_{upstream\ ik}$: Upstream impedance from the node of connection of the customer i to the transformer along the phase k.

$P_{transited\ jk}$: transited power through the node between the considered branch and the branch j for the phase k.

Simultaneously the most disruptive customer is identified: he is the one among the feeder with the biggest average consumption during the 4 timestamps.

Once it is put on the phase with the highest voltage of the studied node, the voltage drop on the model is recalculated and Bal_{branch} also. If the maximal voltage drop on the node has diminished and this operation does not deteriorate Bal_{branch} on any branch of the feeder, then the solution is kept. Voltage drops are then re-estimated along the network, and the process is repeated on the next most badly fed node and so on.

Validation

After the rebalancing phases or transformers’ tap switching, power flows with profile load curves are performed. Indeed, if the voltage constraints seem solved with these solutions on the particular day they are measured, the same solutions should not create new constraints on another kind of situation. Only if the solution provides a full satisfaction on every given situations it will be send to a technician for validation and operation.

WINTER 2015 EXPERIMENTATIONS

During the winter 2014/2015, on the area of the experimentation of Linky meter, 27 LV networks have been automatically studied, and it has lead to 10 rebalancing or transformer’s tap switching operations including 7 directly proposed by the algorithm. For the winter 2015/2016, it has been planned to multiply the engine capacity by 7 in order to reach the 50 operations during the period.

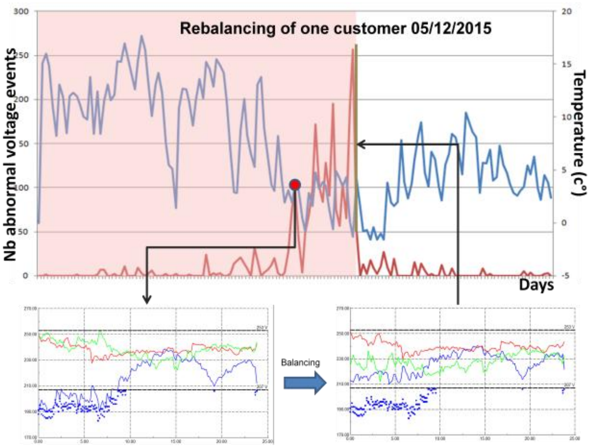

Figure 5 - Example of a complete and successful process

CONCLUSION

This experimentation on Linky’s data is a relatively good (even if local) success. Solving voltage issue is only one of the first steps. The same type of operations can be launched for losses optimization.

With the expansion of Linky perimeter, ERDF should engage an industrialization of this process in the next years. Doing so, solving voltage constraint by operational actions would be a reliable and cost-effective complement to the classical network investment leverage.

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