INNOVATIVE NETWORK DESIGN & OPTIMIZATION USING SMART METERING DATA

Frédéric GORGETTE
ERDF - FRANCE
frederic.gorgette@erdfdistribution.fr

Ni DING
ERDF - FRANCE
ni.ding@erdfdistribution.fr

Guillaume ROUPIOZ
EDF R&D - FRANCE
guillaume.roupioz@edf.fr

ABSTRACT

ERDF develops the Low Voltage (LV) Distribution Networks by using statistical models of the LV consumers. Optimizing investments on the LV Distribution Network is all the more challenging that direct measurements are very limited. The development of LV and MV photovoltaics brings new challenges to LV and MV network design since the system has to be designed to face voltage drops but also nearly equivalent voltage rises.

The ERDF metering pilot project (Linky project) plans to install, in 2010, 300 000 meters in Lyon and near the city of Tours. Alongside, ERDF launched a SmartGrid project that will create value from the Linky information infrastructure and data in order to improve its distribution network operation, control, and development.

Consumers load curves will be used to build day-after curves of LV node voltages and line currents. This will open new applications for :

- Optimizing the set of transformers. Past peak currents will be estimated, and this will help estimate the appropriate rated power to withstand severe conditions and optimize losses,
- Reducing losses. Balancing the three phase currents and reducing neutral current will reduce losses and improve voltage drops,
- Optimizing reinforcement investments. Power flows and node voltages will be estimated, improving current and voltage constraints prediction under peak conditions. Thus a better use of investment funds.

On longer terms development of electric vehicle and innovative offers provided by energy companies will bring new needs of understanding the peaking behaviour of new loads and the elasticity of existing loads. The new system model and design methods meet these needs and foster network development by optimizing investments.

This paper describes the technical solutions and methods that will be used for the future LV network design and development and presents the expected value.

INTRODUCTION

Deployment of smart meters in Tours and Lyon in 2010 is an opportunity for Network Developers to set up new tools and models. The objective of this project is to implement a prototype information system in 2011. This prototype will help proving the concepts, identify technical challenges and confirm estimations of value creation (reduction of cupper losses, optimisation of investments, reduction of operation costs) before a larger deployment of smart meters is launched.

TECHNICAL REQUIREMENTS

AMM data needs to be analyzed with two main objectives in mind:

- build records of past constraints in order to understand their cause and address them,
- build a load model of order to detect future constraints.

Description of the Main Modules

The Network Development Information System will receive the customers load curves a day later after they are collected, and then run power-flows. Three main modules will be necessary :

- **Input Data Collection** : this module performs data updates of network and customer characteristics, AMM load curves collection.
- **Electrical Calculations** : this module prepares data for power-flow and electrical calculations, and filters interesting data. This step is challenging in terms of computing and storage capacities.
- **Network development functions**: this module will generate and use the new load models, and historical models for diagnostics analysis, optimization studies.

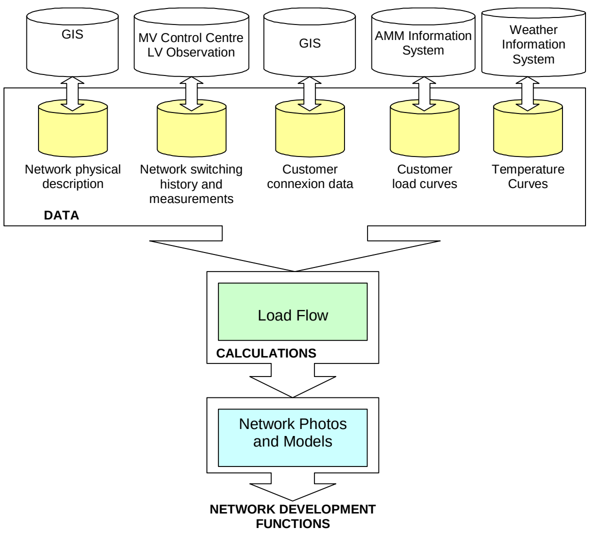

Figure 1: AMM Data Processing

Electrical Calculations

Electrical calculations contain the following modules :

- **Preparation of Network Description.** The switching history of the day before is collected and a model of the network is prepared for every 30 min - period with the right MV switches status.
- **Preparation of Load Models:**
  - For customers without AMM meters, energy indices are used to update a profile load curve. The day-before load curves are prepared and positioned on the network electrical model,
  - AMM "day-before" load curves are collected and positioned on the network electrical model. Data is prepared for loadflow calculation.
- **Load-Flow Calculations** are performed for each 30 minute - period of the day before. It provides phase and neutral voltages of the nodes where customers are connected, and phase and neutral currents of each conductor.
  - For LV networks, load-flow is a three phase unbalanced load-flow (voltage and current calculations for the three phase and neutral).
  - For MV networks, load-flow is a three-phase load-flow based on a positive sequence equivalent model of the system.

Stat Estimation Techniques

State estimation techniques are used in order to derive as much value as possible from the redundant available data :

- Feeder measured current,
- Busbar measured voltage,
- MV customers loads,
- LV customers loads.

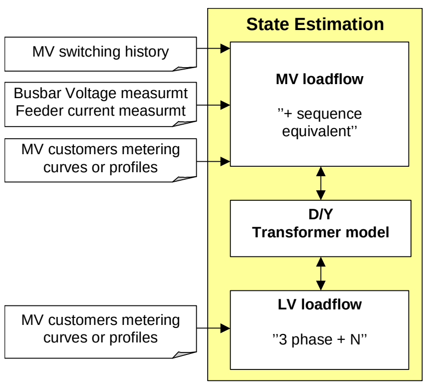

Figure 2: State Estimator Principle

Network Photos and Models

The network photos and models are updated every day. At the end of a calendar year the photos and models are saved in the historical database. At the beginning of a new year, new photos and models are started.

MV/LV Transformer and LV Customers Models

This module determines for each MV/LV transformer :

- reference load curves :
  - "Maximum load curve", the load curve of the day that saw the highest load value of the year,
  - "Minimum load curve": the load curve of the day that saw the lowest (non-zero) load value of the year,
- transformer load model (updated every day) :
  - temperature sensitivity of the load (resulting from a least square regression),
  - contribution of the MV/LV transformer to the feeder peak power.

This module also determines the LV customers load models (first research results described in the last paragraph) including :

- temperature sensitivity of the load,
- non-temperature dependant load.

Line and Node Electrical Photos

From the load flow results the electrical photos are updated every day. The lines electrical photos consist in the following data :

- "Maximum and minimum transit curves", i.e. line transit curve of the day seeing the highest and lowest transit value of the year,
- Duration in hours of thermal constraints non respect,
- number of hours the transit is within 10%, 20%, 30% of the threshold.
- average power,
- average unbalance coefficient,
- cumulated unbalance losses (difference between the losses and the losses if the load was fully balanced).

The nodes electrical photos consist in the following data:

- "Maximum and minimum voltage curves", the voltage curve of the day that saw the highest and the lowest values of the year,
- Duration in hours of thermal constraints non respect,
- The number of hours the voltage is within 1%, 2%, 3% of the threshold.

Network Development Functions

Analysis of Voltage Violations. The objective of this function is to prioritize the LV networks according to the number of customers, the number of non respects per year and the amplitude of the non respect, and give a first explanation of the voltage non respects. At the time of the voltage non respect the following data is provided :

- Busbar voltage value,
- The MV voltage drop, and the fact that the feeder is or is not in normal configuration,
- The MV/LV transformer tap changer value,
- The MV/LV transformer loading and voltage drop,
- The LV voltage drop,
- The phase unbalance.

Optimization of feeder phase balancing : This function prioritizes the LV networks according to their unbalance losses and their voltage non respects, and proposes balancing solutions to optimize the losses and voltage drops.

EXPECTED VALUE OF PROJECT

Optimisation of LV Investment for Voltage Constraints

LV models and electrical calculations have been based up to now on statistical profiles. These models are accurate most of the time, but in 5% of the cases, the models may lead to unnecessary investments. The challenge is therefore a better use of investments to reinforce the system in case of a new customer connexion, at national level impact magnitude is several million euros each year.

Improving LV Networks Balancing

The vast majority of ERDF LV customers are single phase customers. Voltage rules non respect often result of a poor balancing of the LV feeders. Actual phase used by each customer is not available up to now in our information systems. Balancing operations require time consuming measurements and phase testing. Phase unbalance is responsible of additional losses in phase conductors but also in the neutral conductor : undue losses can amount to six times normal losses with fully balanced load.

The knowledge of the phase (provided by the Linky project) is therefore a key to estimate the unbalance, its impact on the voltage and the losses and identify the networks for which a balancing can bring significant value.

Two types of actions can be taken :

- balancing the 10% most unbalanced LV feeders. Impact magnitude is several thousands of euros a year
- balancing LV feeders with less 10 customers.

For our pilot project, the return time of these operations lays between 6 months to two years, for a total cost of less than a couple hundred thousands of euros.

Improve the Response to Customers Complaints

The presently used statistical model may not identify all voltage constraints. If a customer complains about voltage level, a visit of LV network and measurements are required to better assess the situation. AMM data will help explain alleged voltage levels by providing a much richer description of the situations than what is presently provided by measurements. Impact magnitude may be around several hundred thousand euros a year

Improve the Calculation Precision for new Renewables Connections

The development of renewables leads to overvoltages on LV feeders. A better understanding of load curves will enable to better optimize the investments that are necessary to adapt the system to the presence of LV generation. The AMM load curves will bring a better understanding of the behaviour of the loads in day-time low consumption hours.

Avoiding MV/LV Transformers Destruction

AMM load curves will enable to better estimate the transformers load curves and :

- Identify existing repeated overcurrent situations that end up reducing the transformers life time,
- Anticipate overcurrent situations by identifying the transformers that have a high number of hours for which the load is close to transformer rating.

Improving Voltage Quality

By better optimizing network reinforcement, and improving the phase balancing, a couple thousand voltage violations should be avoided with the pilot project. This will reduce impacts for customers in terms of equipment malfunction or damage.

Evolution of the Load and new Profiling Techniques

The development of new electrical appliances (heat pumps, low efficiency lighting, flat TVs, air conditioning), of new insulation standards, and energy optimization systems make customer profiling more difficult and less accurate. There is a need to adapt traditional profiling techniques.

ON-GOING RESEARCH ON CUSTOMER MODELING

Thanks to AMM data, load models can be significantly enriched. The amount of input available data will be significantly higher and storing a whole year of metering data in order to build a model will not be feasible for all customers. This paragraph describes the on-going research on this subject.

<u>Existing LV Customer Model for Network Design</u>

A customer model is necessary to model the system in a low temperature situation. The existing load model is based on 45 customer categories, each having 24-hour week-day and a weekend load profiles. A 24 hour load-profile for a category contains :

- a 24-hour average load curve : $p^{h,0}$
- a standard deviation load curve : σ^{h}

Each customer is characterized by its coefficients (a, b, g) that are derived from its consumption indices and the temperature history of the region: a, b, g

$$average(h) = a.P^{h,0} + g.(T_{heating} - T_{\min})$$

$$std\_deviation(h) = b.\sigma^{h}$$

with g: temperature gradient of the customer

$T_{heating}$: temp. under which heaters are turned on

$T_{\min}$: minimal temperature

The average represent the mean behaviour of the customer. The standard deviation represents the diversity of behaviour the customer has a certain time of the day.

Towards an Enriched Model of LV Customers

This model can be improved with AMM data, but it will not be possible to store a whole year of metering data. Two alternative solutions are investigated to address this storage issue :

Alternative 1 - Customer clustering: each customer is assign to a category. The number of categories is increased from 45 to several thousand.

Alternative 2 - Individual model of the customer: each customer is modelled with its own characteristics load curves and gradient :

- gradient,
- the 24-hour average load curve : $P^{h,0}$
- the standard deviation load curve : σ^{h}

This second alternative is tested using Kalman filtering techniques.

New load model based on Kalman Filtering

This paragraph describes the first results of the research project. A Kalman filter is used to identify temperature gradient (*s*), the value of the temperature non-dependant power $P^{0,h}$ and temperature sensitivity *s*.

Kalman filter observation vector is therefore: $x_k = \begin{pmatrix} P^{0,h} \\ s \end{pmatrix}_k$

Model equation is: $x_k = A.x_{k-1} + G.W_k$

With: $A = 1$ $\quad G = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$

W_k is the model's noise

The observation equation is $y_k = C_k.x_k + V_k$

With $C = [1 \quad \Delta T]$ and the observation noise: V_k

Using Kalman filter, temperature non-dependant power and temperature sensitivity are estimated. The 90% percentile of the power is derived. The method was tested on a substation load curve (see Figure 3). It provides promising results.

Once customer power and temperature sensitivity are estimated through Kalman filter, a clustering method could still be used in order to limit storage requirements.

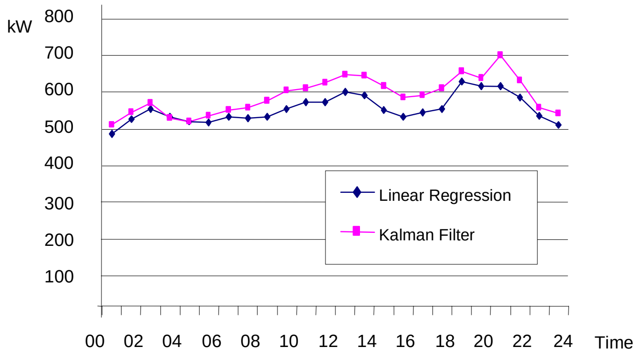

Figure 3: Estimation of the 90% load for a group of customers

CONCLUSION

The "Linky" project launched by ERDF is a smart metering pilot project that will provide useful data for Network Development Activity.

A new information system will be put in place to analyze this data, it will include two main parts :

- building a history of past constraint situations in order to understand and address them,
- building models of LV loads and secondary substation in order to detect future constraints.

Value creation is expected in terms of improved power quality, loss reduction, optimization of investments (specially aimed at reducing voltage drops), improved response to customers complaints, and optimization of transformers.

A research project is under progress in order to build new models for LV customers.

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