FIRST USE OF SMART GRID DATA IN DISTRIBUTION NETWORK PLANNING

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ABSTRACT

ERDF "ERABLE" project aims at creating value from the large amount of data from smart meters in terms of distribution network planning and power quality improvement. The prototype presented in this paper, consists in automatically running a "playback", day after day, of the system. This is made possible by projecting the individual measured load curves on the network models imported from the ERDF GIS into DIgSILENT PowerFactory.
The tool builds dashboards and "snapshots" of each LV network element enabling network resizing or phase-balancing for voltage quality enhancement purpose. The system was used during the 2012 winter on 350 LV networks processing 11 000 individual load curves. Phase-balancing operations are currently being handled on the field.

INTRODUCTION

The French Low Voltage (LV) Distribution Networks operated by ERDF supply about 35 million of customers through 735 000 MV/LV transformers and 600 000 km of lines and cables of 2 million feeders. Optimizing investments on these networks is all the more challenging that measurements are very limited. The historical model uses billing data and statistical profiles to project the behaviour of customers and estimate currents and voltages all over LV grids during peak conditions. Besides, phase connection of single phase customers remain unknown. In addition to a statistical model of consumption, a statistical model of power unbalance between phases is also used. In short the existing LV networks design tool determines the risk of constraints under very specific assumptions.
The development of Smart Grids brings new challenges to LV network design since the system has to be designed considering new equipments and behaviours: PV generators, voltage regulation, electric vehicles, storage devices and demand response. If not well-handled, these new functions can increase losses, degrade quality, damage equipments or on the contrary lead to over-investments. Networks study have thus to be carried out with new tools describing more accurately the LV networks states.
AMM (Automated Metering Management) brings solutions for advanced LV network studies in Smart Grid context as shown in [1]. ERDF is currently testing AMM systems in different parts of France. These meters and infrastructures collect new valuable data:

- Individual load curves reflecting the real customer behaviours,
- Phase connection of single-phase customers giving the real load-balancing all along LV feeders.

The "ERABLE" prototype described in this paper, based on PowerFactory (DIgSILENT), was designed and developed during the last two years to perform:

- The integration of AMM data and LV network description data,
- LV 3-phase load flow calculations,
- LV network state analysis,
- Phase-balancing.

The system was used during the 2012 winter on 350 LV networks processing 11 000 individual load curves. Phase-balancing operations are currently being implemented on the field.

GENERAL TOOL DESCRIPTION

The general idea of the ERABLE prototype consists in interfacing PowerFactory with ERDF GIS, AMM systems and the weather conditions data base to perform daily-3-phase load flow calculations and compute consistent results for LV networks design. These results can then be exported to user's PC equipped with PowerFactory to analyse the LV network states in detail. Figure 1 describes this architecture.

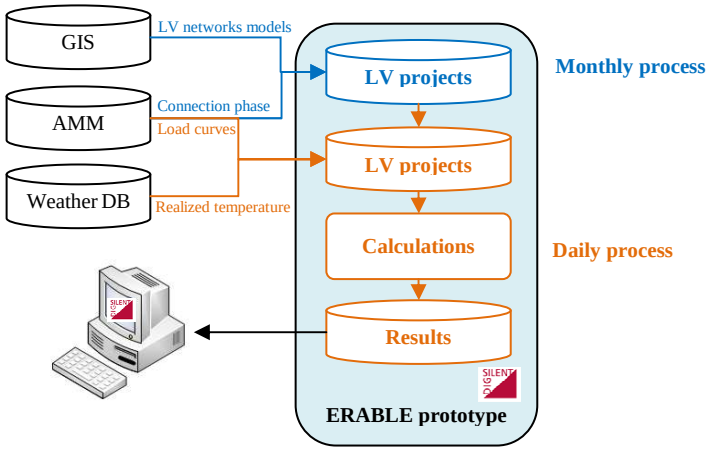

Figure 1 : General architecture of the ERABLE prototype

Two main processes are run by the ERABLE prototype:

- A monthly process which generates a PowerFactory LV "project" (network) for each LV network from GIS data.
- A daily process which updates each LV project with measured load conditions from AMM data, then runs a 3-phase load flow sweep over the considered day with a 30 min calculation step and computes consistent results for each grid component as detailed in [2].

The computed results, dashboards and snapshots of

electrical state of each LV network components (transformers, lines and nodes) and PowerFactory LV projects can be imported to users' PC. On-demand functionalities such as phase-balancing or electric state visualisation can then be run.

Monthly process

Each month, the so-called "static data" are imported, from the input databases (GIS and AMM system) into the PowerFactory database. "Static data" means network topology for the considered perimeter and all the data that are not depending on operation: customer description and connection phases.
Calculations are therefore performed using up-to-date networks.
The monthly process includes the following steps:

- Import the network topologies from CIM-files extracted from ERDF GIS,
- Real phase assignment for customers equipped of smart meters (for these customers, the connected phase is actually known),
- Phase-balancing for customers without smart meters: the algorithm balances the different feeders in order to attribute a phase to customers for which it is not known,
- Preparation of daily cases: construction of characteristics folders, etc.

Monthly process was named like this because it is planned to run once a month but its design is not really dependent on this time frame; if important changes in the network topology are observed for a shorter horizon, the process could be run more frequently.

Daily Process

Daily, data from smart meters are downloaded and saved into the input database. Smart meters record a lot of data; in this application, we are mainly interested in the load/generation characteristics. These characteristics represent the actual consumption/generation for time steps ranging from 10 minutes to 1 hour.
This daily process performs the following actions:

- Reads the daily load / generation characteristics from the input database,
- Builds the missing characteristics (customers without smart meters, errors, etc.) according to the measured temperature for the considered day,
- Executes a 3-phase load-flow sweep over the considered day (calculation step between 10min and 1h),
- Captures extreme conditions and writes corresponding snapshots to the result database,
- Computes / updates average conditions and fill the result database.

On-demand functionalities

On-demand functions are tools built to process the results on users' PCs equipped with PowerFactory. Snapshots and results can be imported back from the result database to PowerFactory to fulfill detailed LV network studies.
This tool library is meant to grow over the years according to the new needs in distribution network planning in a Smart Grid context.
The main tool currently running is the network balancing function: it uses snapshots taken by the daily process and the result database, the optimization algorithm re-affects customers with smart meters (for whom the connection phase is known) to their optimal phase in order to obtain the best voltage profile for their feeders. This algorithm is based on a technico-economic assessment of each phase switching as shown in [3].

POWERFACTORY IMPLEMENTATION ISSUES

The ERABLE prototype is built on a DPL (DIgSILENT Programming Language) script library and the newly available API coming with version 15.0 of PowerFactory.
Most of the computation and optimization tasks are built on standard PowerFactory functions and DPL scripts.
Interfaces with external data sources and data repository have been programmed using the API and the possibility offered by PowerFactory to extend the DPL instruction set using dll.
As smart grid applications are new and all the requirements are not yet fully known, the main advantage of this architecture is that new functions, algorithms can be easily implemented and added to the application: the user can develop new post-processing functions by simply writing new DPL scripts.
The main challenge is managing the quantity of data: a very large number of customers, with each one its load/generation characteristics for every considered day. This is achieved by parallelization; the test system processes small parts of the network independently: the whole network is divided in PowerFactory LV projects. Each project can be processed independently of the rest of the network. When the system will be growing, it will be possible to run independent equivalent systems in parallel.
Tasks are also divided according to their time frame: tasks executed once a year, once a month, tasks executed every day and on-demand tasks.
An interface is built, thanks to the API, allowing to run the different tasks (DPL scripts) from an external application, like Windows Task Scheduler, to automate the whole process.

FIRST RESULTS

The system has been used during the 2012 winter on 350 LV networks processing 11 000 individual load curves.

Large Scale Diagnostic

Dashboards generated by ERABLE prototype turned out to be very useful to detect LV grids having constraints or being close to constraints: overloaded transformers and

feeders with excessive voltage drops. In most cases, phase - unbalance is responsible of these drops. Phase connections being randomly attributed, some LV networks supplying a small number of customers are more unbalanced than average. Those networks have been systematically studied in detailed with PowerFactory.

Approximately, 50% of LV feeders can benefit from phase-balancing, meaning that their performance (losses, quality) can be improved thanks to few smart phase switching. However, only a small proportion of these operations are profitable, less than 10%, since balancing costs (OPEX) can be high in some cases, especially in urban areas.

The following study case shows a real example of a profitable phase-balancing operation.

Phase-Balancing Study Case

The LV network studied in this section is shown in Figure 3. This network contains 4 LV feeders. The blue feeder presents phase unbalance as detected by the ERABLE prototype. Figure 2 shows the unbalance diagnostic of the most loaded feeder (generated by a ERABLE simulation based on the real load curves) : the 24-hour power flow for each phase and the 24-hour voltage values at the end of the feeder and the feeder voltage profile during peak load conditions. Since voltage drop exceeds the 230V-10% threshold on phase 1, phase 1–connected customers located at the end of the feeder can observe voltage values below the limit.

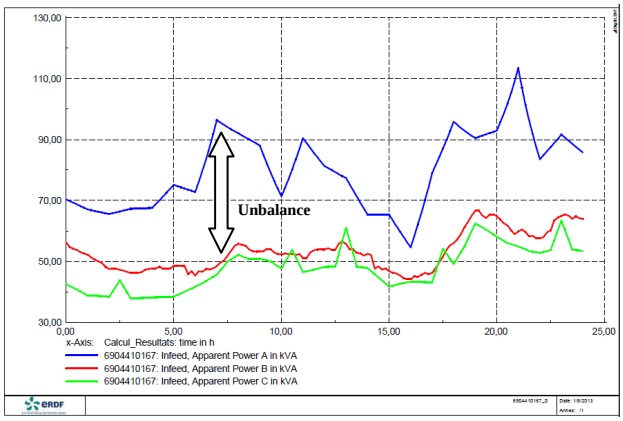

Figure 2-a: 24-hour-most Loaded Feeder Power Flow for each Phase

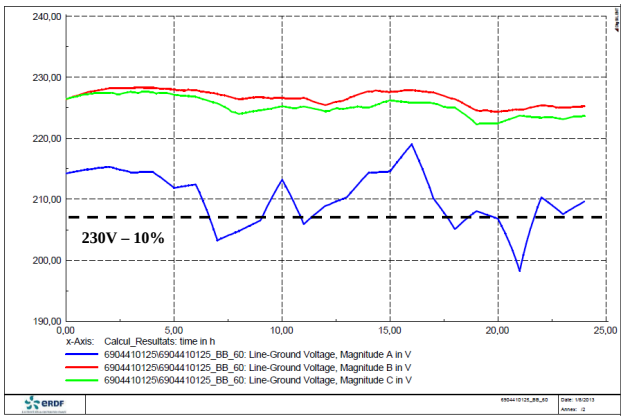

Figure 3-b: End-of-the Feeder 24-hour Voltage Values

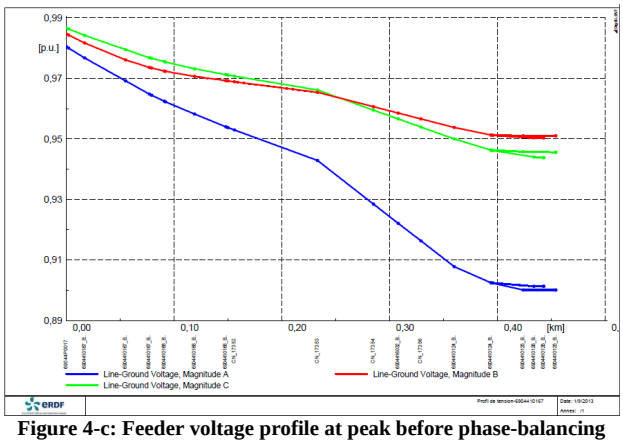

Figure 4-c: Feeder voltage profile at peak before phase-balancing (snapshot based on real load curves)

The ERABLE phase-balancing tool has though been run on this network. It proposes only one “smart” phase-switching: a single-phase customer connected close to the end of the feeder has to be moved from phase 1 to phase 2 as shown in Figure 3.

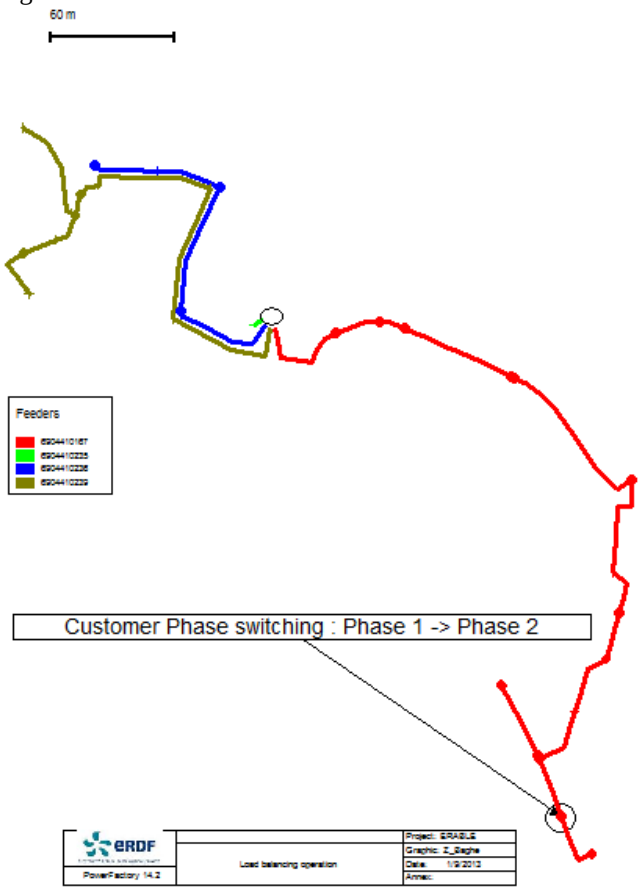

Figure 5 : Optimal phase switching operation for the studied LV grid

This load-balancing operation substantially improves grid’s performances, as shown in Figure 4: voltage constraints are eliminated and power flows are much better balanced. Economically, the 2.6% voltage drop reduction avoids or differs network reinforcements representing about 20 k€ and a 10-year 1 k€ losses reduction (10 years NPV).

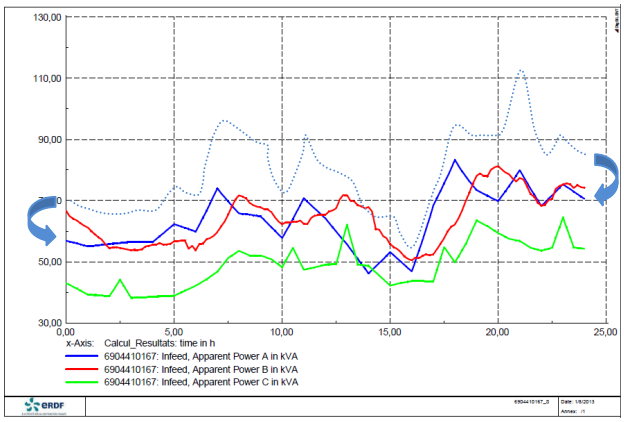

Figure 4-a: 24-hour-most Loaded Feeder Power Flows after Balancing

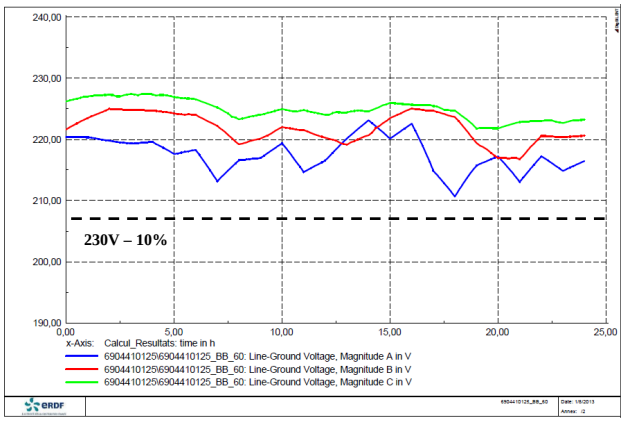

Figure 4-b: End-of-the feeder 24-hour Voltage Values after balancing

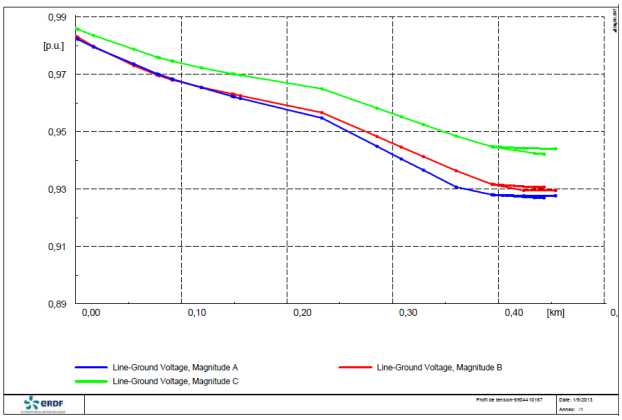

Figure 6-c: Feeder voltage profile at peak after phase-balancing (snapshot based on real load curves)

ON-GOING RESEARCH WORK

The current tool focuses on state reconstitution of LV networks based on AMM load curves, constraints diagnostic and load-balancing. Further work concerns new functionalities for Smart Grid studies: photovoltaic generators and electric vehicle integration considering reinforcement alternatives such as voltage and reactive power regulation, storage and demand response. This Smart Grid study tool requires additional developments on the PowerFactory plateform:

- Implementation of new Smart Grid controls,
- Probabilistic power flow simulations based on individual load model,
- Global simulation integrating MV and LV networks.

CONCLUSION

The ERDF ERABLE project led to a new calculation tool for LV networks design based on AMM data, individual load curves and real phase connections. This prototype, implemented in DIgSILENT PowerFactory solution, has been linked to industrial Information Systems, the GIS and AMM systems, to perform automated server calculations. These calculations allow users to detect constraints and perform detailed LV network studies considering load-balancing as an operational reinforcement alternative.

The system ran over 350 LV grids collecting 11 000 individual measured load curves. PowerFactory proved to be a powerful solution, capable of dealing with significant volume of data and flexible enough to allow specific and progressive developments.

The ERABLE prototype already generated value from the AMM data by optimizing LV grids. Next steps will aim at more precisely quantifying the phase-balancing value stream and also other Smart Grid innovations.

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