OPTIMAL SHORT TERM OPERATIONAL PLANNING FOR DISTRIBUTION NETWORKS

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ABSTRACT

Short term operational electricity distribution network planning (to be distinguished from long-term planning) involves activities aimed at anticipating network constraints and improving network performance within the existing level of basic infrastructure. This concept is commonly used by Transmission Network Operators in order to anticipate and optimize their network operating point at a national and regional level.
Based on the development of local load and generation forecasts tools, for which accurate meteorological forecast is required, short-term operational planning decisions in distribution networks will be made in the near future of operational time (Week-1, Day-1). In addition, real-time network automation functions are used in order to solve the few problems which could not be anticipated. This paper introduces EDF R&D and ERDF's vision of the French Distribution System Evolution and presents the DSO induced needs. The voltage control function is used as an example in order to describe the different time sequences.

INTRODUCTION

The French Distribution System evolution perspectives within the next two decades will be driven by a massive connection of intermittent energy resources (fatal generation) at Low and Medium Voltage levels. The pressure of Distributed Energy Resources (DER) penetration will burst the need for new functions and tools to be integrated in the Distribution Management System (DMS) in order to:
i. overcome the related technical constraints (overvoltage, active and reactive energy transits at the interface between the DSO and the TSO, possible network congestions when using network restoration functions, etc.)
ii. integrate the new margins potentially offered by load-control systems
iii. integrate economical challenges (investments optimization/minimizing flexibility and adjustment markets, etc.)
iv. exchange efficiently with new actors (commercial aggregators) and in an optimized manner with existing actors (TSOs, large Distributed Generators, etc)
v. ensure new missions for the security and safety of a modernized electrical system.
In the technical domain, such functions will have to be able to anticipate and solve local network constraints at different time horizons. Moreover, the improvement of technical margins gained with these functions and their reliability of response will need to be integrated into network planning tools.
First the paper will describe the concept of short-term operational planning and its main objectives which are to anticipate network constraints through simulation and find the optimal network operating point with the help of several network control parameters. Then the paper will focus on how closed-loop real-time functions making decisions based on the assessment of the current operating point of the network (through the use of a distribution system state estimator for example) will help solve network constraints which were not anticipated. Such functions will be connected to SCADA systems in order to react according to real-time information.

SHORT TERM DISTRIBUTION NETWORK OPERATIONAL PLANNING

Short-term operational planning tools are commonly used by TSOs. They enable the day ahead and infra-day planning of the electrical power balances in the national power system. This balancing anticipation is based on short-term load forecast models which are efficient as national load profiles are very smooth with only slow variations. Power plants and large load can then be called through market offers to anticipate the load and generation equilibrium in real time. Short-term operational planning tools are also used to anticipate static network constraints in N-k conditions (network congestions, voltage constraints). Optimisation functions such as Optimal Power Flows are used to solve these constraints with the flexibility of network control parameters (network configuration, capacitor banks or FACTS for reactive power control, etc…) and by ordering any ancillary services required (reactive power of large power stations for example).
Such short term anticipation is not current practice in distribution networks. However, it will be a major requirement with the increase of variability of local flows in the network due to the connection of intermittent generation (Photovoltaics panels and wind farms), new types of loads (Heat pumps, Electric Vehicles) and new load behaviours due to new energy tariffs offered by electric suppliers in the energy market.
Therefore, the first challenge for distribution network operators is to develop and implement short-term local load and generation forecasts. It will help prepare the network actions made in distribution network control centres. Therefore, short-term operational planning tools must have a close link with existing and future real-time control centre tools.

Short-term local load and generation forecasts

Load forecasts

Electricity load profiles variability depends upon the number of aggregated loads. At national level, very smooth load curves can be observed while load curves at the distribution network level are more erratic. Irrespective of the voltage level, existing load forecast models focus on active power, while important research efforts will be required in the future to develop reactive power forecast models. Different “load aggregation” levels can be considered in the distribution network:

- At the HV/MV substation: active and reactive power is currently metered. These consumption data as well as some exogenous variables such as temperature and calendar information can be used to set up the forecasting model of active power. With such models, a top down approach would need to be developed in order to allocate this load to each MV/LV substation.
- At MV feeders heads: only current sensors are currently installed. New active power and reactive power sensors would be required in order to get historic data to develop active power forecast model. Similarly to the previous case, an allocation of this load to each MV/LV substation would be required.
- At the MV/LV substation: no monitoring information is currently available. However the future implementation of smart meters (through the Linky project in ERDF) will help the development of local load forecast model for MV/LV substations relying on the aggregation of individual consumption data provided by smart meters.

The accuracy of meteorological forecast (temperature forecast in particular) will be of most importance in order to develop these models. According to the “load aggregation” level at which the load forecast is expected, some new temperature sensors might need to be installed (at the HV/MV substation or along the MV network) and accurate temperature forecast models used. First models were developed by EDF R&D in order to forecast the active power flow at the beginning of an MV feeder and at an MV/LV substation at a Day-1 time horizon. These models were developed with two years of measurement data obtained with sensors installed in the network and with a correlation with temperature data. Figure 1 and Figure 2 illustrate the results at the MV feeder head and at the MV/LV substation level respectively. Blue curves correspond to the forecasted active power and dark curves correspond to the real active power. At the MV feeder head level, the MAPE (Mean Absolute Percentage Error) coefficient was evaluated at 5-6% for one year, while it was evaluated at 14-15% for the MV/LV substation.

The efficiency of DMS optimization functions on MV networks is on the other hand widely impacted by the information granularity. The closest the previsions are to the anticipated phenomenon generation (consumption and generation) the better their adequacy to DMS needs would be. The best trade-off between forecast accuracy and information granularity leads us –so far- to an “intermediate” prevision aggregation level corresponding to zones in between remote controlled switches in the MV network.

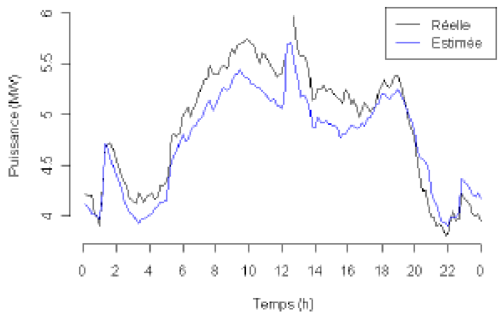

Figure 1 Load forecast at the MV feeder head level

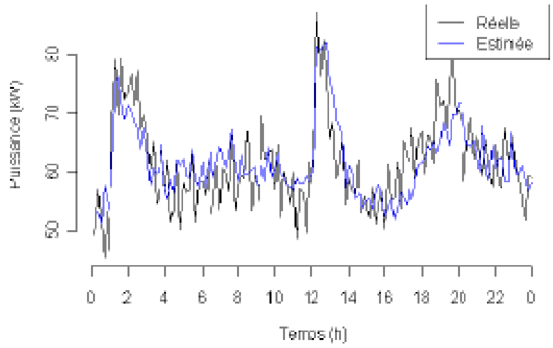

Figure 2 Load forecast at an MV/LV substation

Generation forecasts

The characteristics of decentralised wind farm and photovoltaic power generation and their potential impact on the MV network operation require the network control centers to benefit from the most accurate data for real-time management, to allow for forward looking studies and to ensure the safety of both the distribution and the transmissions networks.

In 2009, an experiment agreement between RTE and ERDF allowed the development of the IPES platform in order to forecast wind power output of wind farms connected in the MV network [1]. Fed by all available production data, a forecast model (based on wind forecast data) and a data base describing the technical characteristics of wind farms, this platform offers a good forecast of wind turbine production injected into the network on D and D-1. However, improvement of such model is needed in the near future.

PV panels output is correlated to very local data: mainly cloud presence and speed. The very dispersed connection of small size PVs in the distribution network makes these forecast very challenging and requires extensive research activities.

Network simulation tool

MV networks

The results of the day-ahead load and generation forecast tools are used as input data by a network simulation module. The latter is based on a load flow calculation in order to assess the power flows and the voltages in the entire MV network. Due to the uncertainties of the load and generation forecast models, the load flow calculation module will need to be able to run load flow calculations with uncertainties: the final result will be an envelope of voltage profiles and power flows.

ERDF's control centres are today equipped with a load flow calculation tool suitable for balanced MV networks. This tool, called FACE, is based on a Backward Forward algorithm. It has been designed for near to real time applications and to run load flow calculations with uncertain inputs (either from load/ generation forecast models or from sensors installed in the network). It is therefore a suitable solution for running load flow calculations for short term operational planning studies.

Once the different electrotechnical variables are assessed by the simulation tool, technical and contractual constraints can be identified by comparing them with technical and contractual limits which must be included in the database and Information system. For ERDF's case, the following constraints will be checked:

- Voltage constraints in the MV network
- Power congestion in the network
- Active and reactive power at the interface between ERDF and RTE

With the implementation of a new capacity market in the next couple of years in the French system and the possibility of load to play a role in the balancing mechanism, commercial aggregation will play an increasing role in the energy market. Through load and DER aggregation, new flexibility offers will be proposed to the markets. Therefore, the network simulator will also be required to validate these different production programs or demand side management programs which would be proposed. No real implementation of such programs could happen without technical validation from both the DSO and the TSO.

LV networks

The Linky project will provide hourly load curves which will open new opportunities for network operation: for final customers, the DSO will no longer have to rely on load profiles derived from a panel of metered customers. Moreover, voltage measurement can be retrieved from smart meters. One can actually rebuild an exact picture of the system in the recent past and store the electrical "snapshot" of the LV network at times of constraints. For such calculation, a three-phase load flow calculation will be required. Short-term operational planning tools will have to be able to consider the potential constraints occurring on the LV network (voltage constraints or congestions in MV/LV transformers). Since a complete simulation of the LV networks behaviour would reveal lengthy to develop and deploy, other solutions such as aggregation mechanisms, deployment of local automatisms for regulation and optimization will also need to be investigated by ERDF.

Optimisation functions and control parameters

Once the operating point of the MV network and constraints on the LV network are evaluated by anticipation, different functions are applied in order to:

- avoid the constraints which have been assessed through network simulation.
- optimize the network operating point when no constraints are expected
- prioritize the different control parameters according to their economic value
- optimize planned outages scheduling, while minimizing their impact on customers and DER

Optimization functions will use Optimal Power Flow applications based on a multi-objective function taking network constraints into account through power flow computation. The related difficulties are twofold:

- The number of different objectives which are pursued (DG integration, quality of supply, avoid network technical and contractual constraints), and the number of control parameters which are of both types, linear and discrete (HV/MV transformers' on-load tap changer, remote controllable switches, capacitor banks, DG active and reactive power control, demand side management solutions)
- Finding optimal network configurations not for a single operating point but for all operating points of the day after (or the week after). At first glance, studies could be performed only at times of the highest load or lowest load forecasted. However, due to the new variabilities of load and generation, network constraints might not only occur at these points of time. Therefore, techniques will need to be developed in order to find optimum control parameters set points for a full period of time.

Due to the high number of objectives, it seems to be difficult to develop a full multi-objective function using all different control parameters. However, several functions could be developed in order to solve a given constraint. For example, if a voltage rise constraint due to DG is expected on the MV network, several functions could be applied:

- Voltage control function finding the optimal voltage control reference value at the MV busbar of the HV/MV substation
- Voltage control function controlling reactive or active power of DG
- MV network reconfiguration
- Local load management according to intermittent generation output

The chosen solution applied the day after would correspond to the cheapest solution considering all operating costs: quality of supply, losses, curtailment costs.

Impact on the Information System (IS) urbanism

The integration of the Short term distribution network operational planning functions will rely on high level of IS "external" exchanges between numerous actors such as DER, Energy Markets, TSO, DSO, energy suppliers, and meteorological forecast Providers.
The Sustainability of these exchanges and the mastering of related IT development costs impose the evolution of IS data and data exchanges towards standardization. On the other hand, DSOs "internal" IT/IS integration, will play an essential role in these functions implementation. In particular all related simulation and optimization tools will rely on data issued from a multitude of different applications i.e. GIS (Geographical Information System), SCADA system, maintenance systems, planning tools, etc. whose integration will be the key of efficiency and sustainability. Finally, the foreseen need to run the functions dedicated to constraints processing in real time, short term and long term planning will imply to redesign the DSO IS architectures.

Operational Planning Implementation Schedule

ERDF intends to implement a first prototype of operational planning including local forecasts, anticipated constraints detection / resolution and optimization tools in 2014. A progressive elaboration / refinement process of the prototype will begin in 2012 with the introduction in ERDF Control Centres of generation and consumption forecast functions coupled with planned outages management and RTE contracts optimization.

REAL-TIME FUNCTIONS

Short-term operational planning tools will help anticipate network constraints. However, real-time unexpected event (occurrence of a fault, high variability of meteorological events, bad forecast results, non availability of demand side resources) will need to be dealt with by real-time network automation functions. After the deployment of fully automated fault detection, fault isolation and power restoration (FDIR functions) used in closed loop [2], ERDF is working with EDF R&D on the implementation of a real-time centralized voltage control function. Based on a cost efficient instrumentation of the MV network a state estimation function enables an assessment in near to real time of the voltage profiles along MV feeders (Figure 3). The voltage management approach determines a voltage control set point at the MV busbar of HV/MV substations in order to keep all voltages in the MV and LV networks within statutory limits: such control signal is sent from the SCADA system to HV/MV substation RTU. This real-time function will be used for events which were not anticipated with the short-term planning decisions. A first experiment of real time VVC function will take place in 2013 in the East of France, with a deployment beginning early 2014. In the future, other real-time automation functions will be required through the use of real-time DG/load curtailment to solve network constraints.

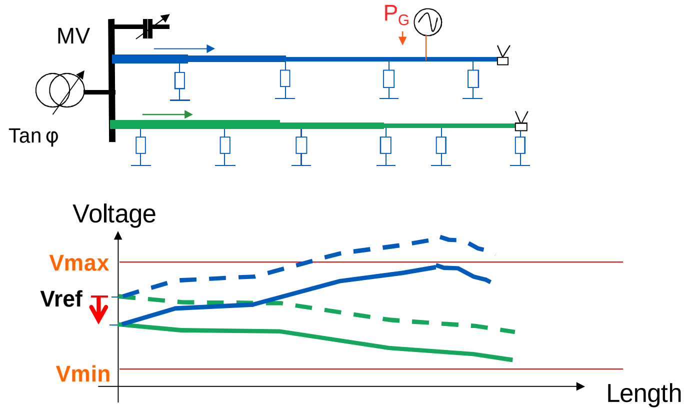

Figure 3 Illustration of the centralised voltage control solution

CONCLUSIONS

Issues related to integration of intermittent distributed generation, new types of load variability and new flexibilities offered by commercial aggregation will require anticipated decisions in distribution system operation. This will require the development of load and generation forecast models which are challenging due to the very localised interdependence between meteorological data and load/generation behaviour. Data provided by smart meters will be of great support in order to envisage such models. Network decisions will be made with the use of network simulation and optimisation tools which will need to be able to consider to new network control parameters: demand side management offers, DG active and reactive power control, etc… All these concepts will be based on the DNO's IS with capabilities of integrating new types of standardised data, new exchanges with other actors Information Systems. Finally, short-term operational planning decisions will be supported by automatic real-time DMS functions which purpose will be to solve network constraints which could not be anticipated.

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