INNOVATIVE SMART GRID SOLUTIONS FOR NETWORK PLANNING AND ACCESS

Rui BENTO, Luís SILVESTRE, José PASCOAL
Pedro GODINHO MATOS, André PAULO,
EDP Distribuição – Portugal
rui.miguelbento@edp.pt

Ricardo FERREIRA, Manuel MATOS,
Jorge PEREIRA, Luís SECA
INESC Porto - Portugal
rjcf@inescporto.pt

ABSTRACT

Smart Grids are the cornerstone for Distribution System Operators transformation. Having new solutions to deal with historical and future problems is key to ensure a smooth transition to an advanced power system that not only integrate a large share of renewables and distributed energy resources (e.g. storage, electrical vehicles), but also requires efficient operation, better planning and exceptional customer service. EDP Distribuição is at the forefront of this transformation, as it is developing Inovgrid, a smart grid project in Évora city (Portugal), where a smart grid infrastructure was deployed, and new data is now available to incorporate in planning and access tools and procedures, hence contributing to a Smarter Grid. This paper discusses the results that EDP Distribuição has attained so far in these areas of the smart grid development, as well as the projected evolution of these innovative approaches to the future of the distribution grid, which are being developed in European projects like SuSTAINABLE (www.sustainableproject.eu).

INTRODUCTION

Smart Grids implementation in EDP Distribuição, with project InovGrid [1], is ongoing for the past four years. Conventional meters in LV consumers are being replaced by EDP Boxes (EB) and Distribution Transformer Controller (DTC) are being installed in MV Substation (MVS). DTCs provide several information from the MVS, namely load diagram of the LV grid, fault detection, power quality, among others. New information, such as load diagram of LV grid, is key for an effective MV grid planning study. Over 300 DTC have been installed in Évora, both in cabin and pole MVS, like the one shown in Figure 1. Together with the EDP Box and evolved IT systems, these new Smart Grid infrastructure allows having an updated and varied amount of data that supports the development of applications and techniques fostering a better management of the distribution grid. In the first section this paper discusses the first steps of a changing planning paradigm for the network, whereas the following section supported on the on-going work from the European FP7 Sustainable [2] project addresses new approaches for grid reinforcement in the presence of a robust Smart Grid, with well-established DER, and advanced state estimation. Finally, a selected example of how new information from the infrastructure leverages current access methodologies with high impact on grid reliability and quality of services, namely MV broken conductors detection.

FIRST STEPS OF SMART PLANNING

Presently planning of HV and MV grid is based on a minimum free capacity scenario of the grid, which in many cases is equal to a maximum load scenario. This scenario is a picture of the grid in a certain moment, where the future is projected to validate the expected conditions and evaluate the economical merit of investment proposals.
To define the study scenario, different power measurement of HV/MV transformers are analysed in order to identify which is the best situation to study, including a characterization of each the current measured at each MV feeder. The load of the MV feeder is distributed along its Medium Voltage Substations (MVS) proportionally to its recent Peak Load. Peak Load of MVS is the maximum power supplied during the previous year, being in many cases obtained using a conventional meter.

Figure 1 - Example of DTC installed in Pole MVS

If the study moment is not the same as the Peak Load moment of the MVS, which may be true for many MVS, distributing the MV load of the feeder proportionally to the Peak Load of its MVS implies an approximation to the MV grid leading to a non-optimal MV configuration. Nevertheless, from a HV perspective, this eventually misleading approach constitutes the best available method, particularly when based on classical technology. To support this analysis the Dplan tools has been used consistently for the past decade. Dplan is an analysis tool developed by Instituto Optimização

Aplicada, with close relation with EDP Distribuição, reflecting common perspectives and EDP effective needs.
Extensive load diagrams have been acquired in DTCs such as those shown in Figure 2. For illustration purposes each daily diagram is normalized to its maximum value.

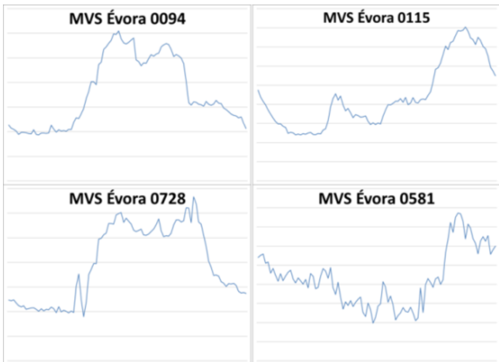

Figure 2 – Load diagram measured in 4 DTC

Should day peak load MVS (94 and 728) be connected in the same feeder, and night peak load connected in the same feeder (MVS 115 and 581), their maximum value would be 1,9 and 2,0 as shown in Figure 3.

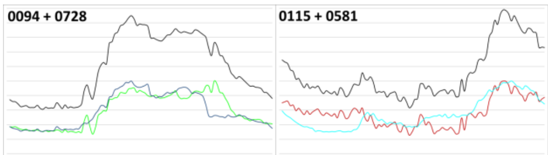

Figure 3 – Load diagram of MVS combination

Nevertheless, if knowledge on load diagrams is effective and the possibility to connect them in a better way exists, for instance MVS 94 and 115, and MVA 581 and 728, one can easily conclude that the maximum value would reduce to 1,8 and 1,5 as shown in Figure 4.

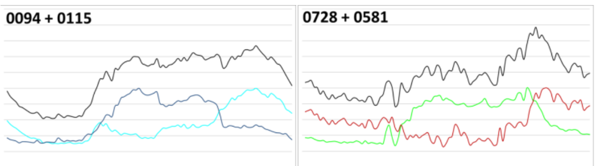

Figure 4 - Load diagram of optimized MVS Combination

This is indeed a particular situation but significant gains both in losses reduction and infrastructure utilization are achievable if using this information.

Dplan has already a production module with chronological analysis for LV grid, similar to what is described for MV grid. Now a chronological module for MV and HV analysis is under development and a new approach to Planning studies is on sight.

PLANNING IN A SMART GRID WORLD

In this section, the issue of network reinforcement planning in a smart grid environment is addressed considering that a large penetration of distributed energy resources (DER) is sought. The acronym DER refers to all controllable small-scale devices connected to the power distribution grid that can either generate or consume electrical energy, or both. In this sense, DER includes not only distributed generation, but also other devices that can react to price signals from the energy market or respond to a centralized set point. Therefore, DER includes not only distributed generation (DG) and micro generation (μG), but also controllable loads (CL) and distributed storage devices (DSD).
Traditionally, power distribution utilities have centred their network's reinforcement plans on satisfying the growth of electrical load. The traditional planning paradigm has consisted in accommodating the foreseen increase in the demand's peak load by means of reinforcing the existing power distribution infrastructure. However, power distribution systems are presently facing new challenges due to increasing levels of DER. On one hand, there are limitations on the acceptance of generation from renewable energy sources (RES). In particular, the large scale integration of DG and μG, especially regarding power injections by RES, may result in several problems for network operation, such as the occurrence of unacceptable voltage profiles and/or branch congestions.
On the other hand, the increased number of DER opens new managing possibilities, namely for voltage control, congestion management and reduction of active power losses. Future power distribution systems are expected to contain substantial and widespread amounts of new types of controllable loads such as electric vehicles (EV) and electrical heat pumps (EHP). Several DSD such as batteries and thermal storage devices should also be available. In this context, the smart grid concept will comprehend many operational actions that take advantage of bidirectional communication, not only with DG and μG, but also with other devices such as CL, DSD and EV. At the same time, new tools and functionalities will be developed at the operation level, such as state estimation, and dynamic load and RES forecasting and automatic network reconfiguration.
The power distribution reinforcement planning exercise is restructured so as to allow obtaining a "smart" investment plan that accounts for the presence of the new functionalities at the operation level, including the costs of the required information and communications technology (ICT), advanced smart metering and renewable generation forecasting. The smart investment plan must reflect the benefits and costs of having the aforementioned

advanced control and management functionalities. Thus, the resulting new investment plan may have a lower final cost than the corresponding conventional plan (without smart grids). However, this can only happen if the costs associated with the necessary ICT and metering infrastructures do not exceed the combined resulting benefits of distribution network investment deferral, reduction of active power losses, reduction of greenhouse gas emissions, and network reliability improvements. Of course, other benefits associated with the availability of information from the consumers should also be considered in the exercise.

The smart investment plan is obtained through multi-objective optimization. In order to do so, several scenarios are defined for operation, reflecting different levels of RES penetration. For each stage of the planning horizon, the input data - including new operation functionalities - are used to evaluate, through multi-temporal operation simulation for typical days, the network's configuration. The simulation allows obtaining the yearly aggregated levels of power losses, as well as the costs and/or benefits of operating the distributed energy resources (DER) within the grid. Moreover, the simulation process will provide a list of the existing grid's limitations, namely branch overloads and bus under and over voltages, therefore allowing identifying the reinforcement needs.

The planning exercise is conducted from a set of scenarios in which multi-temporal operation simulation is used to evaluate not only the impact of reinforcements but also the effects of introducing the smart grid functionalities. For instance, congestion management through and DSD control and/or demand response (by means of CL) may allow postponing reinforcement investments that would be otherwise necessary, as illustrated in Figure 1.

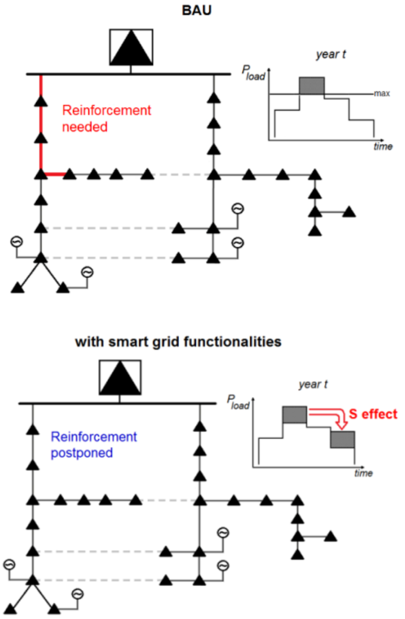

Figure 5 - Network reinforcement planning under the smart grid concept

On the upper side of Figure 5, the reinforcement of a small distribution system is planned using business-as-usual methods. First, a load diagram is forecasted for a given year t within the planning horizon under analysis. Then, that load diagram is used to evaluate the system's performance through AC power flow. If the load growth is large enough, some branches of the distribution grid become overloaded (enlarged branches in Figure 5.. In this situation, it would be necessary to substitute or uprate such branches. On the lower side of Figure 5, the same distribution system is planned in a smart grid environment. The forecasted load diagram can be modified through load shifting, assuming that enough controllable loads (CL) are available and can be operated at critical hours (peak load). One should emphasize that this "smart effect" doesn't necessarily have to be attained through CL, as other devices, namely DSD, can be used for shaping the load diagram. This enhanced flexibility results in a relative flattening of the load diagram, eliminating those branch overloads that had to be substituted under traditional planning.

The ensemble of simulations for the different scenarios solutions will produce a set of efficient like the ones shown in Figure 6, which were generated by considering that, for each foreseen DG level, different combinations of DSD and CL will lead to different costs.

Only the Pareto front is then retained for multi-criteria analysis, by which the planner selects the solution that best fits his benchmarks, trading-off the desirable increase of DG penetration with the associated costs.

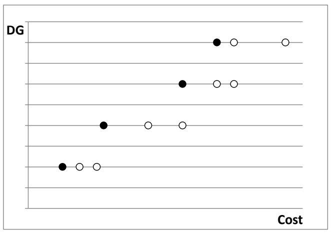

Figure 6 - Set of efficient solutions generated by the simulation process

SMART INFORMATION APLICATION: BROKEN CONDUCTORS DETECTION

Broken conductors in overhead lines are a type of fault that sometimes may be very hard to detect in distribution networks [3]. The traditional approaches limitations are well known and have real impact on the Quality of Service provided to customers.

The vast majority of broken conductor problems arise after a successful reclose maneuver of the MV circuit breaker at the primary substation or third generation recloser (includes overcurrent and earth-fault functions).

Although the MV network is partially restored, most LV and MV customer fed downstream by the broken conductor may suffer a voltage unbalance or in the worst cases a power interruption. From this point the MV Dispatch Center may only begin to suspect the existence of broken conductor when customers start phoning to the Call Center.

In overhead feeders, where this kind of outages is most predominant, most HV/MV substations are equipped with protection systems that are able to detect broken conductors. However the information provided to the Dispatch Center doesn't include the fault distance. Another challenge is to be able to distinguish a single phase broken conductor from unbalanced loads, which may be related to the exploration of the network and not related to a power failure.

The performance on the detection of this kind of problems is as effective as the number of trouble calls received by the customers: the more trouble calls are routed to Dispatch Outage Management System (OMS), the better and faster is able to detect and predict an estimated location of the problem. However, in rural network areas, the low number of trouble calls received doesn't always help to detect the broken conductor as fast as possible.

When the Dispatch Center suspects of a problem, and the information gathered by the trouble calls registered in the OMS is enough to somehow restrict the network affected area, a maintenance team is sent to that location. Usually, one of the first steps is to test the secondary MV/LV substations transformer in order to identify if the outage origin is located here, or if it is located in the MV network. If the broken conductor is located in MV network the detection process is more complex and the global duration of the outage may reach several hours, namely in rural feeders, characterized by high lengths and low loads levels.

The DTC installation, in the secondary MV/LV substations transformer, is going to significantly improve the detection of a broken conductor. The major advantage is that the detection will be made by the analysis of the voltage unbalance, gathered by the DTC, instead of customer trouble calls. In this scenario, the trouble calls are no longer the most important contribution to the broken conductor detection, although they still remain influential to confirm the alarms provided by the DTC.

Every time a successful reclose happens, either by a substation circuit breaker or by a third generation recloser, the Dispatch Center support systems should search for any specific voltage unbalanced alarm that exists in the current EDP Distribuição DTC, and correlate the instantaneous voltage and current levels, in the hope of finding a possible broken conductor. When an unbalanced phase is detected, the next step would be the attempt to figure out the probable location of the broken conductor. The objective is to find the problem before the customer calls to Call Center.

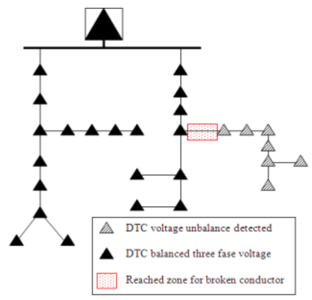

Figure 7 - Reached zone for broken conductor

This procedure is going to be developed and integrated in the Dispatch support systems. The DTC installed in the context of the award winning EDP's InovGrid Project already have unbalanced phase alarms and are able to provide real time voltage and current measures to the corporate systems.

Having in mind the rollout of more than 10 thousand DTCs all over Portugal, which is currently taking place, this kind of detection is a natural step in the direction of gathering useful information from the amount of data generated by the Smart Grid infrastructure. A new set of monitoring systems is arising to give the Dispatch operators the ability to manage the LV network in a similar way than MV and HV networks.

The advantage of this type of proactive actuation is reducing the customer outage duration and consequently improving the Quality of Service.

It is expected that when the customers phone to Call Center to communicate a power failure, the MV Dispatch Center not only is already aware of the problem but also has the estimated time of restoration (ETR), given by OMS. Additionally, the investment in new expensive protective systems may be redirected to other areas.

ADVANCED STATE ESTIMATION FOR MV NETWORK

The Automated Metering Infrastructure (AMI) installed in Évora test site is able to collect, as referred previously, information from LV customers through the installation of EDP box and other Remote Terminal Units (RTU) such as the DTC. This system leverages MV observability as it provides measures for fundamental variables in all secondary substations that have DTC installed. However it may occur that secondary substations have no physical RTU, or communication between DTC and Dispatch center is by some reason compromised. In this case, using some of the measures provided by LV smart meters allows estimating power (active and reactive) at MV node. Even if an RTU exists at Distribution transformer level, using measures from downstream smart

meters allows improving the quality of the measure.
In the Sustainable project, a new approach is being developed in order to take advantage of existing LV information without the need of having real time information for all nodes on MV network.
The base of this functionality is a pseudo-measurement generation method that, without real time measurements for all the MV nodes, provides active and reactive consumption estimation based on monitored LV loads in 15 minutes time intervals. However, the data is not transmitted immediately after measurement or on an hourly basis, but periodically, to a database server.
The LV real time measurements can be used to generate pseudo-measurements for the upstream MV/LV substation load (which aggregates all downstream LV loads and LV generation), and this is done using an expert system trained specifically for this purpose with historical data. This expert system will be trained at the central management level, where historical information is available, and can be located at central management level or at DTC level.
This expert system is based on an auto encoder properly trained. Auto-associative neural networks (AANN) or auto encoders are feed forward neural networks that are built to mirror the input space S in their output. The size of the output layer is the main difference between an auto encoder and a traditional neural network - in an auto encoder the size of its output layer is always the same as the size of its input layer. Therefore, an auto encoder is trained to display an output equal to its input. This is achieved through the projection of the input data onto a different space S' (in the middle layer) and then re-projecting it back to the original space S. With adequate training, an auto encoder learns the data set pattern and stores in its weights information about the training data manifold. The typical architecture of an auto encoder is a neural network with only one middle layer. This simple architecture is frequently adopted because networks with more hidden layers have proved to be difficult to train.
A constrained search approach is applied for finding the missing signals that, in the context of load estimation, are the active and reactive load at MV/LV secondary substations. Within the constrained search approach, an Evolutionary Particle Swarm Optimization (EPSO) was chosen for reconstructing the missing variables.
If for some MV/LV secondary substation in distribution network without real time measurements there are no LV real time measurements, a Load Allocation technique can be used to turn MV network fully observable.
The state estimation algorithm is evaluated using the measurements during a period of time, at least during a week, with a step of 15 minutes. This analysis is done using real data continuously saved during this period of time.
This sophisticated technique has shown good results on simulation based on test networks [4], and is now being tested in information coming from the Évora test site.

CONCLUSION

New information coming from the Smart Grid infrastructure is facilitating and changing traditional ways of dealing with grid planning and access. The data acquired in DTCs along with new tools and functionalities is the first step to better determine the grid performance and will be the trigger to change the planning paradigm.
An alternative methodology which combines the unbalanced phase alarm, provided by DTC, and SCADA information, namely network topology, relay fault data and feeder restoration, is going to improve the detection of a broken conductor. The advantage of this type of proactive actuation is reducing the customer outage duration and consequently improving the Quality of Service.
On the other hand, the availability of smart grid functionalities for congestion management and voltage control using DER such as flexible loads, distributed storage or DG will impact on distribution reinforcement planning, leading to the deferral of network investments while enabling the network to integrate more RES and thus contribute to the reduction of greenhouse gas emissions.
The presence of an AMI allows, together with some novel functionalities like the ones described in this paper, implement the real Smart Grid concept, integrating control and planning tools that foster a more efficient, sustainable and reliable distribution grid.

REFERENCES

[1] Godinho Matos, P., Daniel, P.R., Veiga, A.M., Aires Messias, A., São Miguel Oliveira, M. Líbano Monteiro, P., "Inovgrid, a smart vision for a next generation distribution system", *Electricity Distribution (CIRED 2013), 22nd International Conference and Exhibition*
[2] Godinho Matos, P., Silva N., Madureira A., Seca L., Peças Lopes J., "Maximizing the Integration of Distributed Generation in Smart Grids Distribution Systems", *CIGRE Symposium Lisbon 2013*
[3] Pinto de Sá J., Louro M., 2007, "Evaluation of protection approaches to detect broken conductors in distribution networks", *CIRED 19th International Conference on Electricity Distribution*
[4] Krstulovic, J., Miranda, V., Simoes Costa, A. J., & Pereira, J. (2013). "Towards an Auto-Associative Topology State Estimator", *IEEE Transactions on Power Systems*, (99):1–8, 2013