MONICA: ADVANCED MONITORING AND CONTROL IN MV AND LV DISTRIBUTION NETWORKS

Susana CARILLO
Endesa - Spain
susana.carillo@enel.com

Javier LEIVA
Endesa - Spain
javier.leiva@enel.com

Rubén CARMONA
Endesa - Spain
ruben.carmona@enel.com

ABSTRACT

The MONICA Project is an innovation experience focused on the monitoring and control of the distribution networks of the future, where smart agents such as Distributed Energy Resources, electric vehicles or active end users play a key role. A deployment of sensors have been completed on the Smartcity Málaga Living Lab, involving fifty-nine Secondary Substations and more than nineteen thousand real end users, all of them equipped with smart meters. The core of the MONICA Project is the State Estimator, a disruptive series of algorithms scarcely used until now in medium and low voltage networks in normal operation conditions. This tool determines the operating conditions of the whole network, in the presence of sensors or not, letting the Distribution System Operator apply active strategies to fight against energy losses and to optimize operation and maintenance.

INTRODUCTION

Nowadays the number of active elements connected to the distribution network, such as distributed generation, energy storage, electric vehicles or self-producing consumers, is increasing exponentially. Therefore, the use of monitoring, digitalization and diagnosis tools is crucial in distribution networks. Until a few years ago, the possibility of implementing a state estimator in LV or MV networks was not considered technically or economically feasible. The deployment of smart grids, in particular the deployment of smart meters and remote control associated with distribution automation systems, is providing the distribution network with new information sources.

The main objective of MONICA Project is to develop monitoring and diagnostic tools for distribution networks in medium and low voltage (MV and LV), similar to those that have traditionally existed in transmission networks in high voltage (HV). The use of such tools is going to be crucial in distribution networks.

The State Estimator is the core of the monitoring processes included in the project. The MV and LV state estimation is similar to a conventional state estimation used in transmission networks. However, MV and LV calculation presents a series of peculiarities, such as the reduced length of the cables, which make it necessary to develop a new model. The estimation process is developed in two steps: a medium voltage estimation supposing a balanced situation of the three phases at the MV feeder, and a low voltage estimation taking in account all three phases and the neutral cable.
A whole network of sensors, in medium and low voltage, has been deployed in the Smartcity Málaga (Spain) distribution network. The scope of the project covers two HV/MV Primary Substations, fifty-nine MV/LV Secondary Substations and over nineteen-thousand end users equipped with smart meters. The State Estimator receives all this information in real time from the new sensors deployed at Secondary Substations, and from the smart-meters, and uses these measurements to calculate the state of the distribution network also taking into account its real topology.

The consortium that develops the project is led by Endesa and has the participation of Ayesa Advanced Technologies, Ingelectus Innovative Electrical Solutions, Ormazábal Media Tension and the Electrical Engineering Department of the ETSI of the University of Seville through the AICIA foundation. The total budget is more than 3 million euros, of which about 1.3 million are financed by the Center for Industrial Technological Development (CDTI), supported by the Ministry of Economy, Industry and Competitiveness, as part of the program INNTERCONECTA, and co-financed by the European Regional Development Fund.

The specific objectives in this project are the following ones:

- To develop and deploy new sensorization devices in Smart City Málaga.
- To implement a State Estimator for the MV and LV network.
- To interconnect every kind of data from sensors, smart meters, state estimations and algorithms to Endesa IT systems.
- To study losses, deviations in voltage, current unbalances, line saturations and other important electric parameters from the network.
- To allow Distribution Management Systems operators get valuable and accurate information about the MV and LV distribution network.

DEPLOYMENT OF SENSORIZATION ON THE FIELD

In MONICA Project it has been completed a massive deployment of sensorization in medium voltage and low voltage. The area where MONICA takes place covers two HV/MV Primary Substations that feed more than nineteen-thousand end users, with fifty-nine MV/LV Secondary Substations. Forty Secondary Substations of these fifty-nine are fully and partial sensorized:

- 35 Secondary Substations in their MV side of the transformer.
- 37 Secondary Substations in their LV side of the transformer.
- 15 Secondary Substations in their MV inlet and outlet cabinets.
- 18 Secondary Substations in all their LV feeders.

For that purpose, in MONICA it has been developed some measuring devices that allows to measure the network behavior in real time, so that they can be installed without a network modification and avoiding security criterion concern. Thus, it has been created and implemented current and voltage sensors in medium voltage lines, current sensors to measure the medium voltage and low voltage side of the transformer, current sensors in low voltage feeders and energy measurement sensors. Measurements are available not only per line, but also per each of their phases, hence this architecture provides much more relevant information of the state of the network.

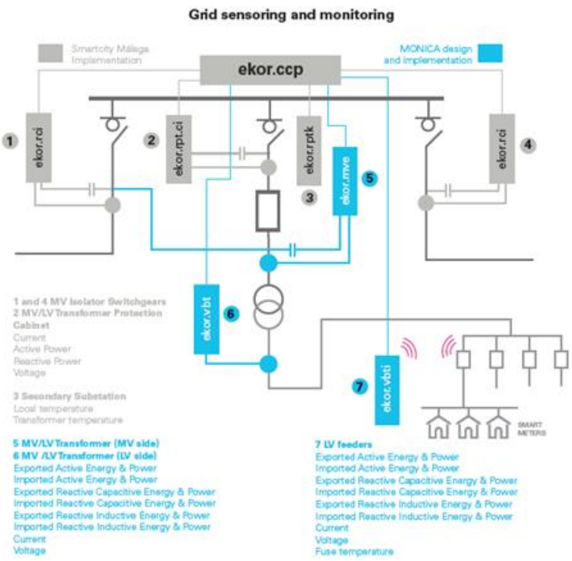

Figure 1. Sensorized Secondary Substation schema.

By doing so, it has been achieved the availability of the following measurements of the network's main electric parameters:
- Active power per phase (kW).
- Reactive power per phase (kVAr).
- Active energy per phase (kWh).
- Reactive energy per phase (kVArh).
- Current per phase (A).
- Voltage per phase (V).
- LV feeder fuse, transformer and local temperature (˚C).

In total, 108 MV voltage sensors, 108 MV current sensors, 90 LV current sensors and 468 LV feeder fuse current sensors have been deployed on field.

THE STATE ESTIMATION AS THE CORE OF MONICA

Once massive sensorization deployed on field has been carried out, and using other data sources like Smart Meters and IT Systems from Endesa, the State Estimator developed in this project for MV and LV network comes into play [3]. The core of MONICA is the State Estimator algorithm especially designed to be implemented in a medium voltage and low voltage context, characterized by a huge number of radial branches weakly coupled, a combination of diverse data, and lower levels of redundancy than the existing ones in electricity transportation systems. Therefore, on the one hand, Distribution Management Systems (DMS) operators will have available an accurate, complete and updated image of the distribution system and, on the other hand, State Estimator's results can be used by the DSO as a necessary valuable information for every daily network operation [5].

The State Estimator stablishes the most likely state of an energy system using some sets of measurements periodically collected by SCADA systems through remote terminal units. Since its introduction by Schweppe at the end of 1960's, state estimation tools have been evolving thanks to a large number of theoretical development and better practices, which are well documented [1].

Recent introduction of new sensorization technology and smart meters raises new challenges but, also, gives the possibility to improve the performance and refinement of the DMS, reaching levels closer to the electricity transportation networks. In fact, an important number of utilities and researchers all over the world are currently carrying out or considering the use of smart meter measurements in a large number of applications related to the electricity network, like phase imbalance, outage management, feeder equalization, demand management, supply quality monitoring, losses, etc [2]. All of them are in an initial stage of development or in conceptual design. This evidences how state estimation tools have not been sufficiently emphasized so far, despite being the appropriate tool for this purpose, namely, the monitoring and tracking of the real state of the network that optimally processes sets of redundant, uncertain and inconsistent measurements with accuracy, as MONICA Project has successfully demonstrated.

Therefore, the State Estimator is a tool capable of managing measures from a very diverse nature and accuracy to determine the real state of the system in every point of the network, whether sensorized or not. It uses high precision measurements from sensors and from smart meters and, also, consumption predictions at those moments when real measurements are not available. All this information, with their associated quality, is combined with the detailed network topology.

Thus, main innovative items included in MONICA due to the State Estimator are:

1) Development of a 4 wire, three-phase one-neutral, state estimation process in real time.
2) Low voltage three-phase estimator integration with a medium voltage single phase estimator in Real Time.
3) Measurements synchronization with different updating periods and uncertainty levels.

MONICA SYSTEMS

One of the main milestones achieved in MONICA Project is being able to implement all the data collected from sensors into Endesa own systems, and the use of the corporative tool for network data visualization, instead of using an external application. MONICA systems, built using Big Data technologies, have carried out the following:

- Development of a smart measurement management module, which is in charge of the real time managing of the data, enriching the historic management process and allowing a correct execution of the State Estimator.
- Allow the constant execution of the State Estimator with the data from sensors, Smart Meters and network topology.
- Development and implementation of a web platform where to display the results from the State Estimation executions of every monitored network's asset.
- Development of a dashboard formed by a set of 56 key performance indicators (KPI).

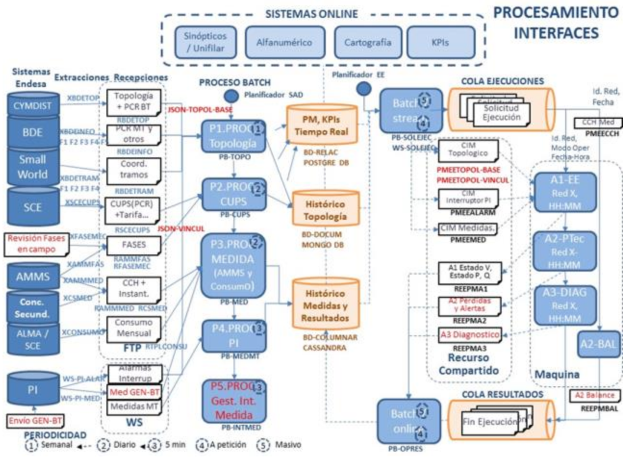

Figure 2. Complex schema of MONICA systems.

Following the scheme shown in Figure 2, MONICA systems process 1,200,000 measurements per day from sensors, and 1,584,000 measurements of energy and 6,240,000 additional measurements per day from smart meters. After processing, MONICA returns 7,200,000 measurements per day calculated by the State Estimator for 7,500 nodes and network branches, achieving 300,000 executions with a 93.5% success.

REAL MONITORING, ALARMS AND RESULTS

Statistics data analysis

One of the main benefits that the network monitoring and the results of the State Estimator executions have provided in MONICA Project is the possibility of studying systematic problems in the network and knowing how it behaves in reality, focusing this analysis in saturation, voltage deviations and energy losses.

Saturation levels

Knowing the current that flows in every phase of every line of the Secondary Substations provides a very important information about how saturated is each phase, how oversized is the network in every moment, and the significant differences between lines that come from the same Secondary Substation.

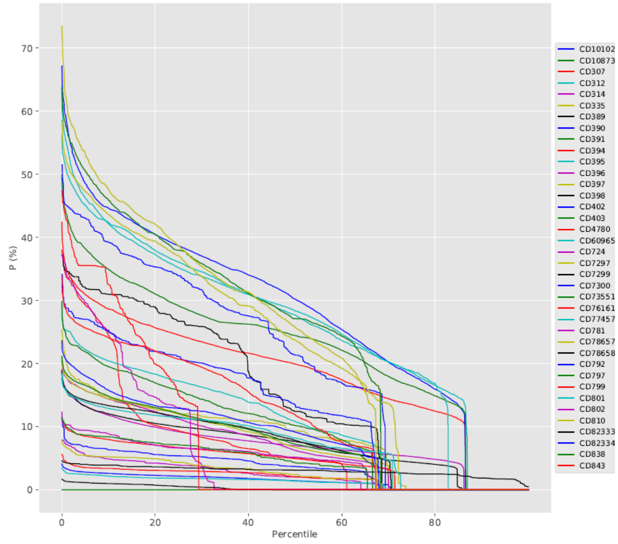

Figure 3. Saturation monotonous.

The previous image shows the monotonous graph of the load of Secondary Substations studied in MONICA. Here, two details are remarkable: the load in only 9 Secondary Substations overcomes a 40%, and in more than half of the Secondary Substations never overcomes a 20%.

Voltage levels

In the case of voltage, it is also possible to monitor its value in low voltage level.

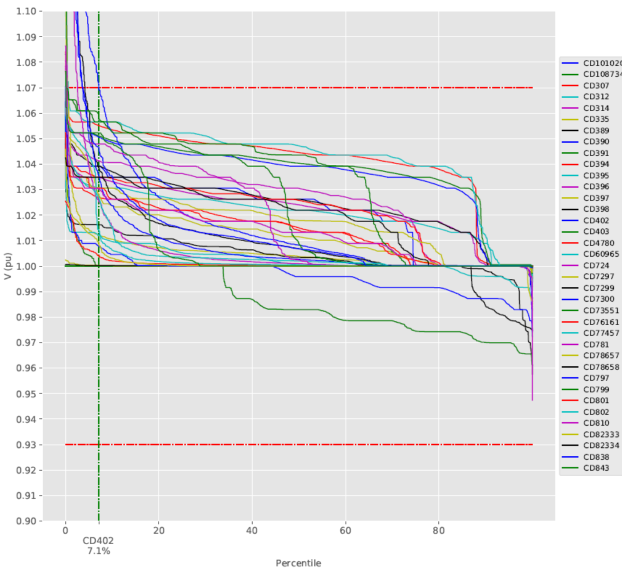

Figure 4. Voltage monotonous per unit (p.u.)

Using figure 4, corresponding to the LV voltage monotonous, is easy to see that operation voltages are high (the majority exceeds 1 p.u.) with some Secondary Substations infringing overvoltage. One of this cases is the Secondary Substation number 402, with a 7.1% of its scenarios with overvoltage. In the future stage of the electricity distribution, where new agents like distributed energy resources and electric vehicles must be taken into account, it is necessary to reconsider the voltage levels in LV network operation.

Technical energy losses

It has also been analyzed the technical losses in MV and LV levels.

In MV, technical losses varies among 1.25% and 2.25% of the total power consumption at Primary Substation level. In LV, as it can be seen in the image below, technical losses' median are between 1% and 2% of the energy consumption at Secondary Substation level, from which those with high ratio are normally related to low demand power scenarios.

Furthermore, it has been checked that, deepening in the losses analysis by comparing feeders from a single Secondary Substation gives the opportunity of having information about how unbalanced is each LV line. This is something that could be reduced by designing client reorganization strategies.

In the end, MV-LV system's total technical losses are between 2% and 3% of the consumed energy, of which a 50% is due to the transformers in the Secondary Substations, and a 30% is related to cable losses.

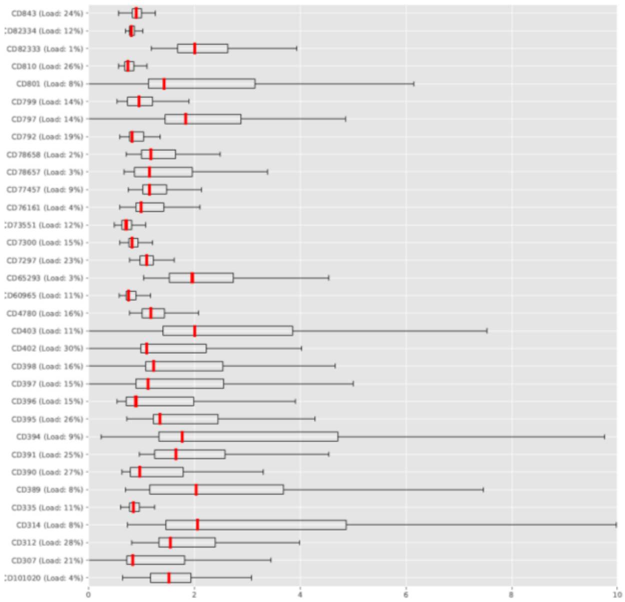

Figure 5. Voltages boxplot per CD

Non-technical energy losses

Once defined and calculated all technical losses in the network, and by considering total losses, it has been carried out energy balances in MONICA Secondary Substations in order to determine the non-technical losses. This may be due to different factors:

- Errors in estimated measurements.
- Errors in the synchronization between sensors and smart meters.
- Errors in sensors measurements.
- Errors in the electric model.
- Possible energy frauds.

This analysis shows non-technical losses values between 5% and 17%, depending on the Secondary Substation and the period of time. Moreover, the tools developed in MONICA project, and especially the State Estimator, not only enable to calculate global values of non-technical losses but find the specific section and point of the grid where these losses may be taking place.

Real Time control by alarms

The security of the state of the network is controlled in real time (overvoltage, unusual voltage values or reactive power flows), as well as their evolution, by using alarms in order to help DSO operators having a detailed and punctual sight of the possible risks in the electricity supply. All these alarms are sent via SMS or mail to the network operators, who are in charge of accomplishing the daily work on field.

Approximately, 300 alarms are received monthly and, in the last months, over 50 field operations have been successfully completed in order to improve the quality of the service. Some of those operations are:

- Low voltage fuse sensors upgrade.
- Phase balancing client redistribution.

CONCLUSIONS

The MONICA Project implements a State Estimator in MV and LV networks in Smartcity Málaga Living Lab, involving two HV/MV Primary Substations, fifty-nine MV/LV Secondary Substations and more than nineteen-thousand end users equipped with smart meters. The hundreds of sensors and thousands of meters deployed provide data to be handled by the State Estimator, in addition to the present topology characteristics of the network, to generate daily more than seven million results with a 93.5% success rate in the calculations carried out. Apart from determining accurately the disaggregated technical energy losses, around 2% and 3% in this network, a useful set of alarms let DSO operators prevent severe incidents by means of early notification of congestion levels, deviations in voltage or unbalance in technical parameters. This let execute preventive actions on field in advance, as fuse upgrade or clients redistribution, avoiding potential risks and optimizing the quality of service provided to the end users.

REFERENCES

[1] A. Abur and A. Gómez-Expósito, Power System State Estimation: Theory and Implementation. New York: Marcel Dekker, 2004.

[2] Gómez Expósito, Antonio; De la Villa Jaen, Antonio; Cruz Romero, Pedro Luis; Carillo, S. ; Leiva, J., et. al., 2017, "State estimation based evaluation of distribution network losses: challenges and limitations", *IEEE PES General Meeting 2017. Chicago (EEUU).*

[3] Gomez-Quiles, C.; Gomez-Exposito, A.; de la Villa Jaen, A.; "State Estimation for Smart Distribution Substations" IEEET Trans. on Smartgrids, Special Issue on "Applications of Smart Grid Technologies on Power Distribution Systems", vol.3 (2), pp. 986-995, June 2012.

[4] Gómez Expósito, Antonio; Gómez-Quiles, Catalina; Izudin Dzafic, 2015; "State Estimation in two time scales for Smart distribution systems", *IEEE SG.*

[5] Carmona Delgado, Cristina; Romero Ramos, Esther; Riquelme Santo, Jesús; 2013,"Fast and reliable distribution load and state estimator", *Elsevier, Electric Power System Research,* vol. 101, 110-124.

[6] de la Villa-Jaen A.; Cruz Romero, P.; Gómez Expósito, A.; "Substation data validation by a local three-phase generalized state estimator", IEEE Transactions on Power System, Vol 20 (1), pp. 264-271, Feb. 2005.

[7] Heydt, G.T., "The Next Generation of Power Distribution Systems," Smart Grid, IEEE Transactions on , vol.1, no.3, pp.225,235, Dec. 2010.