ONLINE MONITORING LEADS TO IMPROVE THE RELIABILITY AND SUSTAINABILITY OF POWER GRIDS

Doina Vornicu
CEZ Romania - Romania
doina.vornicu@cez.ro

Laurentia Predescu
CEZ Romania - Romania
laurentia.predescu@cez.ro

Alessandro Mingotti
University of Bologna - Italy
alessandro.mingotti2@unibo.it

Lorenzo Peretto
University of Bologna-Italy
lorenzo.peretto@unibo.it

ABSTRACT

The paper aims to address the concept of virtualized grid automation. This approach will be developed within CEZ Romania ongoing EU H2020 project entitled "Service Oriented Grid for the Network of the Future – SOGNO", by combining the application of data visualization techniques, sensor analysis tools, advanced energy measurement and ICT technologies to ensure the visibility and control of electricity grids. The development of advanced distributed processing solutions will solve time-critical issues.

INTRODUCTION

Distribution system operators (DSOs) are, according to [1], "natural or legal person[s] responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area (…) for ensuring the long-term ability of the system to meet" the electricity demand of "end-users [connected to the medium-voltage grid (MV) and the low-voltage grid (LV)] in a secure, reliable and efficient manner".
In order to benefit from current developments, DSOs are required to build up new grid data processing capabilities and to scout new possible solution such as the one developed in [2, 3].
CEZ Romania wants to monitor online the distribution network for the grid operation optimization at MV and LV. This way, with the support of real-time data, it will be able to remotely optimize the operations.

Fig. 1 MV sensors, provided by ALTEA, installed at the MV busbars of a power transformer

CONCEPTS AND APPROACH

In SOGNO project CEZ is responsible of different field trials. In which, a set of advanced sensors connected to Phasor Measurement Units will be deployed in the MV

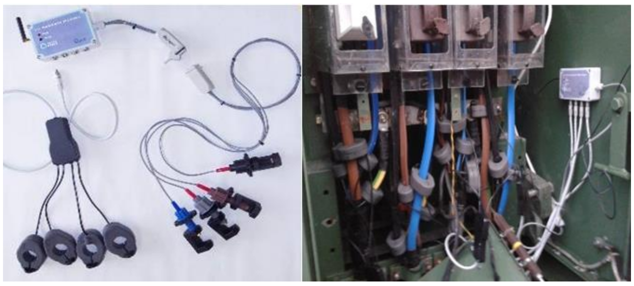

Fig. 2 LV sensors, provided by MAC, installed at a 4-feeder LV network

and LV networks (see Fig. 1 and Fig. 2). Such measurement units will send measurement information to the service server located at the DSO premises by using available communications networks and 5G.
Appropriate control room displays will be connected to the in-field setups to display the results of the data analysis (data stream coming from the sensors).

<u>Preparing for the Future</u>

The recent evolutions and requirements in power networks such as: the penetration of the renewable energy sources, the variety of a new equipment connected to the network, the prosumers and aggregators appearance, the users' participation in the electricity market, the conditions for bidirectional circulation of energy flows, inclusion of energy storage systems in the electricity network, etc., represent big challenges for DSOs.
Up-to-date electricity distribution management must feature adaptability, intelligent grid operation with proactive voltage and Distributed Generation (DG) unit control, automatic fault recovery, automated reaction to unusual transient behaviour and real-time grid-monitoring driven by ICT-connected measurement devices [4].
By providing tools for monitoring, analysis, prediction, planning, control and automation, the DSO is supported to accelerate the transformation of today's power networks into smart grids.
The final goal is the improvement of the networks performance in order to become more flexible and resilient.
New functionalities are required for having a smarter and flexible DSOs in the future. The evolution of the energy

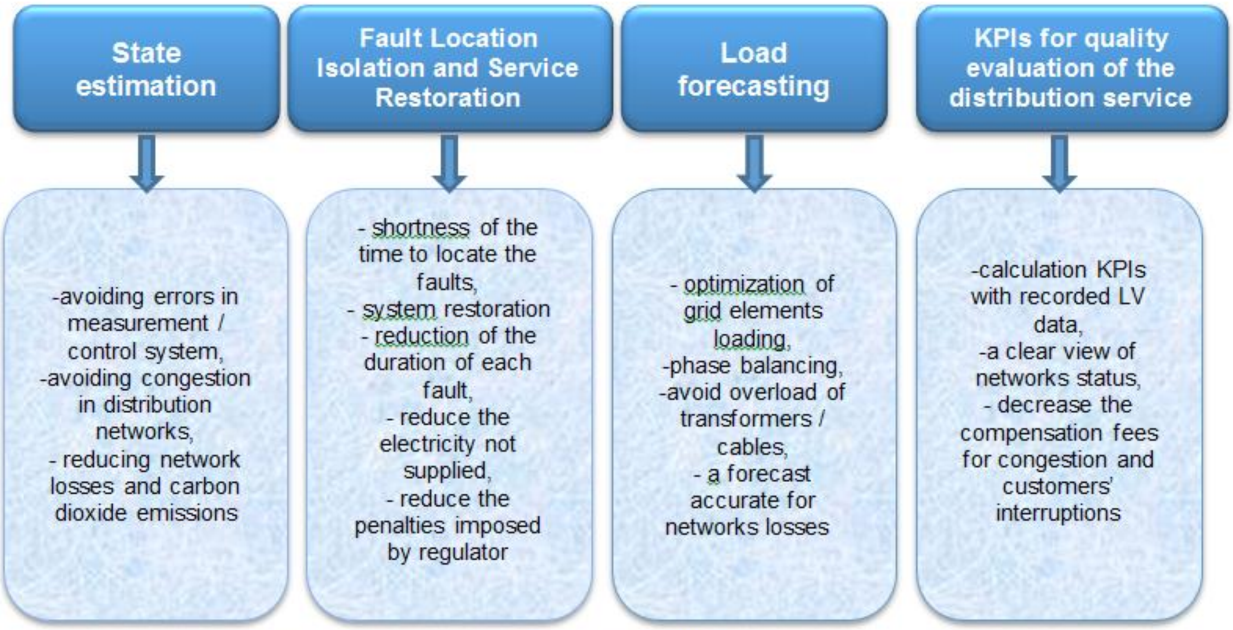

Fig. 3 - Services developed within the SOGNO project

sector is increasingly focused on energy as a service.
In light of the aforementioned, the main services tracked in the SOGNO project for development of DSO capabilities are detailed in the following and summarised in Fig. 3.

The State Estimation (SE) service allows the electric grid monitoring. The goal of SE is to provide the operating state of the network at a given instant of time by processing the measurement information collected by the measurement units deployed in the field. The monitoring data, output of the SE algorithm, can be used by grid operators to assess the and enhance the performance of their network and to detect possible anomalies in the grid operation. In addition, they can serve as an input for more complex management/control functions implemented by the DSO to operate their network more efficiently and in a reliable way. Other services that could use SE results information, include network topology reconfiguration, V/VAr control and, in a near future perspective, demand side management and demand response [5].
The SE service (see Fig. 4) relies as input on the information of the electric grid topology, the electric line parameters and the real-time measurements provided by the instrumentation deployed on the field. Given this set of inputs, the SE algorithm processes the received data to provide the most likely operating state of the network at the considered time instant (the same time at which the measurements are collected). Finally, the results of the SE algorithm are sent to a control room to give situational awareness to the DSO. SE results are usually also stored in a database for possible a posteriori analysis. For its operation, the SE service thus needs as input some important information of the grid characteristics, the deployed measurement infrastructure, as well as the real-time measurement data collected from the measurement

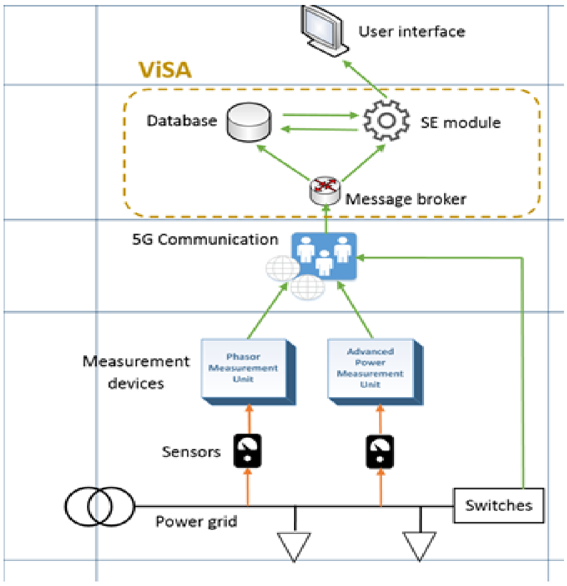

Fig. 4 Component layer of the SE Service developed in SOGNO

units in the field [6].
In detail, the power system input requirements can be differentiated between static data (i.e. fixed data that are not going to change at every SE run) and real-time data (i.e. data that change at each run of the SE service).
Static data input includes:
• Electric grid topology, which is the information about the different nodes and the connections (branches) among them in the grid.
• Electric grid parameters (e.g. impedances of the lines, data characteristics of transformers, etc.).
• Location of the distributed measurement systems (i.e. specific branches or nodes of the grid where the measurement devices are installed).

• Measured quantities provided by each measurement unit; in general, measurements useful for the SE service are: voltage, current, active/reactive power (either the flow on a branch or the consumption/injection at a node) and power quality information.
• Nominal data of the loads or generators connected to the grid.

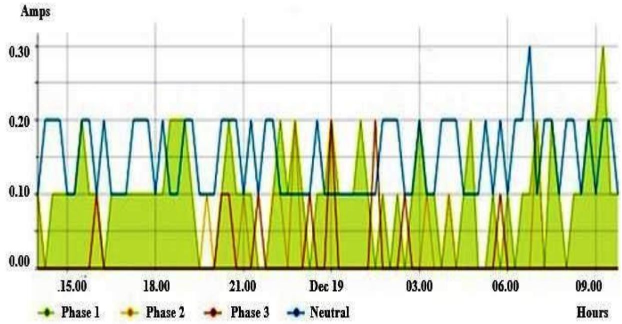

Fig. 5 The current measured by the sensors installed on CEZ LV OHL

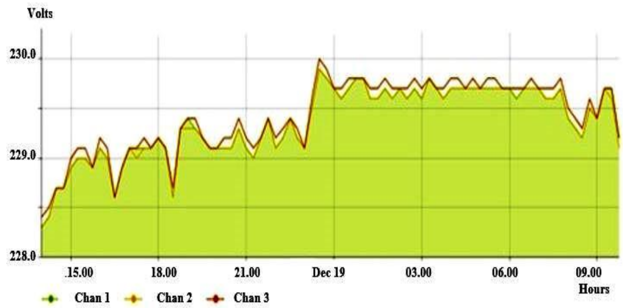

Fig. 6 The voltage measured by the sensors installed on CEZ LV OHL

Real-time data input includes:
• real-time values of the measurements provided by the deployed instrumentation.
• real-time notification of a change in the status of switching devices.

Afterwards, the estimated electrical quantities, **output** of the SE algorithm service, include:
• voltage magnitude and phase-angle at the different nodes of the grid;
• active and reactive power flowing in the branches of the grid;
• current magnitude and phase-angle at the different branches of the grid;
• active and reactive power consumption or injection at the different nodes of the grid [6].

In field, sensors and measurement devices are responsible of measuring the grid electrical quantities. Sensors for performing measurements of electrical quantities of the grid shall feature specific requirements in term of accuracy, bandwidth and time stability. In Fig. 5 and Fig. 6, we present some of the electrical quantities measured by the sensors mounted on CEZ LV networks within this project.
In the SOGNO project vision, measurements are transmitted to the cloud platform in the Virtualized Substation (ViSA) by using the 5G communication infrastructure. They are collected by a message broker which, in turn, forwards them to the different software and application modules. After estimating the grid state, the SE service pushes the SE output to the database. SE results are also sent to the control room of the DSO, where they are visualized to provide situational awareness to the grid operations.

The Fault Location Isolation and Service Restoration (FLISR) service (see Fig. 7) is devised to automatically handle the emergency conditions that follow a fault event. Moreover, it aims at limiting the interruption of the power supply to a relatively small number of customers as well as at providing helpful information on the location of the fault, allowing its search and resolution in a shorter amount of time. The FLISR algorithm is based on processing measurements, and other data coming from the field, after a fault occurrence, to pursue, sequentially,

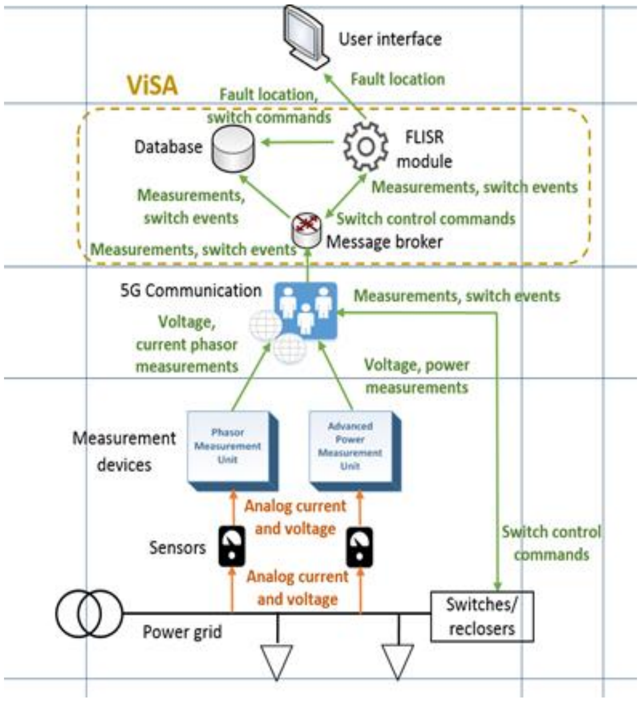

Fig. 7 Information layer of the FLISR Service developed in SOGNO

the following goals [7]:
i) location of the point in the grid where the fault occurred;
ii) isolation of the faulty section by opening the switches immediately upstream and downstream the fault;
iii) restoration of the power supply to all other customers connected to sections of the grid not directly affected by

the fault and out of the previously isolated area, again by opening or closing remotely controllable switches.

The FLISR service require, as input, both *static data* related to the grid topology, parameters and components, and *real-time* measurements associated to the fault occurrence:

• electric grid topology;

• electric grid parameters;

• location of all the grid components involved in the management of the faults or in the reconfiguration of the grid, such as circuit breakers, fuses, reclosers, sectionalizes and other switches;

• location of the measurement devices;

• knowledge about the measured quantities provided by each measurement unit; in general, measurement useful for the FLISR service are: voltage, current, power flow direction, acquired during the fault occurrence.

Real-time data include all or a subset of the following items:

• voltage at the different measurement points during the fault occurrence;

• current at the different measurement points during the fault occurrence.

• direction of the power flow or other fault indicators;

• information about the opening/closing event for any of the breakers/switches located in the grid.

Beyond the requirements related to the measurement chain, the FLISR service also requires bi-directional communication to allow the remote control of the switches, which is needed to apply the isolation and service restoration procedures identified by the algorithm. In fact, **the outputs** of the FLISR service are:

• location of the fault;

• switch control commands (opening and closing actuation commands) in order to guarantee the isolation of the faulty area of the grid and to restore the power supply back for all the other portions of the network. These actuation commands need therefore to be sent from the FLISR service to the switch components in the field as fast as possible to guarantee the minimum fault time of the grid.

The deployment of an automatic FLISR service has the potential to bring significant advantages to customers in terms of reduction of number and duration of the outages, as well as to DSO in terms of improvements of the indicators (like, for instance, the well-known System Average Interruption Duration/Frequency Index, SAIDI and SAIFI) associated to the reliability of the power supply and the continuity of the service.

Avoiding possible penalties applied to DSOs in case of high indicators on the provision of power supply to the end customers, the use of FLISR turns into a clear business case for the DSOs and for this reason it is one of the most critical and important services to be considered when designing a fully-automated distribution grid.

***The Load Forecasting (LF)* service** aims at predicting the future values of power consumption, in order to give to the DSOs the awareness on how the grid operating conditions are expected to evolve in the near future. This algorithm works by processing also the historical data on the power consumption of the customer, that is likely to affect the powerlevels (e.g. like weather conditions, temperature, etc.). The forecast given by the LF can refer to different time horizons and can have a different time resolution, according to the requirements of the DSO. As an example, day ahead forecasts (for example with a time resolution of 15 minutes) can be generated in order to predict possible contingencies and, in case, to be prepared to take adequate countermeasures. Day ahead forecasts could be refined by shorter-term forecasts, e.g. a forecast referred to the next hour, which in general could be more reliable since it can be based on more recent information on the grid status. This could be, for example, a solution to apply preventive control schemes aimed at minimizing the risk of problems in the grid.

On the other side, longer term forecasts (e.g. on a seasonal or yearly basis) are also possible and they can support DSO in planning and in taking strategical decisions for the grid reinforcement.

In summary, the data required **as input** to the LF service are:

• active and reactive power consumption measured at the customer or in the substations; data should cover a quite long period of time (months or years) to improve the accuracy of the forecasting;

• weather forecast data (irradiance, temperature, cloudiness, etc.) as input to the Generation Prediction service (forecast of the amount of energy to be produced in the near future).

The output of the LF service is the forecast of active (and if applicable reactive) power for the time horizon of the prediction with a given time resolution.

The evaluation of Key Performance Indexes (KPIs) is not a SOGNO service, but still they represent essential information for DSO. Hence, they have been considered and will be computed during the project. In addition, the use of 5G technology will increase significantly their usefulness.

KPIs provide in most cases an actual situation of the network's performance [6].

In summary, a KPIs measures and monitor the "continuity of supply", hence if or not the customers are being electrically satisfied.

It must be noted that:

- most of the time KPIs are a statistical parameters due to the shortage of measurements;
- continuity of supply definition strictly depends on the time of the interruption (real or presumed).

Database and Data Processing

For two areas in Romania, Olteni and Babaita, where, in the framework of the SOGNO project, pilots will be run. Data on interruptions occurred in MV and LV networks in 2017 are presented in Table 1. It contains all the indexes relevant to the interruptions occurred during the year.

Table 1. Olteni and Babaita interruption parameters during 2017

Grid Level	LV		MV	
Area	Olteni	Băbăiţa	Olteni	Băbăiţa
No. of unplanned interruptions	90	124	24	64
Mean 'No. Of clients affected/interruption'	1,26	1,62	901,25	818,42
Standard Deviation 'No. Of clients affected/interruption'	1,2	1,73	213,67	206,66
Minutes without electricity / client	15,66	30,27	2,93	3,35
No of penalized interruptions / year	20	36	5	3
Share of interruptions penalized	22,22%	29,03%	20,83%	4,69%
Penalty threshold (min)	240	240	240	240
Penalty Costs / client	6,50 €	6,50 €	43,10 €	43,10 €
Mean 'Duration of Interruption' (min)	172,75	216,51	46,37	46,37
Standard Deviation 'Duration of interruptions'	106,9	203,84	88,86	88,86

Value Creation by implementation of SOGNO Services

The SOGNO services will create value by improving the operational performance of DSO that is measured by KPIs.

There are five KPIs that are monitored in the network: SAIDI, SAIFI, Energy Not Supplied, Mean Average Interruption Frequency Index (MAIFI), and Average Interruption Time (AIT). CEZ is collecting input data from the sensors installed in all measurement points (end customers, secondary substations, etc..) as well as other transmission facilities in the SCADA model.

In SOGNO pilots the FLISR will contribute to decrease the “duration of unplanned interruptions”. In order to evaluate the effectiveness of FLISR, SAIDI and SAIFI will be evaluated. For DSO, in which the ‘duration of unplanned interruptions’ is subject to regulatory rewards or penalties, also the monetary value of FLISR will be quantifiable.

SE service evaluates power losses in the grid by measuring voltage and currents phasors in the nodes and branches of the electric grid. This directly provides the DSO’s the understanding of the grid and, in particular, the understanding of loss reduction possibilities and facilitates corresponding planning activities.

LF service directly will provide to the DSO’s situational awareness regarding potential issues in the grid, yielding to an enhancement in the planning of corresponding countermeasures. In particular, the accuracy in day-ahead load and generation forecasting will be increased.

CONCLUSIONS

DSOs will need turnkey solutions to monitor the real-time dynamic stability of their power networks.

The implementation of SOGNO project will allow the company to manage the resources more efficiently in order to reduce the operational costs and better manage the capital expenditures. Furthermore, improving the monitoring of the grid will provide more awareness of the grid status, allowing CEZ to have its full control.

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