Development of highly secure and reliable power grid

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Abstract: The recent radical transformation of the network has altered the management challenges faced by distribution system operators. For this reason, they are always searching for fresh, clever ideas to apply on their networks in order to get accurate and comprehensive data for quick, effective grid management. This article presents a real-world case study in which the CEZ Romania networks served as a test bed for impromptu, cleverly constructed network control solutions.

1 Introduction

The renewable energy sources (RESs) [1–3] penetration and the spread of new actors like intelligent electronic devices, storage systems [4, 5], and measurement systems among the medium voltage (MV) power networks complicated the way in which they are managed by distribution system operators (DSOs). Consequently, system operators require solutions that may support their control and management of the network, considering the presence of such new actors among the grid. For example, several algorithms can be found in literature concerning: (i) synchronisation of electrical quantities [6, 7], (ii) state estimation (SE) [8, 9], fault location [10, 11] etc.

For this purpose, CEZ Romania and the University of Bologna are involved in the European Union (EU) project called 'Service Oriented Grid for the Network of the Future – SOGNO'. The project is the perfect chance to solve the DSO's need for innovation and smart solution for the typical network monitoring activities. During the project, data visualisation techniques, sensor analysis tools, advanced energy measurement and information and communication technologies – to ensure the visibility and control of electricity grids – have been developed to provide complete monitoring solutions to DSOs.

From the specific point of view of CEZ Romania, the aim is to implement online monitoring of its MV and low voltage (LV) distribution networks. In addition, the second goal is to collect sufficient information from the grid to enable the real-time active management of the network operations.

In this work, after a brief description of the SOGNO project, a section is dedicated to introduce the Romanian area involved in the project trials and to the services implemented and running in power networks involved. Afterwards, comments and lesson learnt during the project are presented.

2 SOGNO (Italian word for 'dream')

The SOGNO project aims to respond to DSO's growing needs to have a real-time perspective on the functioning of their networks and to be able to remotely optimise their operations by using new data analysis techniques. SOGNO also offers viable and innovative solutions to DSOs in order to increase their flexibility and move from a capital expenditure (CAPEX) to an operating expense (OPEX) type of investment.

The services developed within the SOGNO project are very useful to the distribution operator. The results of the project will include a set of tools for monitoring the DSOs' networks, by combining the application of deep intelligence techniques, industry-grade data analysis and visualisation tools, advanced sensors, an advanced power measurement unit and 5G-based ICT to provide fine-grained visibility and control of both MV and LV power networks using end to end automation in a virtualised environment.

3 Smart solutions for resilient distribution networks

Distribution network

One of the CEZ Romania companies is 'Distributie Energie Oltenia (DEO)'. DEO is one of the main distribution operators in Romania and provides electricity supply to >1.4 M customers.

Market share for DEO was ~15% in 2019 considering distributed energy in Romania.

The common view of CEZ and DEO is that a project like SOGNO should provide:

† Continuation of development, modernisation and refurbishment action of the electricity distribution networks.
† Support of research and development activity and dissemination of research results applicable.
† Further measures to reduce the negative impact of the energy sector against the environment towards rehabilitation of affected areas and restoring the natural environment.
† Introducing energy-efficient technologies, modern systems of measurement and control, energy management system for monitoring, continuous assessment of energy efficiency and forecasting consumption.

The above points are supported by the fact that, in the current state of things, it is not possible to have good monitoring systems for LV networks and platforms able to support the complete set of services for secondary-substation automation in distribution systems.

To implement the SOGNO services, we have chosen appropriate areas for the pilot projects. These areas have a high density of customers, especially connected to the LV network, high electricity demand, and a balance between non-household and household customers. As for the household customers, they are equipped with smart devices.

Among the reasons that lead us to choose these are there is the fact that the number of faults is high, hence it is necessary to better monitor the functioning of the network. This could lead to improve the quality indicators of the electricity distribution service.

Finally, it is expected that such areas will experience, in the near future, huge penetration of RES; hence, DEO will require a new perspective for the control and management of the network. In Fig. 1 a picture of the considered Romanian area is depicted.

Smart solutions

Within the SOGNO framework, several services have been developed and tested. Each DSO of the project, according to its needs, decided which of them will be tested in its facilities.

As for CEZ, we selected: SE, fault location isolation and service restoration (FLISR) and load forecasting (LF).

State estimation: SE service allows electric grid monitoring. The goal of SE is to provide the operating state of thenetwork at a given instant of time by processing the measurementinformation collected by the measurement units deployed in the field. The monitoring data and output of the SE algorithm can be used by grid operators to assess 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 its network more efficiently and in a reliable way.

Fault location isolation and service restoration: The FLISR algorithm is based on processing measurements, and other data coming from the field, after a fault occurrence, to pursue, sequentially, the following goals:

† Location of the point in the grid where the fault occurred.
† Isolation of the faulty section by opening the switches immediately upstream and downstream the fault.
† Restoration of the power supply to all other customers connected to sections of the grid not directly affected by opening or closing remotely controllable switches.

Load forecasting: This procedure is considered to be a regression problem solved using collected data from the grid and aims to find the functional relationship between load parametersand network parameters.

In general, deep convolutional networks are suitable for complex regression analysis which can be used for LF.

The benefits are:

- Optimisation of grid elements loading and phase balancing.
- Avoid overload of transformers/cables.
- A forecast as accurate as possible of networks losses.

Fig. 1 *Picture of the area considered for the first SOGNO pilot project*

- Can be used to evaluate the evolution of customer consumption.
- It is important to forecast generation from renewables.

Results

State estimation: The SE service is completely active and running in CEZ networks. Some of the results, taken from measurements on an LV network, are presented in Figs. 2 and 3.In Fig. 2, the voltage, current, and frequency of the three-phase system monitored are depicted. The time interval of the measurements is one day, and each set of quantities is updated every minute. In Fig. 3 instead, apparent, active, reactive powerand power factor are shown, for each phase. Both set of information described in Figs. 2 and 3 are used as input quantities for all services developed in SOGNO. Therefore, in Table 1 the

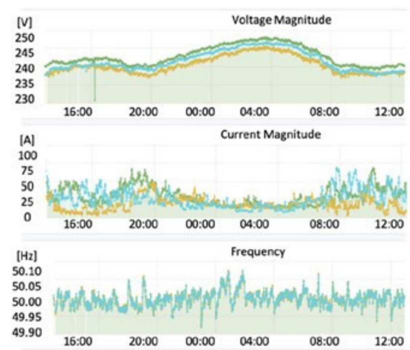

Fig. 2 *Voltage, current and frequency measured in-field at a three-phaseLV system*

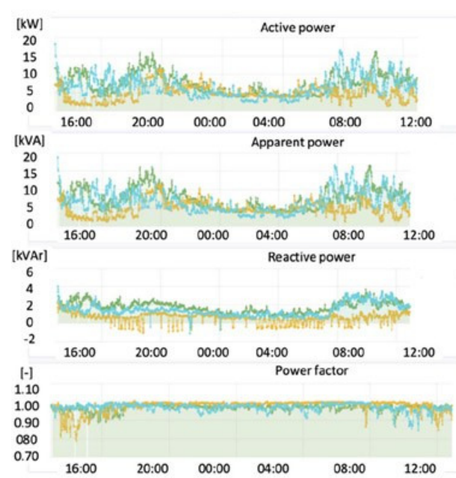

Fig. 3 *Computed values of apparent, active, reactive power and power factor of a three-phase LV system*

Table 1 SE results in terms of voltage amplitude and phase, for someof the monitored nodes in an LV network

Node	Amplitude, V			Angle, deg.		
	Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
1	220.09	223.93	205.78	−42.28	−157.62	85.77
2	224.60	223.58	208.45	−42.51	−157.16	85.54
3	222.85	223.59	205.36	−41.60	−157.16	85.71
4	222.57	224.38	207.50	−42.23	−157.33	85.49
5	221.16	225.25	210.95	−42.28	−157.51	85.71
6	221.09	224.60	209.54	−42.34	−157.22	85.66
7	220.84	223.92	209.07	−42.06	−157.39	85.26

results of the SE algorithm are presented. Note how for each node of the considered network the amplitude and the phase of the voltage are collected. Then, a colour code is adopted to immediately inform the DSOs of issues on the grid. When all parameters are within the limits, the green colour is associated with the nodes, otherwise, orange and red are used for troublesome values associated with the voltage.

With the same notation adopted for Tables 1 and 2 collections of some of SE results gathered from an MV network is done.

It is worth to highlight that, after the implementation of SE service on the CEZ power networks, it has been possible to manage the network faster than before. Furthermore, several power network issues have been solved immediately after their detection with the SE service.

Fault location isolation and service restoration: This service is being implemented in the second SOGNO pilot project of CEZ Romania. The single-line diagram of the networks is presented in Fig. 4. All the switches are equipped with remote terminal units, to be able to receive remote operational commands (open/closed) when a fault in the network is detected.

With the implementation of this service, CEZ aims to decrease SAIFI and SAIDI indices. Furthermore, with FLISR, CEZ will reduce the electricity not delivered to consumers and the penalties imposed by the regulatory authority. Therefore, there will be benefits for both the involved parts, DSOs and customers.

Preliminary in-field tests are confirming the validity of FLISR, the effectiveness of which has been verified in the first part of SOGNO with laboratory simulations and testing.

Load forecasting: The LF service is taking more time thanthe other services due to the required inputs. As a matter of fact, all the data collected from the grid, as depicted in Fig. 3, is being collected and evaluated by the LF software to train artificial intelligence. Once there will be sufficient data, the LF algorithm will predict the demanded load with a variable time resolution. Finally, it will be implemented in the same network where SE is running, in order to compare the predicted loads with actual in-field measurements.

Table 2 SE results in terms of voltage amplitude and phase, for someof the monitored nodes in an MV network

Node	Amplitude, kV			Angle, deg.		
	Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
1	11.97	11.90	12.10	−0.83	−120.04	119.73
2	11.97	11.93	12.11	−0.72	−120.04	119.77
3	11.97	11.92	12.10	−0.70	−120.03	119.77
4	11.99	11.97	12.13	−0.52	−120.03	119.84
5	11.96	11.81	12.03	−1.25	−120.05	119.61
6	11.96	11.86	12.06	−1.01	−120.04	119.69
7	11.96	11.80	12.02	−1.28	−120.05	119.61

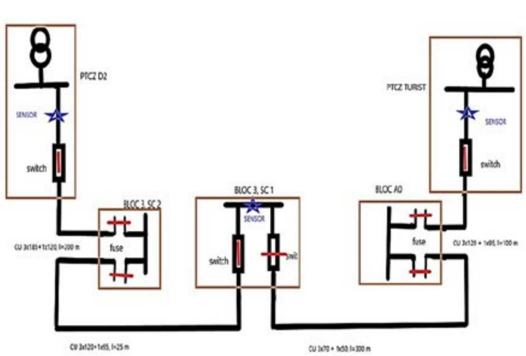

Fig. 4 *Single-line diagram of the portion of the network in which the FLISR service is tested*

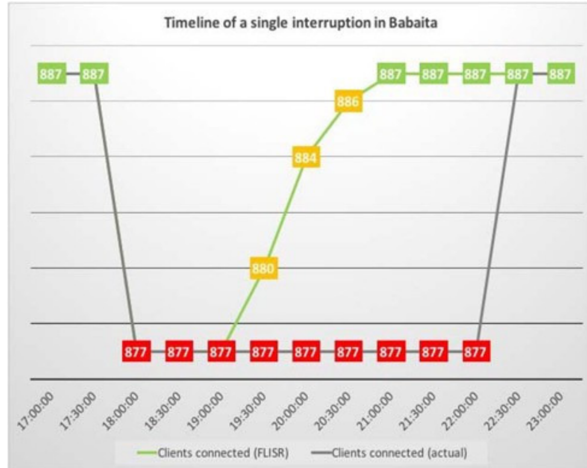

Fig. 5 *Case study on improving indicators performance of the distribution service developed in SOGNO*

4 Power quality evaluation

A case study analysed within the SOGNO project, based on the data provided by CEZ Romania, shows the improvement of the performance indicators of the distribution networks, following the implementation of the FLISR service, in the area related to the pilot project Babaita (see Fig. 5).

5 Conclusion

This work presented some of the advantages that new solutions and distributed measurement system may introduce for network monitoring.

Of course, there are and there will be issues in the implementation of such breakthrough solutions due to the technical difficulties and the physical limitations of the network.

However, it is clear that new monitoring systems and innovative solution may help the huge efforts of DSO in the control and management of power networks that are evolving day-by-day including a variety of new actors.

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