SMART RURAL GRID

Ramon Gallart Fernández
Head of Innovarion in EyPESA

Santiago M. Farrero
CEO in EyPESA

Luisa Candido
Innovation Assistant in EyPESA

ABSTRACT

Distribution System Operator (DSO), as well as many types of multi-utilities around the world, are rolling out what is known as the Smart Grid (SG), either by a legal mandate or because the technology is ready and sufficiently mature for a deployment of this magnitude. Another driver of this transition consists in the opportunity to create new business models, that will bring benefit to the companies involved in this technological challenge.

An SG is an electricity network that can integrate profitably the behavior and actions of all users connected to it, such as generators, consumers and prosumers, to ensure an economically efficient and sustainable energy system with low losses, high levels of quality, and safety. The Smart Rural Grid project, has sought to make a clear definition of the stakeholders involved, trying to clarify what are the expectations of the society and what the risks., This investigation has resulted in a proposition: to avoid another Digital Divide between urban and rural citizens, due to a partial or complete lack of access to Information and Communication Technologies (ICT), of a part of the population. This project emerges to meet these challenges and it also helps to respond to the different technical and operational issues in the particular case of rural networks, taking advantage of the convergence between electricity and telecommunication networks. It also examines the best way to make the transition from the current rural distribution network to a new electricity grid using smart technologies, while always considering new possible business concepts, associated with this new paradigm, and with a robust environmental awareness and a solid social responsibility.

INTRODUCTION

The Smart Rural Grid (SRG) project arises to respond to the farms owners connected to the grid and concerned about the particular case of electrical rural networks. In this sense, the SRG project explores and shows how to exploit the convergence between electricity and telecommunications networks. The purpose of this work is to show how electricity distribution companies can operate more distribution energy resources, while interconnecting energy prosumers in order to allow a multi-directional electric flow. It also examines the best way to make the transition from the current distribution of rural electricity grid to a new electrical framework, with SG technologies, without economic losses.

The SRG project, that was financed with European funds, defines a new architecture for smart rural networks. The pilot study was implemented in a part of the distribution network of Estabanell and Pahisa Energía (EyPESA) in Vallfogona del Ripollés, Catalonia, Spain. EyPESA, combines the functions of DSO and those of energy retailer. The project consortium was led by EyPESA in collaboration with: (i) CITCEA, which is dedicated to research, innovation and technology transfer to the industry in the fields of mechatronics and enertronics; ii) ZIV Communications, which is a Spanish manufacturer with a complete range of communications systems Power Line Communications (PLC), digital protection and control equipment for high and medium voltage power networks iii) Xarxa Oberta de Catalunya (XOC), which provides fiber optic services in Catalonia; (iv) KISTERS (Germany), which offers leading technological solutions in advanced software for the energy market; (v) SWRO, which distributes electricity, gas, water and district heating in Rosenheim, Germany; (vi) Crompton Greaves Automation (CGA), which is a leading Irish provider of control and automation solutions, services and products for monitoring and control of transport and distribution networks in various market sectors, that carried out system integration and, finally, (vii) SMARTIO, which is a group of Norwegian academic companies and institutions, which carried out the dissemination of the SRG.

Thanks to the SRG consortium's experience, the project has developed a set of devices and services for energy management, that helped to achieve the objectives of the smart rural network pilot. These cutting-edge technologies aim to increase the interoperability, resilience, and efficiency of the existing rural distribution network, through the use of new SG technologies: i) Intelligent Distribution Power Router (IDPR); (ii) new PLC technology for a rural distribution network; (iii) a solid communications network that allows management between distributed energy resources and the IDPR; iv) a data management system based on time series that manages the local energy micro-production as well as the IDPR.

PROJECT DESCRIPTION

The SRG project is validated on a real rural distribution (RD) network, presenting potential for efficiency improvement, particularly with regard to sub-supply. The RD corresponds to the final segment of the 5-kV distribution grid in a rural area of the EyPESA network. EyPESA [1] is a Distributor that operates in Catalonia (Spain) and has more than 56,000 suppliers points connected in its network along its 1,500 km of lines. The

main peculiarity of the EyPESA network is that around 50% of the network is deployed in a rural environment where more than two thirds of the clients are from the domestic and service sectors.
This network corresponds to an area with low population density, with only 25 clients distributed in four Secondary Substation (SS), as shown in Figure-1. It is characterized by a non-automated radial infrastructure, where human action is required for the operation, by means of manual disconnectors and fuses. In addition, in this region, access to the infrastructure and detection of faults result complicated because the medium voltage lines of the network cross valleys and mountains and they are exposed to adverse weather conditions. In the upper right-hand corner of Figure 1, the electrical diagram of the network is represented. Low-Voltage (LV) networks provide electricity to customers scattered throughout the rural area. Each one of them is equipped with a smart meter.

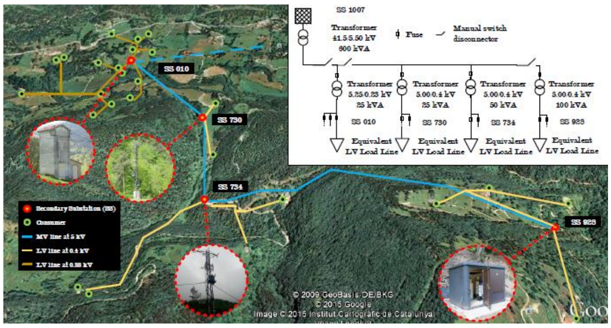

Figure 1 Network in the Smart Rural Grid pilot area.

METHODOLOGY

The biggest challenge of the SRG project [2] has been the development of an IDPR. This device is composed of an innovative energy conversion system based on power electronics. The IDPR allows for further integration of distributed generation, renewable sources, residential and industrial consumptions and electrical vehicles (EV) in the distribution systems. In addition, it favors the integration of energy storage devices and, finally, it improves the quality of service and the network support. The IDPR is designed to be connected in parallel with the low voltage network and also with an energy storage device (see Figure-2).

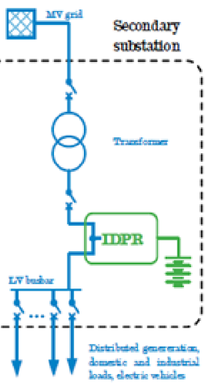

Figure 2 IDPR.

In terms of performance, the power stage implements an extremely compact topology, with a new, highly efficient silicon carbide semiconductor transistor. In addition, the IDPR control system is easily managed by the DSO through set points.
After implementing the innovative network architecture and addressing the adoption of new tools and technologies, the pilot's network has been transformed, resulting in the scheme of Figure-3.

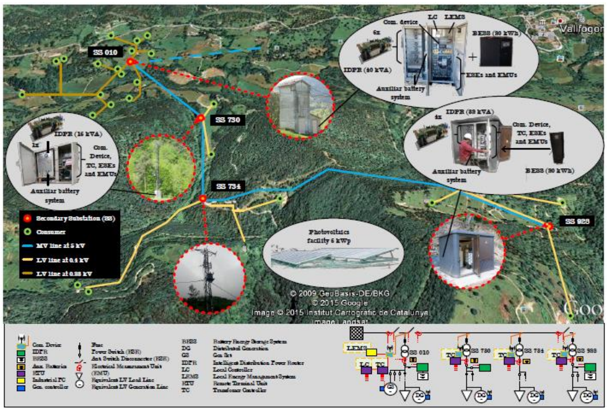

Figure 3 Final architecture.

The presence of renewable generation in electrical networks is gaining more and more importance [3]. The growth of DG will improve security of supply to customers and increase the energy efficiency of the network. Therefore, it is necessary to introduce new protection devices that permit to isolate only part of the electricity grid in case of a critical event. Moreover, modern rural networks require a certain degree of flexibility to offer new electrical configurations and new modes of operation. For instance, the isolated operation and the automatic reconnection of some parts of the network should be allowed, in case of faults, incidents or congestion issues. For this reason, the low voltage lines must be managed independently in order to energize these islands through the local energy resources and storage.

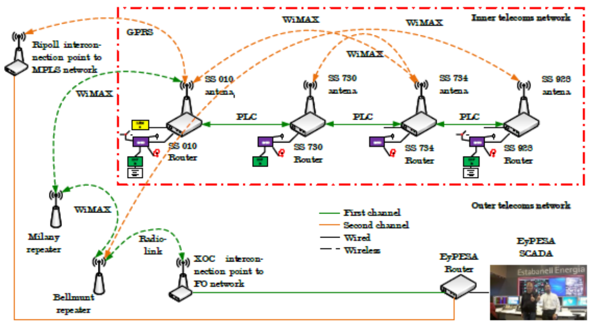

Figure 4 Telecommunications infrastructure

The SRG project also explores the convergence between electricity and Telecommunications Networks (TN) (Figure-4), with the objective of guaranteeing the integration and management of DG, battery resources and new protection and control devices through Remote Terminal Units (RTU). This infrastructure is made up of two differentiated environments: a local TN based on

WiMAX technology [4] and PLC technology and a second access i, based on WiMAX technology and fiber optic (FO) technology, which makes it possible to establish communication between the SSs and the control room (COX) of EyPESA as well as offering broadband in rural areas that are not covered by telecommunications operators.

In order to effectively manage the network, various agents are defined, which interact with each other through the exchange of data and commands. From a bottom-up approach, the management hierarchy is configured by the Transformer Controller (TC), the Local Controller (LC), the Local Energy Management System (LEMS), the SCADA and, finally, at the top of the structure, there is the Global Energy Management System (GEMS) [5] The hierarchy and relationships are represented in the Figure-5.

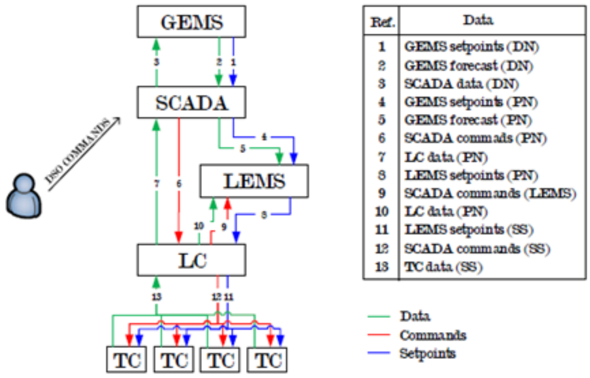

Figure 5 Management hierarchy

OUTCOMES

In this section, the behavior of the IDPR in the low voltage network has been described. From the COX of EyPESA, the IDPR is managed, as well as the set of elements that structure the pilot.

However, to check the instantaneous values of voltage and current, an oscilloscope has been used to record data with better quality, and the data obtained have been analyzed with mathematical software (Matlab). Next, the situations in which the IDPR [6] interacts with the DSO are shown in the following cases: (i) IDPR balances the currents of the active phases and compensates the power; (ii) the IDPR cancels harmonic currents; iii) combines cases (i) and (ii) and delivers 12 kVAR to the network. The low voltage waveforms are shown on the left side of Figure-6 and the currents are displayed on the right side. Regarding the voltage case, it can be seen that all the waveforms are sinusoidal and around 230 V phase-to-phase. However, observing in detail the voltages of Figure-6 (a) and Figure-6 (c), a voltage variation of 2.5 V is observed (considering all phases). This value can be used to calculate the network impedance module. In another case, on the waveforms of Figure-6 (b), it can be deduced that when the balancing function is disabled, the rural network presents important currents imbalances. Therefore, the IDPR helps reduce asymmetric losses. On the other hand, it should be noted that although in Figure-6 (a) the IDPR is balancing the currents of the network, it is also possible to observe irregular peaks. This is the typical effect on the loads of rural end-users. Finally, in order to validate with the commonly used criteria the capacities and contributions of the IDPR on tension and the Total Harmonic Distortion (THD), the Power Factor (PF) and the degree of disequilibrium (DU) of the currents are calculated by contrasting cases (i) and (ii). After the compensation of the harmonic current the obtained values are better, around 1.5%. However, the current THD has a significant impact on the THD value of the voltage.

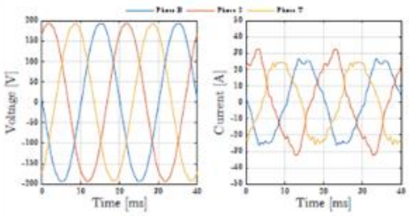

Figure 6 Case (i)

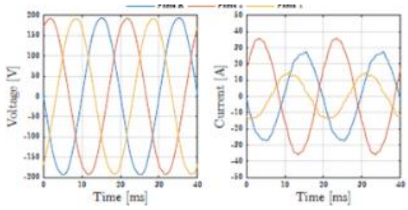

Figure 6 Case (ii)

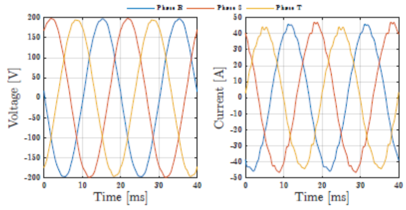

Figure 6 Case (iii)

Table I shows the THD values of voltage and current, Table II shows the values of the power factor (PF) and finally Table III shows the initial and final DU. It is remarkable how the IDPR allows to properly balance the network currents.

Table I Voltage & current THD

	Phase R	Phase S	Phase T
Initial Voltage	1.66%	2.52%	2.09%
Initial Current	12.42%	17.09%	15.83%
Final Voltage	1.46%	1.50%	1.50%
Final Current	6.44%	6.54%	6.77%

Table II Power factor

	Phase R	Phase S	Phase T
Initial	0.9949	0.8380	0.6005
Final	0.9999	0.9982	0.9910

Table III Imbalance factor

	Phase R	Phase S	Phase T
Initial	35.5%	46.3%	18.2%
Final	33.6%	34.0%	32.4%

One of the results on the correct functioning of the network in island mode, can be seen in Figure-7, where it is possible to observe the stability of the micro-network connecting loads to the IDPR.

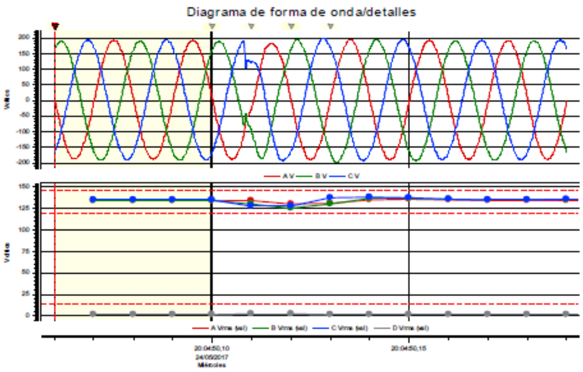

Figure 7 Island mode wave forms

CONCLUSIONS

This technological development allows migrating towards smart grids from the existing electricity grids, so it has an important impact on society. In rural areas there is a risk of being disconnected from the Intelligent Network and not having the possibility of taking advantage of the new business models provided by digitalization. This phenomenon is known as the Digital Division.

The Smart Rural Grid project has developed special tools and technology to overcome these technological and social challenges. The IDPR is an innovative versatile device based on power electronics, which allows rural networks to operate in different operating modes over a traditional radio network. This introduces new degrees of freedom in the operation of these networks, such as the quasi-grid concept, understood as a virtual infrastructure that is composed of the mentioned technology, offering the possibility of supplying power to users in case of an incident in the headers of the network, without the need to build new infrastructures such as medium voltage power lines, with the environmental impact that this implies. In addition, thanks to the architecture based on distributed intelligence dispersed in the area and through the DSO own network, it is possible to make various network configurations. Given its variability and flexibility, it has been called a dynamic network of micro-networks, allowing electric distributors to find solutions to avoid the consequences of blackouts, natural disasters, overloads and, at the same time, improve the quality of energy, between others. In addition, it facilitates new business models based on a local approach. The solution based on the IDPR should be integrated with a telecommunications network, taking into account the special locations of these rural areas, so that the challenges of bandwidth and long distances can be overcome, as well as their complete integration into a system of SCADA control for decentralized operation.

REFERENCES

[1] "Estabanell Energia, Els orígens d'Estabanell Energia." 2016.

[2] F. Girbau-Llistuella, A. Sumper, R. Gallart-Fernandez, and V. Buehner, "Operation of rural distribution grids with intermittent generation in connected and island mode using the open source EMS solver SCIP," in *2015 International Conference on Renewable Energy Research and Applications (ICRERA)*, 2015.

[3] "Project Deliverables - Smart Rural Grid project," 2016. [Online]. Available: http://smartruralgrid.eu/archive_category/project-deliverables/. [Accessed: 10-Apr-2016].F. Girbau-Llistuella, F. Díaz-González, A. Sumper, and R. Gallart-Fernández, "Smart grid architecture for rural distribution networks: application to a Spanish Pilot Network."

[4] J. G. Andrews, A. Ghosh, and R. Muhamed, *Fundamentals of WiMAX: understanding broadband wireless networking*. Pearson Education, 2007.

[5] M. M. Rodriguez-Bernuz, E. Prieto-Araujo, F. Girbau-Llistuella, A. Sumper, R. Villafafila- Robles, J.-A. A. Vidal-Clos, P. Joan-Marc Rodriguez-Bernuz, E. Prieto-Araujo, F. Girbau- Llistuella, A. Sumper, R. Villafafila-Robles, and J.-A. A. Vidal-Clos, "Experimental validation of a single phase Intelligent Power Router," *Sustain. Energy, Grids Networks*, vol. 4, pp. 1–15, 2015.

[6] D. Heredero-Peris, C. Chillon-Anton, M. Pages-Gimenez, G. Gross, D. Montesinos-Miracle, and others, "Implementation of grid-connected to/from off-grid transference for micro-grid inverters," in *Industrial Electronics Society, IECON 2013-39th Annual Conference of the IEEE*, 2013, pp. 840–845.