ENEL SMART INFRASTRUCTURE FOR THE REMOTE CONTROL AND AUTOMATION OF LV GRID

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ABSTRACT

In the last years the grow of Distributed Generation systems has allowed the changeover from a "passive" to an "active" Low Voltage grid. This new configuration of LV grid needs the use of smart grid devices able to improve the grid management and the quality of service. This paper presents the design and the development of a Smart Infrastructure based on Remote Terminal Unit and on a Remote Control System for several applications in LV grid.

I. INTRODUCTION

The Low Voltage (LV) distribution grids are based on a traditional centralized structure, where energy flows from generation plants to customers. In this case, the transmission and distribution systems are unidirectional. In the last years the concept of electrical power system is changing. The increasing demand of energy, the power supply reliability, the integration of distributed generation systems (DG), the management of unpredictable power flows, cannot easily be met by existing network infrastructure [1]-[7].

In fact, the "classic" Low Voltage distribution grid is usually not structured to make it possible to know the real time grid status in terms of power flow.

A smart grid**,** instead, is a electrical grid where analogue and digital data are collect from the field by electronic devices and by wider communications technology to gather information, including information about the behavior of customers, in an automated mode, used to improve the efficiency, reliability, economics and sustainability of the production and distribution of electricity [1]-[4].

The smart grid can be considered a modern electric power grid infrastructure for enhanced efficiency and reliability through automated control, high-power converters, modern communications infrastructure, sensing and metering technologies and enables modern energy management techniques for the optimization of demand, energy and network availability. The concept of Smart Grid has led Enel to design a new infrastructure for the LV grid management based on:

- Low Voltage Remote Control Center (LV-RCC);
- Multi carrier communication system;
- Smart Remote Terminal Unit (S-RTU);

The new idea that Enel introduces in its own LV grid it is the presence of a remote controlled grid node. This paper, in particular, presents the design and the development of S-RTU and LC-RCC for several applications in a on-field test project. The primary functions of S-RTU are the controlling and the acquiring of data from the field and the transferring of these data back to the Enel LV-RCC. With the S-RTU it is possible to monitor and to send to the LV-RCC various filed quantities (e.g. voltage, current, temperatures, switch status, etc.). The S-RTU device is applied, also, for local voltage and current analyzing for automatic fault isolation and restoration, by using different automatic methods [1]-[7].

The LV-RCC system allows to integrate the functions of supervision, remote management, event history and data storage. The LV-RCC system is unique in the current landscape of remote control systems.

The presents paper investigates all these topics. It is organized as follows: Section II discusses the system design requirement; Section III describes the Low Voltage Remote Control Center (LV-RCC). Section IV is focused on applications and future works.

II. SYSTEM DESIGN REQUIREMENT

The S-RTU system is used to improve the management of the LV grid. From one hand it is useful to improve the quality of service, because it reduces electrical outages with its automation functions, and from the other hand it allows the real time measurement and state communication from the field to the LV-RCC. The S-RTU will be installed into the junction boxes of the LV lines. In order to achieve the functions of measurements, switching, remote control and automation, the S-RTU is composed by the following main components:

- Protection, disconnection and measuring;
- Micro peripheral unit (µUP);
- Supply;
- Communication;

The S-RTU architecture is presented in Fig.1. The macroblocks are defined as follows:

Protection, disconnection and measuring: this macro-block defines all the components that they are able to provide the electrical continuity between input and output, as well as the disconnection and isolation through motorized breakers or disconnectors. This macro-block include the device for the measurement of electrical values (voltage and current). The architecture allows to use motorized switches or disconnectors, as well as the use of measurement modules buil-in disconnect device or separated from. All the devices are remote controllable by ModBus standard communication.

Micro Peripheral unit (µUP): this macro-block represents the core or S-RTU. The µUP receives in input the measures and the states sent by the remote controlled breaker and the state of the power supply via ModBus standard. At the same time it is able to manage the open/close commands of disconnectors/switches and the calibration of the protections. It can also communicate with the Enel LV-RCC with IEC 60870-5-101/104 standard, on 4G or GMS/GPRS connection. This connection allows the S-RTU to send to the LV-RCC measures, states and alarms, as well as to receive commands from LV-RCC. The µUP performs the following functions:

- *Remote control*: The µUP communicates with LV-RCC and it ensures the possibility to remotely control the state (opening/closing) of disconnectors in the junction box. The µUP is able to establish autonomously the connection with the LV-RCC as a results of events that can be set by thresholds alarms;
- *Monitoring*: the µUP is able to record and manage the measures received from the field;
- *Automation*: the µUP implements automatic procedures for the selection of faulty line section.

The µUP is also arranged to manage directly external input/output signals: the device integrates two digital input ports (DI) and two digital output ports (DO);

Power supply: this macro-block is composed by all the elements required for supply power to the circuits and for detecting the network voltage. It is composed by:

- ➢ *Power supply for electronics*: circuit for µUP, Router, GSM/GPRS Modem and transmission device power management. This circuit is fed by the line-to-neutral network voltage. It has two power inputs (connected at both side of the switch) and it checks simultaneously the voltage upstream and downstream the disconnector. Through the ModBus standard, it is able to send to the µUP its operating status;
- ➢ *Back-up batteries*: these elements are used in order to supply the S-RTU devices for a period of time, to allow automated or remote-controlled refeeding operations in case of outages;

Communication: this macro-block contemplates the functionalities needed for the communication between S-RTU and the remote control system. It is composed by:

- ➢ *Router and signal transmission device*: equipment necessary to route data from/to the µUP and to allow signals transmission/reception on 3G/4G public telecommunication network;
- ➢ *GSM/GPRS modem*: needed to route the data using GSM/GPRS connections as an alternative to always on connections.

In Fig.2 is shown the photo of the junction box with S-RTU. For the placement along the low voltage lines, the main aims of the S-RTU should be considered:

- fast and automatic fault recovering: this feature is important for the re-feeding of largest numbers of customers in the shortest time that it is possible. At the same time another benefit is the knowledge, in real time, of electrical values along the LV lines, very useful to avoid the re-enticement of the fault, which would lead an early aging of the cables and breakers;
- increase of efficiency of the distribution network: the knowledge of the power flows is needed to be able to determine the best network structure and to modify it (even in real time, if it's possible) to ensure, in each moment, the "minimum losses configuration".

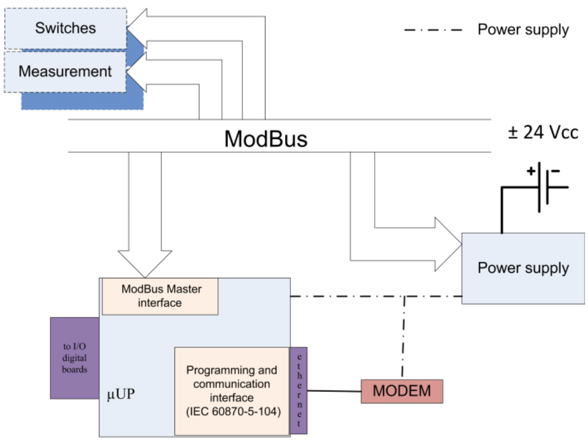

Fig. 1: Control scheme of S-RTU.

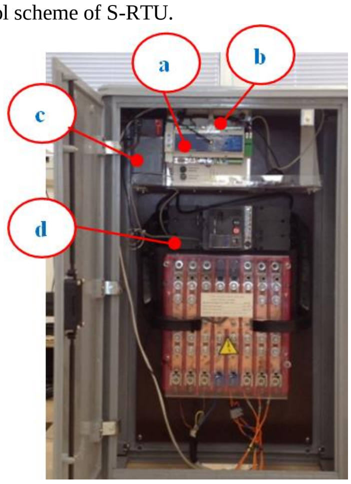

Fig. 2: Photo of the junction box with S-RTU: a) µUP, b) power supply, c) battery, d) motorized switch.

III. LOW VOLTAGE REMOTE CONTROL CENTER (LV-RCC)

The new conception of Smart Grid requires the implementation of a brand new remote control center (LV-RCC). The LV-RCC will be developed as a web application. This approach has been considered useful due to a considerable number of aspects.

Client-server architecture: The LV network, in areas of jurisdiction of Enel Distribuzione, is managed by many specific departments located along the territory and it has to be separated from MV remote control center. The MV network is managed by a limited number of operational centers in which a complex SCADA infrastructure can be implemented. The same approach cannot be realized for the centers by which the LV network will be operated. The high number of them requires a more flexible solution consisting in a few centralized database servers, graphic servers and application servers. Thanks to it, all the clients will be normal PCs connected to the remote control network and they are able to operate through a simple browser (see Fig. 3).

Extensibility of the remote control to mobile devices: Some functionalities of the system could be extended to mobile devices in a future evolutionary phase of it, Fig.4. In fact, an appropriately customized interface would enable some remote actions reducing the intervention times in term of logistics. All the developments strictly connected to this aim will be sustained only after appropriate tests on the potentiality of the system and checks on the possible consequences in terms of security.

Simplified network management thanks to a "geographical look and feel": The LV-RCC will be equipped with the functionality of geographical representation of the LV network in order to better identify the network elements at the points where they are connected. It will be possible to represent the LV grid on the cartography, simply open the S-RTU scheme by double-clicking on its icon and monitor all the events and alarms related to it. The GIS environment will enable the following features (see Fig. 5):

1. Simplified representation of the LV network and its basic elements over OpenStreetMap background cartography;
2. Parametric theming: the grid objects will be represented using specific colors depending, for example, on the current or on the normal state of the network. The symbol library will be customizable and dynamic;
3. Simplified navigation by zoom and pan functions;
4. User friendly interface;
5. Intuitive representation of the network objects attributes through InfoWindows or pop-up windows.

On-demand view of specific lines or single node schemas: Once imported from Enel archives, the whole LV network topology of the area will be available on LV-RCC,. So, the web application will give the opportunity to isolate a specific line and its reverse current feeding lines to ensure a better operation of the grid.

The LV-RCC system will be able to control the S-RTUs, that will be installed into junction boxes, but also to record functional commands in order to track the connection state of the non-remote controlled junction boxes.

A telecommunications network will be realized using heterogeneous solutions in order to identify the best ones in terms of scalability and efficiency and to test the remote control functionalities. In the Fig. 7 is shown an high level configuration of the telecommunications architecture.

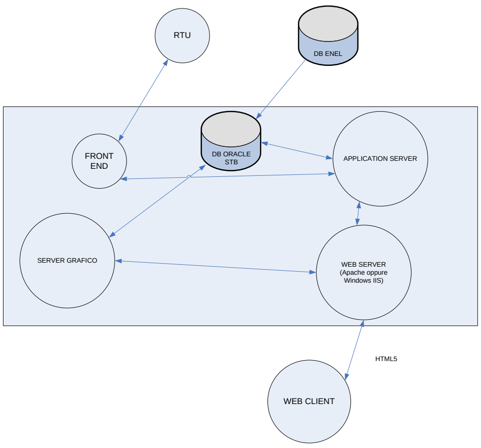

Fig. 3: LV-RCC client-server architecture.

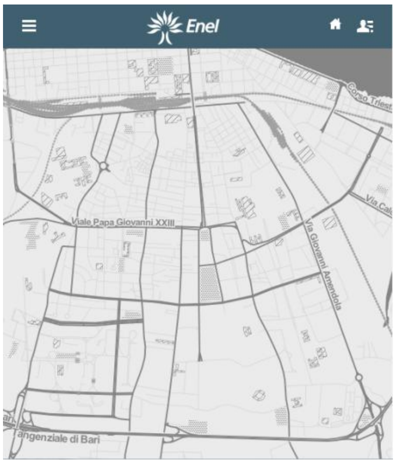

Fig. 4: Interface of remote control from mobile devices.

Fig. 5: Geographical look and feel of the city of Bari (Puglia, South of Italy).

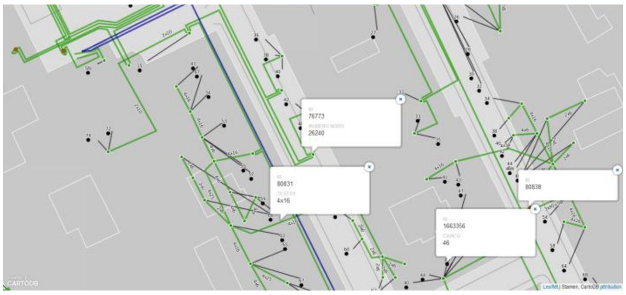

Fig. 6: On-demand view of specific lines or single node schemas.

The architecture is realized taking into account the possibility of using radio or optical fiber connectivity. As it is possible to observe from the left part of the Fig. 7, the basic configuration of the network allows a radio communication between the center and the RTUs (secondary substation and junction box) through a dedicated APN. In fact, as seen in the previous part of the paper, the S-RTU allows 3G/4G and GSM/GPRS connection.

At the same time, a part of the communication infrastructure will be equipped with the laying of optical fiber to test the logical selectivity between S-RTUs on the same LV line, exploiting the higher speed of this transmission medium. To make it possible, every S-RTU will be connected to the optical fiber ring by an optical switch. The end point of the ring will be located into a secondary station in which all the traffic on the fiber will be collected and sent toward the LV-RCC through the 3G/4G network.

IV. APPLICATIONS AND FUTURE WORKS

In this section the application of the LV-RCC will be shown. It will be realized to manage the S-RTUs that will be installed on the real LV grid field test in the city of Bari (Puglia, South of Italy). No 19 S-RTUs devices will be installed in three different areas of the city. Specifically, the following installations are planned, using two different versions of S-RTU (wireless communication version and optical fiber communication version):

1. **First area** - Here will be installed 9 wireless S-RTUs on 5 lines of the LV network. On each line 1 or 2 S-RTU and 1 remotely controlled breaker (at the top of the line in Secondary Substation) will be installed. In this context the following test will be done:
   a) integration of the S-RTUs with LV-RCC by wireless communication;
   b) local and remote S-RTU automation;
   c) overload selectivity between S-RTUs.

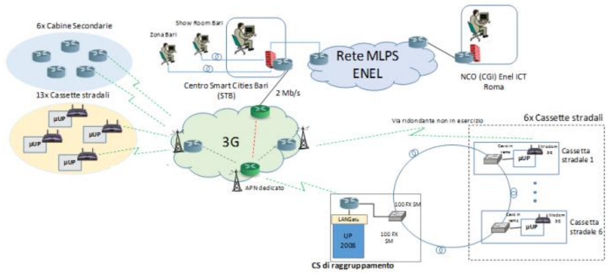

Fig. 7: High level configuration of the telecommunications architecture.

The Fig. 8 shows one of the line on which the tests will be done. In this line 2 S-RTUs (blue square) and 1 remotely controlled breaker (in the first MV/LV secondary substation) will be installed. In the figure the network diagram is simplified and the loads of the line are grouped in some points of the network.

2. **Second Area** – In this area will be installed 5 S-RTUs with optical fiber communication on LV network. As it is shown in Fig.9, the grid under test has no load and the 3 S-RTUs are connected respectively to 3 LV lines (see Fig. 9 and 10)
   In this context the following tests will be done:
   a. integration of the S-RTUs with LV-RCC by wireless communication;
   b. local and remote S-RTU automations;
   c. overload and short circuit selectivity between the S-RTUs installed on the line, using the fiber optic communication.
3. **Third area** - In this area 2 wireless S-RTUs will be installed on 2 LV lines outgoing from to 2 secondary substations. Along the line, an Energy Storage System will be connected (Energy/Power characteristics 200 kWh/100 kW). In the Fig. 11 the electrical network scheme and the point of connections of the S-RTUs and storage are shown. In this area the following activities will be tested:
   a. integration of the S-RTUs with LV-RCC by wireless communication;
   b. local and remote S-RTU automations;
   c. overload selectivity between S-RTU and breaker installed in Secondary Substation;
   d. load assignment to network;
   e. network support through storage services. The communication between the LV-RCC and storage is based on 61850 standard [5-7].

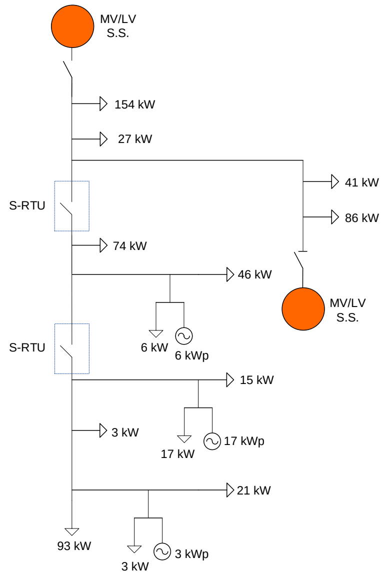

Fig. 8: Single-line diagram of the grid under test.

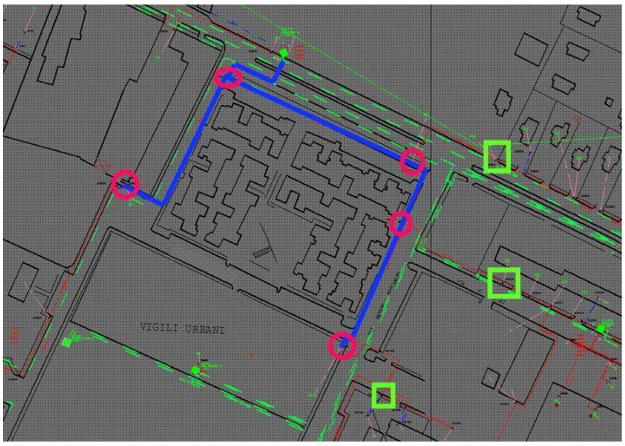

Fig. 9: View of optical fiber installation.

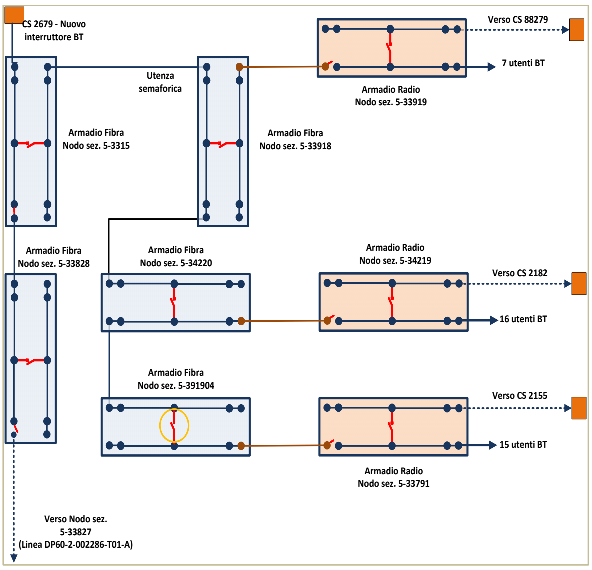

Fig. 10: Scheme of optical fiber installation.

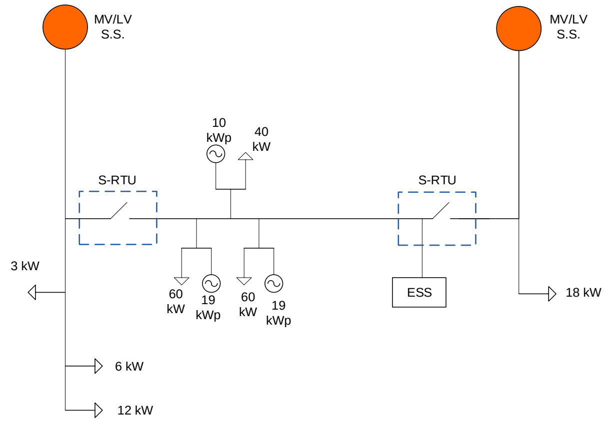

Fig. 11: Network electrical scheme and the point of connections of the S-RTUs and storage.

V. CONCLUSIONS

The results about the S-RTU operations on the field test will be analyzed in order to obtain the best placement of the S-RTUs in terms of: number of installed elements; their positions along the selected LV lines according to loads connected downstream the junction box; the fault rate. Once the benefits of equipping the LV grid with S-RTUs have been recognized, in order to include such components in the regulated asset base of the distribution operator, we need to define a lower target cost and make a re-design to meet such target cost.

VI. REFERENCES

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