THE ENEL SMART GRID TEST SYSTEM: A REAL-TIME DIGITAL SIMULATOR-BASED INFRASTRUCTURE

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ABSTRACT

Working on Smart Grids, Enel Distribuzione is introducing innovative devices for grid operation, regulation and supervision. The complete infrastructure, based on an always-on communication network which uses IEC 61850 standard, needs to be accurately tested. Tests involve Intelligent Electronic Devices (IEDs), communication infrastructure and integration with the existing Enel SCADA.

In order to satisfy these important needs, Enel created a specific Test Center to perform tests on devices and systems.

This infrastructure uses a Real-Time Digital Simulator (RTDS) and involves Enel SCADA.

In this paper Test Infrastructure and Smart Grid devices (IEDs) are described focusing on real hardware and IEC 61850 data exchange tests, performed in a mix of simulated and real environment.

INTRODUCTION

The widespread of the Distributed Generation (DG) connected to the distribution grid impacts the future development of modern Power Systems, which evolves towards Smart Grids. Fundamental topics of the Smart Grid context are Automatic Voltage Regulation and Advanced Network Automation based on fast communication channels.

Enel Distribuzione has specified physical devices (Intelligent Electronic Devices - IEDs), algorithms and systems for several pilot-projects on Smart Grids.

The always-on communication infrastructure, which has been also specified by Enel Distribuzione, uses IEC 61850 standard protocol.

All devices communicate in real-time. In order to test the up cited devices, algorithms and systems, under real operation conditions, Enel Distribuzione has realized a Smart Grid Test System. This infrastructure, realized by the Enel Test Center in Milan, is based on the Canadian Real-Time Digital Simulator (RTDS).

FACILITY HARDWARE

The RTDS is based on parallel computing technology allowing electric networks to be numerically simulated in real-time. Signals and messages exchanged between RTDS and connected real devices can be exchanged via wired interfaces (for digital and analog quantities) or via IEC 61850 protocol. Moreover the RTDS allows to simulate IEDs, using the IED Capability Description (.icd) file and implementing IED algorithms in the simulator. In other words, the RTDS can work as several IEDs.

These important features allow to connect real devices to a simulated grid, so as to have a complete-safe real-time Smart Grid "Hardware-in-the-loop" Test System, which realizes future scenarios before operation in real field.

The following list describes Enel IEDs developed for Smart Grids tested using the RTDS:

TPT2020: it's a new generation of HV/MV substation RTU. In addition to standard remote control features, it is able to manage advanced voltage regulation functions, acting on local MV busbar and on GD set-points thanks to the capability to manage the entire MV grid in terms of IEC 61850 communication.

DV7500: it is a transformer protection with MV busbar automatic voltage regulator capable to apply optimal voltage profiles in primary substation. It receives a busbar set-point time profile from the TPT2020 and applys it acting on the transformer tap-changer.

DV901/A3: it's a Primary Substation feeder protection panel, with advanced network automation features, based on IEC 61850 communication with other RGDMs on the same feeder.

RGDM: it is an advanced fault detector with high measuring accuracy, installed within MV/LV substation switchgears. It provides advanced network automation features, also thanks to the possibility to be broadband-and-always-on-connected with other RGDMs on the same feeder. Furthermore, it runs local DG management algorithms.

IC: it is a simplified version of an RGDM for retrofitting purposes. Empowers the existing RTU and fault detectors, in order to make available all the new Advanced Network Automation and GD management features.

IRE: it is a unified interface, improved with local intelligence, between Enel Smart Grid Infrastructure and the customer controllable plant. IRE receives set-point requests and properly forward it to the existing regulation devices. It is important to note that IRE is a communication interface

defined by a IEC 61850 data model. This data model must be implemented in physical devices able to act on the plant controllers. The plant must be obviously controllable in one or more parts (generators, storages and loads). This kind of plant will be identified with the FCP acronym (Full Controllable Plant). For the scope of the current testing, Enel decided to split IRE data model in two parts, realizing two physical devices called:

IREHW, the plant device that implement functions and algorithms of the IRE interface oriented to generators regulation,

DV7300, the plant device to manage existing protection devices and DG disconnection (or load curtailment).

Enel MV Smart Grid communication structure

IEDs are connected each other to form the Enel Smart Grid communication structure, represented in Figure 1. We can distinguish:

WAN: it is the Wide Area Network which connects all Secondary Substations (SS) geographically distributed along MV feeders. This net supports IEC 61850 GOOSE and MMS messages and TCP-IP traffic. The physical topology may be ring or hub-spoke.

PS LAN: it is the Primary Substation (PS) LAN. This ring-topology net connects the DV901/A3 feeder protections, the DV7500 transformer panel and the TPT2020 RTU.

SS LAN: it is the Secondary Substation LAN which connects the RGDM advanced fault detector and the UP RTU via a "101 to 104" protocol converter.

FCP LAN: it is the Full Controllable Plant LAN. It connects IREHW and DV7300 devices.

STM: it is the Enel SCADA, able to manage all IEDs before mentioned.

DMS: it is the Distribution Management System which, for example, calculates set-points for DG and Storages installed in the Smart Grid.

This communications infrastructure is currently under construction as part of the Enel pilot project on smart grids called POI-P3, funded by the Italian Ministry for Economic Development. It is already fully realized with ring fiber optic technology for the feeder "Torre", in the Italian region Calabria, while it is in advanced stage of construction for the other five experimental feeders, using IP radio technologies.

The Enel MV Smart Grid test system

A well-done technical development must evolve through a comprehensive test sessions. These test sessions have been divided into three steps:

single product testing, focused on the technical specification compliance verification;

comprehensive testing in laboratory environment, focusing on devices interaction operation;

field testing, useful to underline possible integration problems before the real operation.

In this moment Enel is completing the first point and is developing the second point with the Smart Grid test system. In this Real-Time Digital Simulator-based infrastructure each device really exists but can be also simulated. This strategy allows to simulate multiple devices using one real prototype and simulating the others. The word "Simulated" means that it is possible to simulate the entire IEC 61850 interface, for a large number of devices (for network load tests) or a single device functionality (for interaction tests, also when not all the devices are physically available).

In Figure 4 is represented the test configuration schema. The colored area, representing RTDS, contains simulated devices.
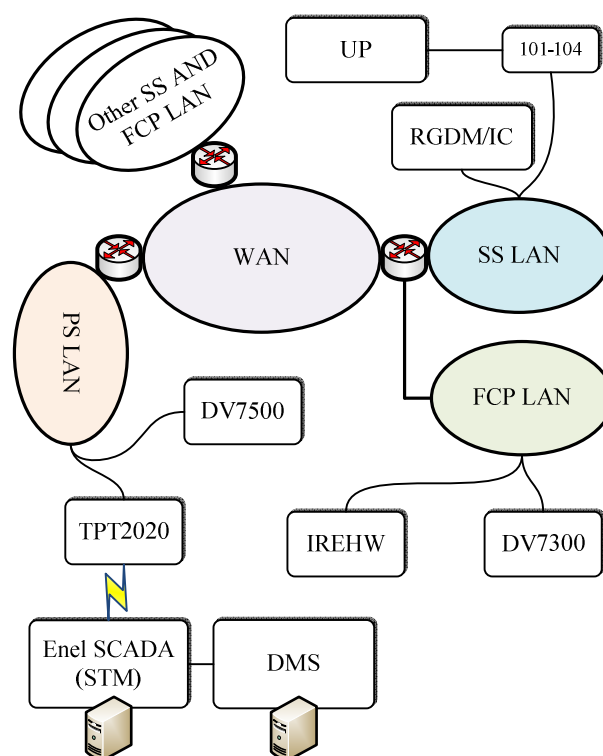

Figure 1. The Enel MV Smart Grid *communication* structure.

On the edge of this area there are physical connections with real devices, either wired or LAN.

In Figure 4 there are other devices, not mentioned before:

DY800: it is a remote controlled compact MV circuit breaker;

DG: it's the general switchgear (main FCP switchgear);

PG: it's the general protection panel (main FCP protection panel);

DI: it's the generator interface switchgear;

PI: it's the generator interface protection panel;

DDG: it's the generator automatic switchgear.

The device IREHW, in this moment under construction, is simulated using the RTDS. We underline that not all the IRE functions have been simulated, but only those compliant with the scope of the on going projects.
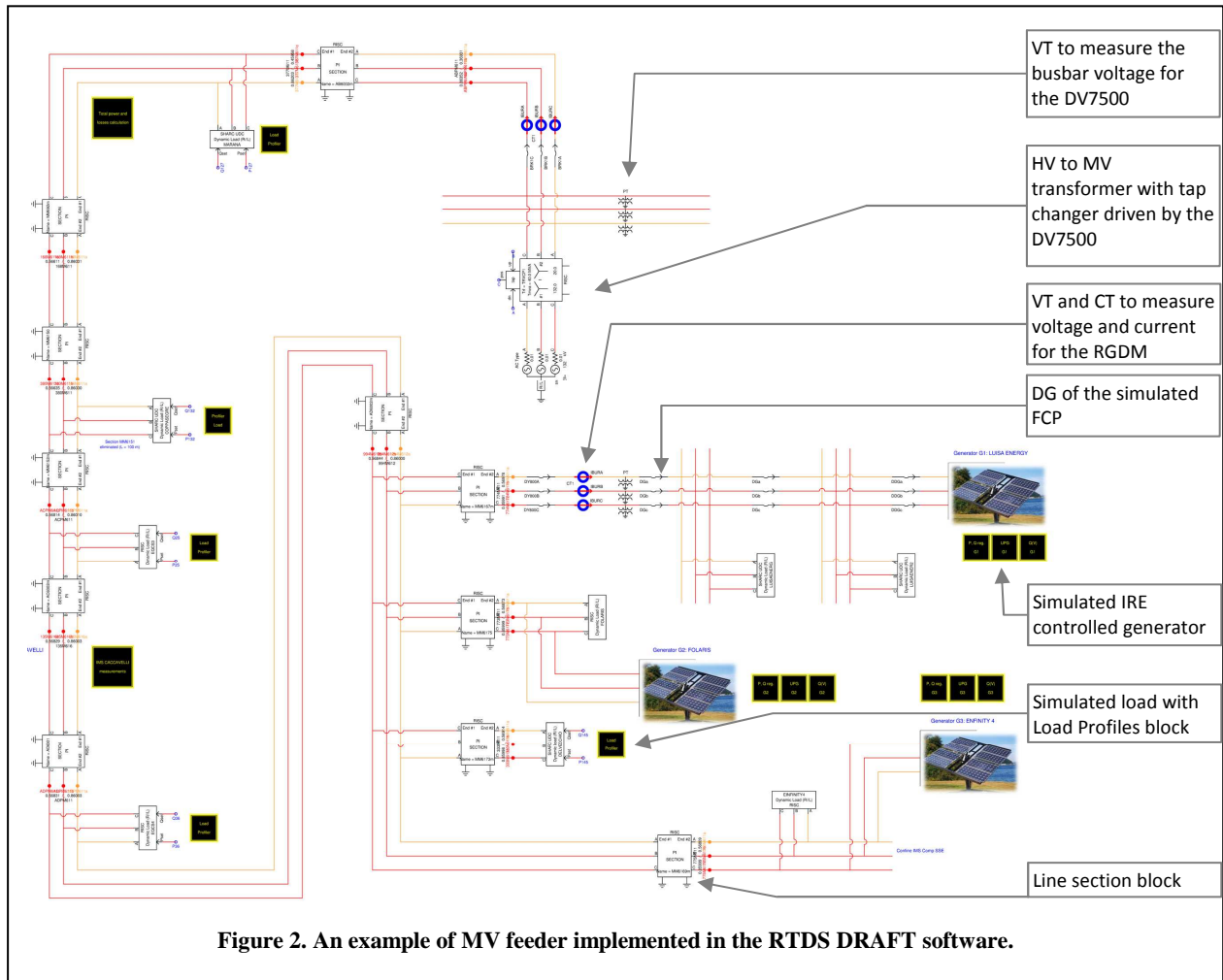
VT to measure the busbar voltage for the DV7500

HV to MV transformer with tap changer driven by the DV7500

VT and CT to measure voltage and current for the RGDM

DG of the simulated FCP

Simulated IRE controlled generator

Simulated load with Load Profiles block

Line section block

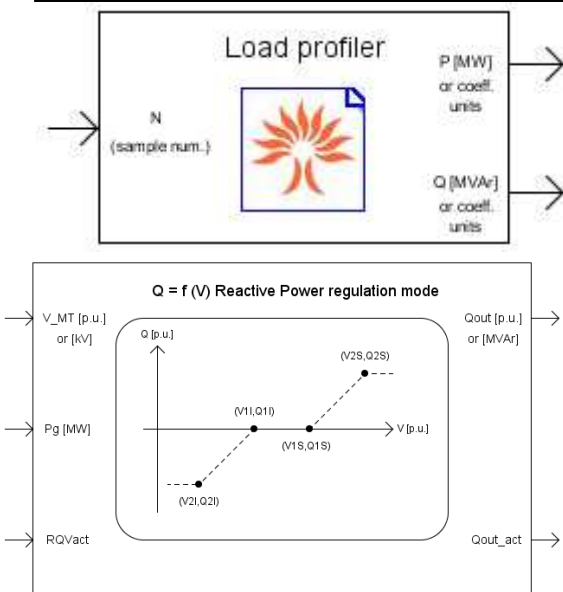**Figure 2. An example of MV feeder implemented in the RTDS DRAFT software.**

Figure 3. The load profiler control block and the reactive power-voltage drop based regulation (Q(V)) control block, an IRE functionality.

The test scenario

RTDS uses a software, called DRAFT, to graphically build up a network with both power and control components. Moreover, the C-Builder software, another RTDS application, allows to program in C++ language both power system and control models. This means that RTDS users can build custom libraries to simulate their devices, components and control systems. In particular, Enel built the so-called "Test Center Library", which brings a lot of functionalities contained in real devices, as the before mentioned IEDs.

Figure 2 shows an example of MV network implemented in RTDS DRAFT. We can see power system components, like generators, loads, line sections, etc.

By using the C-Builder software, also control blocks can be implemented in the RTDS. In Figure 3 we can see the "load profiles" control block and the "reactive power-voltage drop" based regulation (Q(V)) control block. The first control block capitalizes the Distributor knowledge of load curves, imposing on simulated loads a statistically significant P-Q behavior.
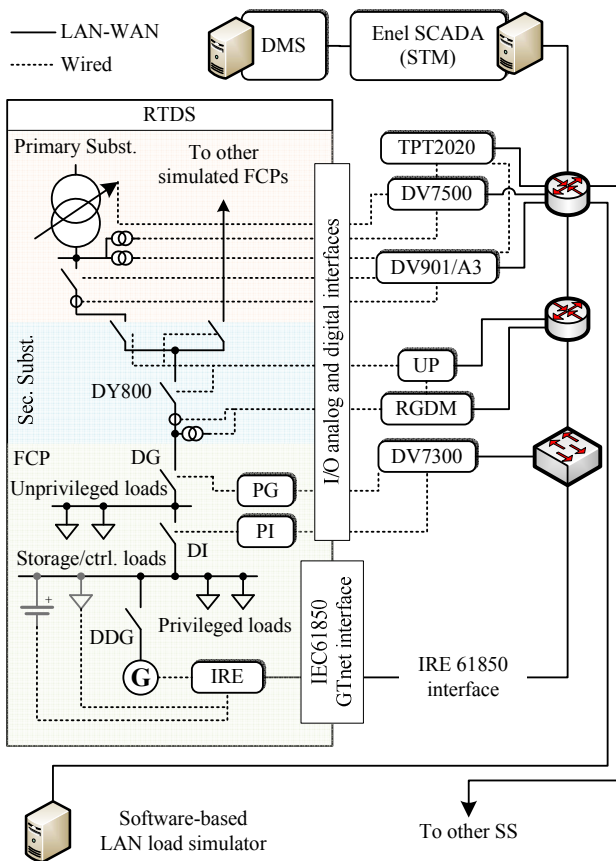
Figure 4. Logical schema.

Figure 5. Hardware.

The Q(V) control block, instead, is a part of the IRE interface, simulated in RTDS as represented in Figure 4. The simulated Q(V) function works using as input the delivery point voltage. This voltage coming from the simulated grid, is produced using RTDS I/O DAC interfaces and is wired to the input of a real RGDM. In this way, the RGDM measures the voltage and publishes it on the LAN, using IEC 61850 GOOSE messages. The RTDS reads the GOOSE messages, using the GTnet card, like a real IREHW, and uses this GOOSE measurements as input for the simulated IRE Q(V) regulation function. IRE calculates the reactive power set-point Q and applies it to the simulated generator regulator.

At this step the loop is closed: a simulated grid voltage is read by a real device which generates real measurements used by a simulated regulation function, which regulates simulated generators. The same concept is applied to all real devices listed before. Each real device reads measurements and grid states related to the simulated grid, and act on it applying state changes and regulations (e.g. on the simulated transformer tap-changer for the DV7500). When the physical device IREHW will be available, we can test its behavior by replacing the currently simulated counterpart.

Finally, SCADA is present in this infrastructure. In fact the TPT2020 and the UP are connected to STM, the Enel SCADA, installed in the Test Center.

In other words, a complete hardware-in-the-loop infrastructure, based on the IEC 61850 protocol, have been created and interfaced with SCADA system.
Of course, this is just one of the scenarios that are being realized in order to test the proper interoperability of all the mentioned smart grid devices.

CONCLUSIONS

The Enel Smart Grid Test System allows to test devices, processes and algorithms under real field conditions.
These tests are currently used to develop all the devices, algorithm and processes to be used in pilot projects on Smart Grids: e.g. "POI-P3", "Isernia Project", ScheMA (refunded by the Italian Government and Authority) and "Grid4EU" (refunded by the European Community).
Both functional and communication tests are performed. Usually Enel specifies devices, systems and processes, while manufacturers build them in compliance with these requirements. The fundamental purpose of these tests is to check the proper functioning of the devices, in their local functions, but particularly in the interaction with other network devices and control systems.
Another important feature is the devices' pre-tuning possibility. For example let's consider the IREHW: this device must be able to interface several kind of power plants (e.g. solar, hydro, biomass, etc.). Each one has different dynamics, delays etc. Test System is used before

field installation: the specific power plant is modelled in RTDS and the specific IREHW is pre-tuned in the simulated environment.

Of course, also the devices used currently in the present network can be tested by the described system (e.g. RTUs, Petersen Coil regulators, tap-changer regulators, protections, etc.). This is certainly usefull, after upgrades or new firmware release.

REFERENCES

[1]   G. Di Lembo, A. Cerretti, L. Consiglio, A. Fatica, 2011, "Advanced management of distributed generation on MV network", *21st International Conference on Electricity Distribution*, Frankfurt, 6-9 June 2011, Paper 0465

[2]   G. Bianco, G. Di Lembo, G. Sapienza, 2012, "Interface for energy regulation: an application for distributed generation control", CIRED Workshop, Lisbon 29-30 May 2012, Paper 0217