IEC 61850 PROFILE FOR THE ENERGY REGULATION INTERFACE. A PROPOSAL OF COMMUNICATION BETWEEN THE DISTRIBUTOR SYSTEM OPERATOR AND THE FULL CONTROLLABLE PLANT

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ABSTRACT

The integration of the distributed generation (DG), based on constantly increasing renewable energy sources (RES), is one of the biggest challenges of the modern Distribution System Operator (DSO). This big number of distributed generators can be seen as a resource for the network because they can offer a lot of useful services to the grid. Looking to the Smart Grids, Enel Distribuzione has developed an Energy Regulation Interface that allows to manage the energy flows between the generic user plant and the network. In this paper we want focus to the communication between IRE (Energy regulation interface) and DSO. In particular the focus is on the IEC61850 profile to standardize the communication between the "full controllable plant" and the DSO. The Full controllable plant it's an user plant that has generators and/or storage and/or loads and offers the capability to be controllable.

INTRODUCTION

In this paper the Interface for Energy Regulation (IRE) [1], developed by Enel Distribuzione in partnership with SMA Solar Technology AG, is presented in terms of IEC61850 profile and the main functionalities. Further the laboratory and the field tests [2] already completed are here presented in order to show how the system works.
Enel Distribuzione has developed a complex, always on, communication architecture in order to have a powerful communication network where IEDs (Intelligent Electronic Devices) communicates using the services provided by the standard IEC 61850. It implies that for all devices it's implemented an IEC 61850 profile to describe, both to the other devices and to the control centre, how it is composed and how it works. The Interface for Energy Regulation (IRE) is a set of functionalities related to a plant controller and its communication interface to the DSO. It is possible to integrate IRE inside an existing device, already present in the plant, or to create a device to host IRE functionalities. The communication is based on the IEC61850 relating to DER specific section (IEC 61850-7-420 [4] and the newest IEC61850-90-7 [5]). SMA Solar Technology as member of the Working Group 17 in IEC TC 57 contributed to the development of the technical report IEC 61850-90-7 and IRE is one of the first plant controller based on the technical report and tested both in Test Centers and on the field. The profile that has been developed describes the capabilities of the generators and of the energy storage system as DER controller characteristics. The capabilities of the loads are described as operational characteristics of the plant. The states and the alarms are provided as DER unit states. But the most interesting topics are the regulation functions. IRE can work with Set-Point regulation (P, Q, cosphi) and Curve Regulation (like Q(V), P(f), cosphi(P) and the main functions provide in the TS 50549-1 and 2); Actually IEC61850 doesn't fulfill all needs of the Enel developments, so some extensions to the existing Logical Nodes were applied, based on the current standard rules.

THE POI-P3 PROJECT

The Interface for Energy Regulation has been developed within the smart grid project "POI-P3", founded by the Italian government. This project involves some Regions Italian government in the south of the country, with the purpose to increase the "hosting capacity" of the MV network.
The main points of POI-P3 application are:

- a communication infrastructure based on a broadband, "always on" technology to connect MV producers, passive customers, main secondary substations along the feeder and the relevant Primary Substations (PS);
- communication according IEC 61850 model, to realized an extended Primary Substation network;
- new protection and control system, adopting new criteria to manage the On-load tap changer of HV/MV transformer (the current technique is not effective because of DER);
- a suitable HW/SW at peripheral and central level to implement control functions and data collection.

Enel Distribuzione has specified physical devices (IEDs), algorithms and systems for this pilot-project on Smart Grids. In particular, IRE is one of the main periphery device of the project. It is installed inside the private power plants and interacts with the distributor control system by means of the communication system.

NETWORK ARCHITECTURE AND IEC61850 SERVICES

Within the POI-P3 several new devices has been developed in order to create a new architecture IEC61850 based. In particular the new RTU (TPT2020)

for the HV/MV station has the role of the client and all the other devices located along the line have the role of servers. With reference to Figure 1, TPT2020 can be seen as the gate between the DSO control center and the field devices;
RGDM is the Advanced Fault Passage Indicator, it provides measurements, fault detection and automation.
DV7300 is an IEC61850/wired converter in order to manage the protection system of the user.

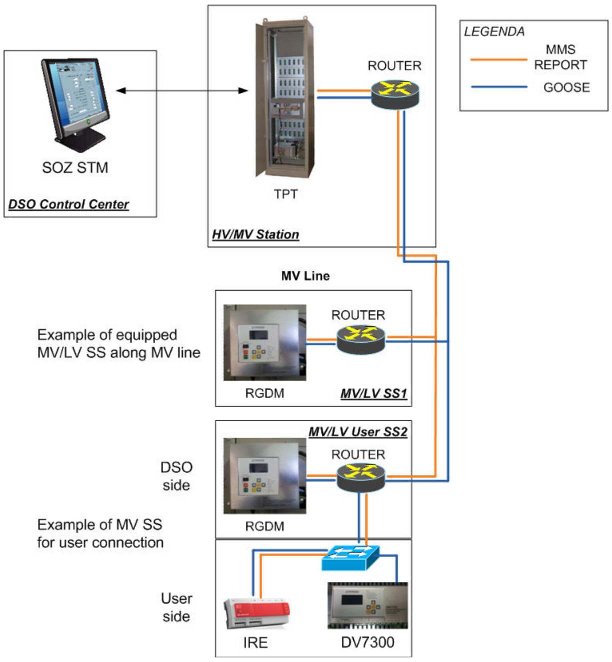

Figure 1 - Enel IEDs architecture

The *Router* connects devices to the wide broadband communication network.
In this architecture both GOOSE messages and MMS/Report travel between the above mentioned IEDs. In particular, IRE is able to publish and subscribe GOOSE messages with the other servers and communicate through spontaneous report with the client. It is also able to receive some commands or request, trough MMS, from the client.

The Full Controllable Plant

The full controllable plant (Figure 2) is defined like an user plant that includes generators (maybe with different primary source), loads and energy storage systems, and each of this section is totally controllable. Although the full controllable plant has each section controllable, IRE can manage also the plants that allow the control just in one or more of these sections.
IRE is able to know all the features of the plant, all needed measurements and all operating parameters. DSO can ask to IRE a specific regulation or information about the plant.

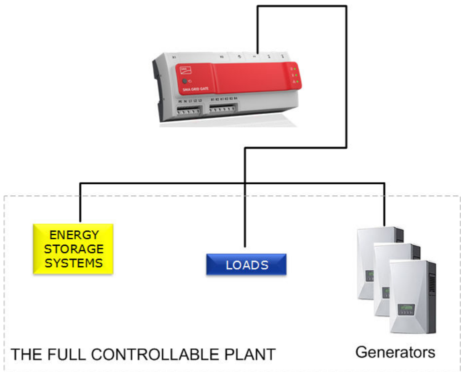

Figure 2 - The Full controllable plant

IRE is able to manage the requests of DSO (obviously limited to the capability of the plant) and can send commands to the plant in order to obtain regulation services for the distribution network through:

- Generation management
- Loads managements (e.g.: to detach partial or total load in an emergency situation)
- Energy Storage System management to better obtain all the services required

So IRE defines which of the above "macro-blocks" has to act and how it can fulfill the request.

FUNCTIONAL INFORMATION

As already said, all the functional information are transmitted to and from the DSO control centre using the IEC 61850 standard.
These information can be divided in four groups showed below with their related LN representation.

Messages relates to the plant features**:** Information from the plant about configuration, features and design capacity. These information are not editable by remote processes.

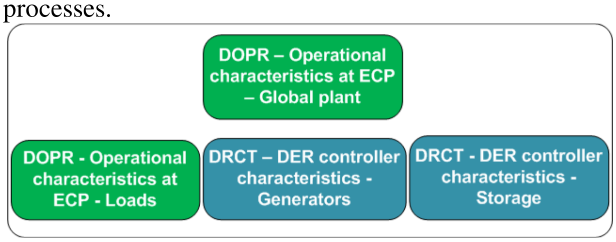

Figure 3 - Capabilities modeling

The LN Class DOPR (Figure 3) is used for the features of the overall plant and of the loads. The LN Class DRCT is used for the features of the macro-blocks generators and Energy Storage System.

Messages relates to the operating status: Information about physical equipment present in the plant and the operating status of the system, such as the positions of the switches or state of the regulation function (Figure 4). The state can change as a result of events in the plant or as a result of remote command.

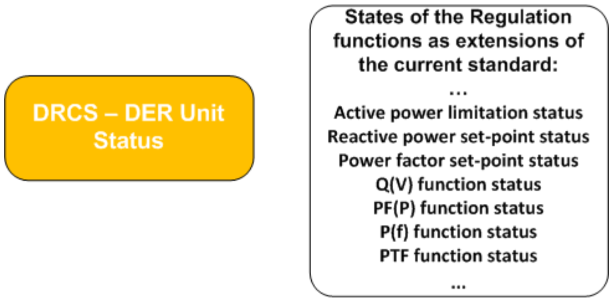

Figure 4 - States modeling

The states of the regulation function are listed in Table 1:

State	*Description*
Off	The function is disabled.
On	The function is enabled, but through the actual conditions, the regulation doesn't act and no energy is managed by this function.
Act	The function is enabled and by the actual conditions the regulation is working

Table 1 - States of the regulation functions

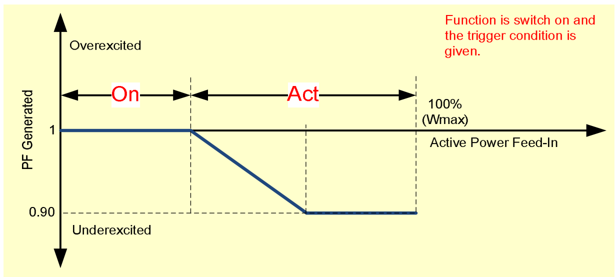

Figure 5 - Possible states of one function

Messages relates to plant measurements: Analog values measured directly or determined by processing of measured quantities such as voltage, current, power, etc. These information are represented by LN MMXU with different instances depending on the period time on which they should be provided.

***Messages relates to the operating parameter values*:** This section contains the reference values for functions and algorithms. The parameters are set during initialization of the device and can subsequently be modified by remote.
The regulation function and the related operating parameters can be seen as logical boxes that compose the complete functionality (Figure 6). There are two approaches for the regulation functions: the first one is a fixed parameters approach and is based on set points mode; the second one is a curve regulation approach and is based on curve mode. Both operating modes are logically divided into two boxes.

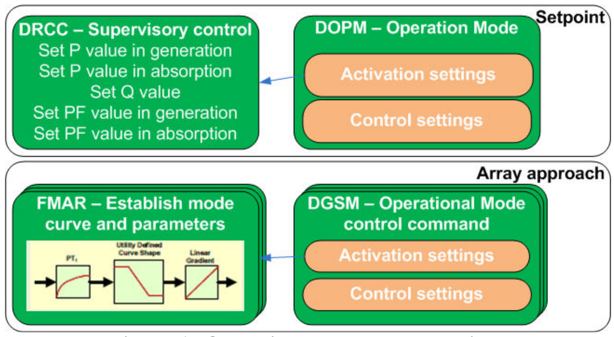

Figure 6 - Operating parameters modeling

The first box is used to set the values of the set point "DRCC" (for the first approach) or the points of the curve "FMAR" (for the second approach). The second box is used for the activation bit of the related regulation function. So there a logic separation between the activation of a specific function and the parameters the regulation will work with.

SCALABILITY OF THE MODEL

The model proposed has a large scalability due to the fact that it is thought for the full controllable plant.
An important example of this large scalability and flexibility is represented by the way as the regulation function are managed in terms of capabilities:
For all the functionalities provided, the model can be adapted according to the capabilities of the plant. In fact each functionality is modeled through an enumerative, in order to represent the several possibilities within the plant can fulfill the requested function (Table 2):

State	*Description*
Autonomous	The function is autonomously controlled and the DSO control is not possible.
Remote	The remote control of the function is allowed.
Local	The function can be controlled by *local*.
Remote+Local	Remote and local controls are allowed
NA	Not available

Table 2 - Capability of the plant regarding the regulation function

The state "*Local*" means that the function can be controlled through the local RGDM. In fact RGDM has some internal logic that is able to manage some functionalities of IRE, by local.
The state "Remote" means that the function can be remote controlled by Enel Scada.
If one functionality is just autonomous or not available for a particular kind of plant, then it will declares it.
Also the regulation curve mode has a large flexibility given by the use of the FMAR LN Class, that allow to manage several curve set freely editable.

So IRE is able to know which are the functionalities allowed by the plant. Further, in order to accomplish all the needs of the DSO, some extensions have been added, but totally compliant to standard IEC61850.

LABORATORY AND FIELD TESTS

The model proposed has been tested as interface for the communication between IRE and DSO. Several tests regarding the interface and all the functionalities have been done. The laboratory test has been performed using the Enel Test Center in Milan (Italy) and the SMA Test Center in Kassel (Germany). The test field was composed by one inverter of 17 kVA (nominal apparent power) and one PV simulator of 12 kW. The inverter is able to manage reactive power at maximum until 50% of the nominal apparent power. The IRE was connected to the inverter in order to manage it according the DSO requests. The information between IRE and DSO are conveyed passing through RGDM.
In particular an example of the regulation with the fixed parameter approach is shown below.

- Power factor set-point of -0.95 (minus sign means an inductive behavior): the RGDM sends the GOOSE message related to IRE configuration with the power factor set-point and related activation bit. (Figure 7)

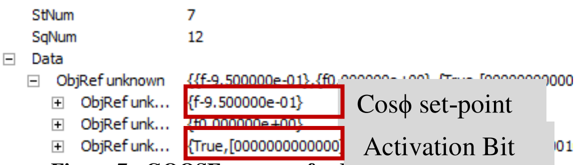

Figure 7 - GOOSE message for IRE configuration

IRE returns the GOOSE messages for the measurements of the plant (Figure 8) and the current states of the functions (Figure 9):

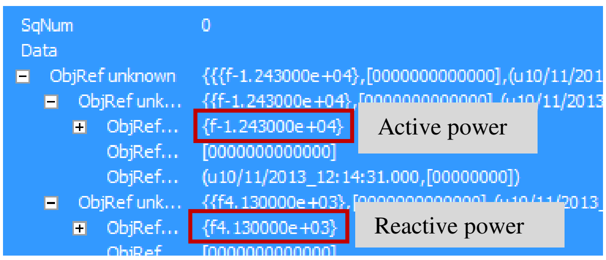

Figure 8 - GOOSE message showing the measurements of the plant after the PF set-point

After the command, the GOOSE of the measurements shows that the plant is working at 12 kW (so the active power remained at the previous value) and 4 kVAr. The reactive power correspond to the correct value according to the PF set-point command:

$$Q = P \cdot tan\varphi = 12.4 \cdot 0.328 \cong 4\ kVAr$$

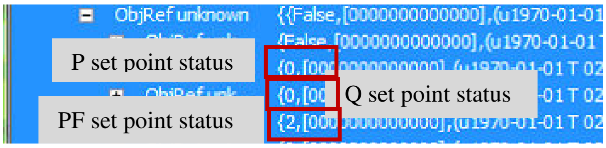

Figure 9 - GOOSE message showing the states after the PF set-point

Due to the enumerative choices, the number 2 indicates that the function is "Active" according to the logic adopted for the regulation functions states and shown in the paragraph "Functional Information".

- Active power limitation at 50% of the nominal apparent power (Figure 10):

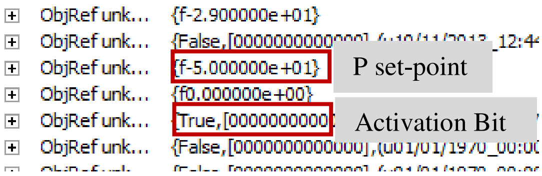

Figure 10 - GOOSE message for the configuration of the P limitation

IRE returns the GOOSE messages for the measurements of the plant (Figure 11):

Figure 11 - GOOSE message showing the states after the P limitation

After the command, the GOOSE of the measurements, shows that the plant is working at 8.5 kW that corresponds to half of the nominal apparent power (17 kVA).

- Reactive power set-point (Figure 12) exceeding the capability of the plant: Q=70%S (S is the nominal apparent power)

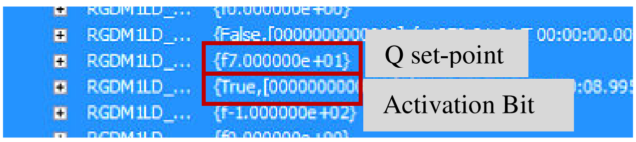

Figure 12 - GOOSE message for the configuration of the Q set-point

The measurements show (Figure 13):

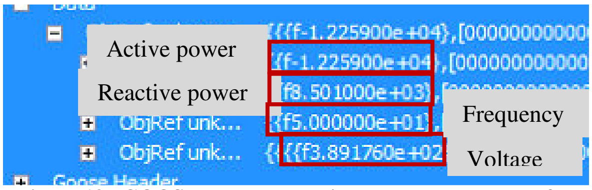

Figure 13 - GOOSE message showing the measurements of the plant after a Q set-point exceeding the maximum capability of the plant

So the reactive power was limited at its maximum: 50% of the nominal apparent power, corresponding to 8.5 kVAr.

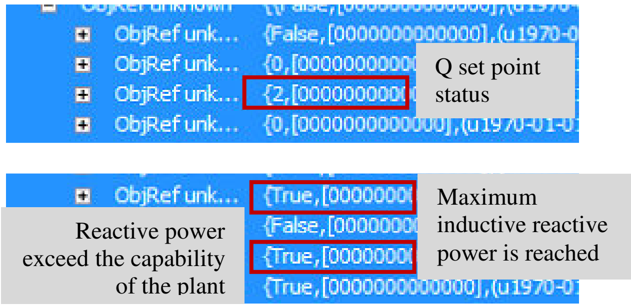

Figure 14 - GOOSE message showing the states after a Q set-point exceeding the maximum capability of the plant

The message of the states (Figure 14) shows also that the Q set point is activated but the request exceed the capability of the plant. After these tests, IRE was installed in several plants for the pilot project and the same tests were performed also on the field plants, with more inverters and PV module, obtaining the same results.

CONCLUSIONS

Enel defined the Interface for Energy Regulation (IRE) in terms of functionalities for the plant controller and, in partnership with SMA Solar Technology AG, its related interface for the communication with DSO. The data model was based on the international IEC standards and technical reports but took also into account the technical issues of the Italian distribution grid (ENEL) as well as the opportunities offered by PV inverters (SMA). All these functionalities and the interface for the communication have been tested both in Test Center and on the field. In fact these developments, carried on for the POI-P3 project, are now really located to the field, in the DER plants involved in the project. Both the laboratory tests and the field tests gave the expected results, and with these developments the DSO is now able to ask some useful services to DER. This experience, enhanced by the related developments done, could be used as a proposal for DER control to the international standard committee.

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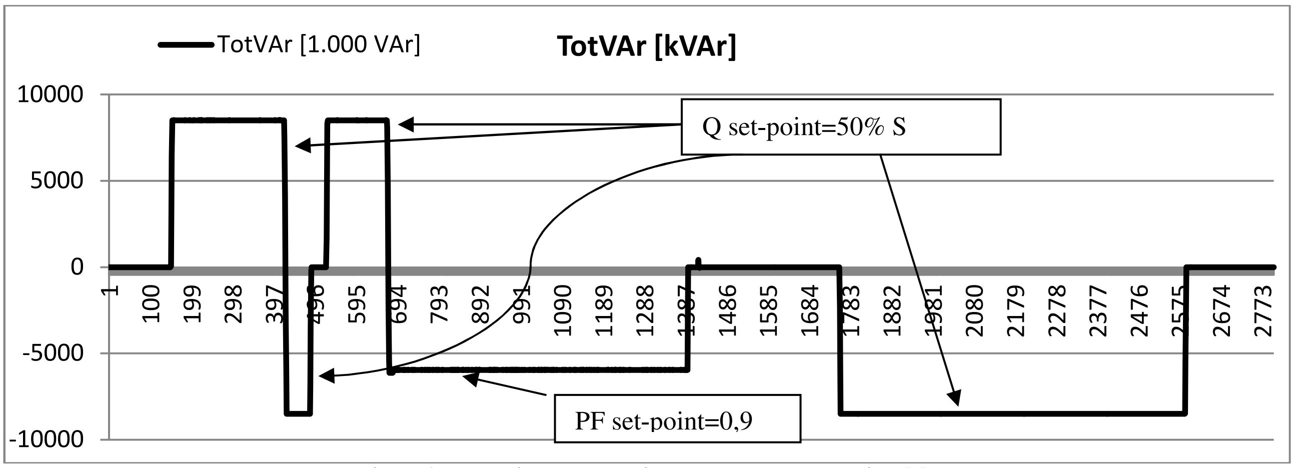

Figure 15 - Reactive power during the laboratory tests time [s]