INTERFACE FOR ENERGY REGULATION: AN APPLICATION FOR DISTRIBUTED GENERATION CONTROL

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ABSTRACT

In this paper the main technical features of IRE (Interface for energy regulation) are presented. It is a control device specified by Enel Distribuzione in order to support voltage regulation and power flow control on MV "active" networks, in the scope of some demonstrative/pilot projects in Italy.

IRE performs its functions adjusting active and/or reactive energy of private power plants connected to the MV distribution network. These functions are defined independently from the specific device that actuate the requested variation of power parameters (inverters, storage systems, capacitors, etc).

The Distributor can dynamically impose the energy flows conditions for each MV client sending this request to IRE devices along the feeders. IRE will process the request actuating the settings in a reasonable time span.

The results of simulations are also described, to demonstrate the effectiveness of the implemented algorithm.

INTRODUCTION

The wide diffusion of Distributed Energy Resources (DER) represents the future of Energy systems in the world, which are evolving towards the Smart Grids.

In the Smart Grid context, protection, regulation and control functions have to be as close as possible to the power plants. A controller, which works as a local Energy Manager, is also necessary in order to regulate the relevant energy flow according to grid constraints.

Real time measurements regarding voltage and active/reactive power can also be provided by the same equipment to distribution central control systems.

Of course a wide broadband communication infrastructure is the essential background to apply the Smart functions, that are all based on sending and receiving data from the field.

Using these guidelines Enel Distribuzione (hereafter ENEL), the major Italian Distribution System Operator (DSO), defined a Smart Grid architecture including Central control system, peripheral devices, algorithms and communication.

The developments related to this architecture are included in a specific project, financed by Italian government, named "POI-P3 project".

The preliminary functional tests of the new devices and functions have been performed using the Real-Time Digital Simulator (RTDS), modeling the relevant network on this system and the main functional blocks to be verified.

ENERGY REGULATION IN SMART GRIDS

The Italian pilot project "POI-P3"

Moving towards Smart Grids, the Italian Ministry of Economic Development financed a pilot project, named POI (the Italian acronym of "Interregional Operative Project") involving the networks of some Regions in the south of the country. The scope was "Upgrading of MV network to allow distributed generators to be connected": in other worlds to increase the "hosting capacity" of the MV network.

This project is divided in some sub-projects each one having a specific task: the scope of P3 sub-project is the increase of hosting capacity preventing the islanding conditions and voltage variation on MV feeders.

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.

With reference to the last point, IRE (Interface for Energy regulation) 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.

The Full Controllable Plant (FCP)

In principle, a distributed power plant can be composed by a mix of the following macro-blocks:

- distributed generators, mostly based on renewable sources;
- energy storage systems, e.g. based on static batteries;
- loads.

The group of these macro-blocks is called, in this document, "Full Controllable Plant" (FCP). Therefore, a regulation action, requested by the DSO in a specified MV delivery point, can be satisfied acting on one or more FCP components; it is up to the FCP internal control system choosing the action to be performed by each component in order to satisfy the DSO request. This is a very important concept to understand IRE philosophy: using a unified interface (IRE), the DSO can request a energy regulation action, no mind of which hardware and which technique the relevant FCP adopts to actuate this action.

A simple schematization of a FCP is represented in Figure 1, where *G*, *L* and *St* represent, respectively, generators, loads and energy storage. Obviously, it is possible to use IRE also for simple power plants, such as a single generator, a single storage or only a simple passive load.

The above mentioned DSO requests are necessary for several purposes, such as Voltage Control (VC), active power modulation, frequency control (function required by the Italian TSO), peak leveling, etc.

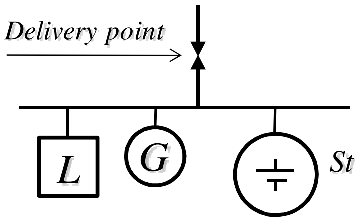

Figure 1. The FCP structure.

The IRE location

The Enel infrastructure for the POI-P3 project is described in [1] and summarized, with reference to a secondary substation connecting a FCP, in Figure 2, where:

- the *Router* connects devices to the wide broadband communication network;
- the *Optical fiber* represents the communication medium between the Secondary Substation (SS) belonging to the Distributor and the FCP;
- the *RGDM/IC* is the sensors equipped-device for measurements, fault detection and automation;
- the *General Protection* device (PG) and the producer *Interface Protection* (PI), ensure appropriate voltage, current and frequency based protection, remote command actuation, telesetting, status signal, etc.;
- the *IRE interface*, located inside the distributed power plants, is designed to regulate energy exchange parameter at the interconnection point.

IRE FUNCTIONS

IRE implements a wide set of functions to perform energy regulation. Each function can be deeply parameterized and optionally activated. However, the present set of functions can be extended simply modifying its IEC 61850 profile. IRE allows managing FCP macro-blocks in order to reach the goal requested by the DSO without penalizing the client and being compatible with the plant necessity (According to the current Italian regulatory rules, the DSO requests are not mandatory and the producer is not obliged to comply with them).

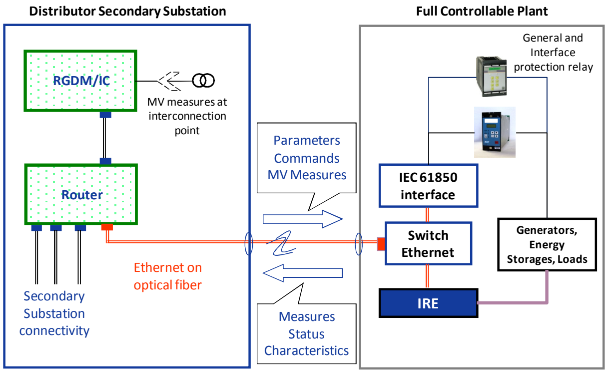

Figure 2. POI-P3 project architecture.

Active power regulation function

The active power regulation function is able to limit the injected/absorbed active power at the delivery point (see Figure 3). A limitation of the injected active power can be necessary in case of network contingency; however, the FCP could store the exceeding power in a storage, so avoiding loosing energy. The same concept can be applied to load limitation; in this case, the limitation can be performed absorbing the necessary energy from the storage.

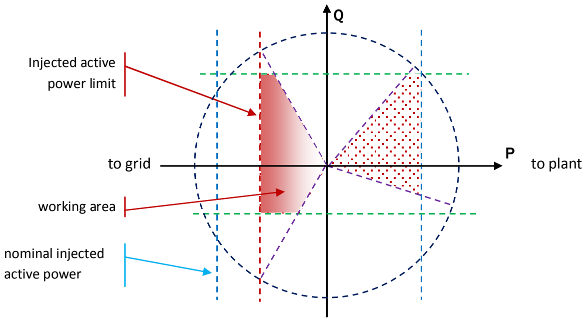

Figure 3. Working area in case of injected active power limitation.

Active power-frequency regulation function

This function satisfies the TSO request in terms of power system stability improvement, when a large Distributed Generation (DG) is present inside the distribution network.

This function allows reducing the injected active power when frequency grows up. Of course, the active power reduction occurs only when the frequency goes outside a defined "dead-band". The active power drop can be defined in the function parameters. The active power-frequency regulation function characteristic is sketched in Figure 4.

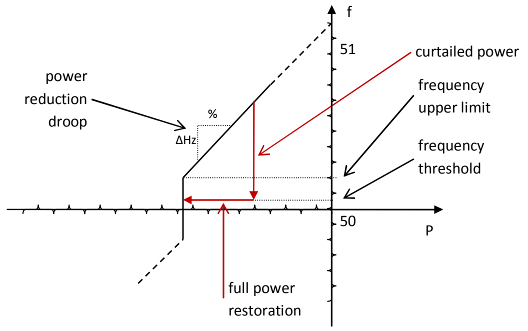

Figure 4. Active power-frequency regulation function characteristic.

Peak-leveling and power tracking function

Let us consider Figure 5. The *outgoing power P* is defined by loads and generators installed in the outgoing section of the line; it is real-time measured by RGDM/IC sensor and contemporarily calculated by the Distribution Management System (DMS, see [1]) as forecasted set of values. The *compensated power* P' represents the DSO requested power flow at the incoming section. The peak-leveling and active power tracking function modulates the FCP active power (*power compensation flow*) in order to obtain the compensated power profile.

This function is now being implemented in a real storage system installed in another Italian pilot project [2].

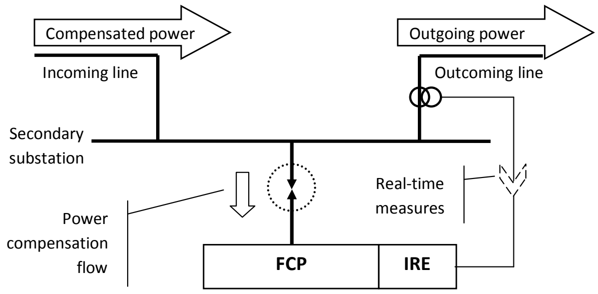

Figure 5. Power tracking functional diagram.

Reactive power regulation functions

The reactive power regulation functions are necessary in order to meet several goals: such as network voltage control and reactive power flows management. These functions can be listed as follows:

1. Q(V) [1], which locally calculates the reactive power set-point related to the requested *Voltage* at the network connection point,
2. PF(P), which locally calculates the active power set-point related to the requested *Power factor* at the network connection point,
3. Q-set, which remotely imposes, to the FCP, a reactive power set-point
4. PF-set, which remotely imposes, to the FCP, a power factor set-point.

Functions 1 and 2 are based on local actions performed directly by IRE without any intervention of Central control.

The centralized set-point management can be performed the functions n. 3 and 4. Remote control can be used when a local regulation is not enough to reach the goal. For example, if the voltage in a connection point exceeds a pre-defined maximum value, despite local actions, the Control Center can sent reactive power set-points to the FCPs that are very close (from an electrical point of view) to the first one, in order to restore the correct voltage value (see [4]-[5]).

Let start from the Q(V) function description, referring to Figure 6, where V is the measured voltage and Q is the absorbed reactive power at the connection point. The voltage measure is provided to IRE by the RGDM/IC sensor installed at the connection point in the distributor secondary substation (see Figure 2). The same for reactive power that is sent in order to allow a closed-loop regulation (all these measured values are exchanged via IEC 61850 GOOSE messages).

The voltage range V2-V3 is the regulation dead-band, which avoids unnecessary reactive power exchanges when V is very close to the nominal voltage; outside the dead band, the relationship between V an Q is linear.

Since network dynamics can create continuous working point oscillations, a voltage hysteresis is also defined. The Q steps due to the hysteresis are smoothed using a settable "actuation ramp".

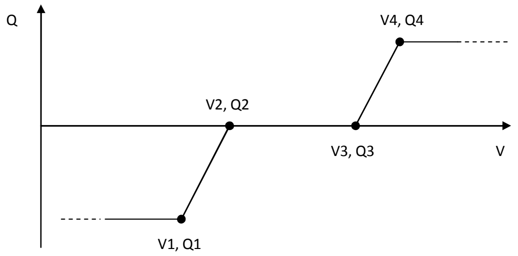

Figure 6. Q(V) function characteristic example.

The PF(P) function operates analogously to Q(V). Figure 7 represents an example of the PF(P) function characteristic. Also in this case the relationship between PF and P is linear.

It is important to highlight that the curves in Fig.6 and 7 are defined by points (4 points in Figure 6 and 2 points in Figure 7). The number of these points can vary with the complexity of the curve that is why IRE is projected to accept more complex shapes.

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[1] Further information on PF(P) and Q(V) are available in [3].

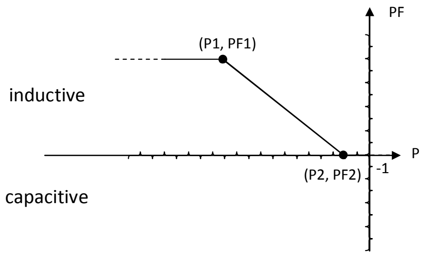


Figure 7. FP(P) function characteristic example.

Capability, Status and Measurements

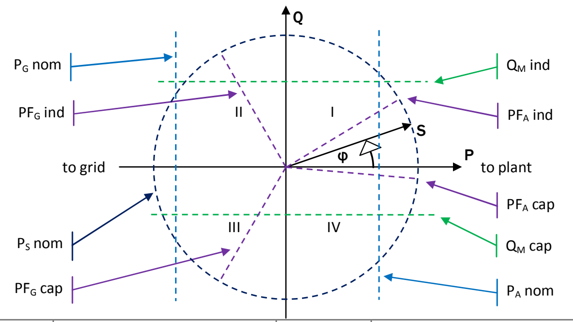
In a Smart Grid context the DSO must know FCP capabilities, its status and the main measures regarding power flow and voltage. In order to reach this goal, IRE communicates a set of data to the remote control centre.

With reference to FCP capability curves, IRE manages only a synthetic subset of parameters, avoiding complexity. As a matter of fact it is enough to know the macro-blocks power limits, as reported in Figure 8.

In fact, the DSO has not certainty about distributed power plant control because, in several situations, a power plant cannot be able to satisfy a specific request even if it usually has the capability to do it.

Therefore DSO must work in a probabilistic way: it sends a reasonable request to the FCP based on macro-blocks limits but the effective response is not guaranteed. However, due to the big number of power plants, it is very likely to obtain a shared contribution, in terms of regulation.

IRE also acquires status signal and measurement from the plant, and transmits them to the remote control centre in order to know the macro-blocks status and correct the estimations regarding the real capability of each one. The real amount of load and generation will be also sent to the TSO, divided per generation source and aggregated for each HV/MV transformer.



$P_G$nom/ P_A nom	Nominal active power in generation/absorption	P_S nom	Nominal apparent power
Q_M ind	Maximum reactive inductive power	Q_M cap	Maximum reactive capacitive power limit
PF_G ind/ PF_A ind	Maximum inductive power factor in generation/absorption	PF_G cap/ PF_A cap	Maximum capacitive power factor in generation/absorption

Figure 8. Representation of macro-blocks power limits.

RESULTS FROM SIMULATIONS

Q(V) voltage control function analysis

Some experimental results, obtained using the Real-Time Digital Simulator (RTDS), have been already performed in our laboratories. The simulated network consisted in a 30 km length MV feeder with 5 DGs (4 solar-based and 1 wind-based), homogeneously disposed along the line. The total nominal generated power was 4 MW and the total load peak power was 3.2 MW. Each generator was equipped by IRE simulated functions.

The first "base" case study, was related to the network without any voltage regulation. The second one presented the above described Q(V) regulation function enabled in each DG connection point.

In a real situation of case study 2, the generator that overcame the maximum allowed voltage was G5 (solar-based 1 MW generator, installed at the end of the feeder). G5 daily voltage profile is represented in Figure 9, where the cyan curve and the green curve represent, respectively, the first study (without voltage regulation) and the second one (with the Q(V) function activated). It is important to note that the Q(V) voltage regulation produced a voltage reduction of about 0.03 p.u. In the base case, the generator peak voltage was close to 1.11 p.u., value which causes the interface protection tripping. With the local voltage regulation no trips occurred. Moreover, we can observe an increase in the hosting capacity of the feeder.

In particular, the maximum hosting capacity increase, is close to +27 %, using a 1.10 p.u. voltage limit in all nodes.

The violet dashed line shows the reactive power measured at G5 terminals (the positive value corresponds to reactive power absorption from the grid). The stepped shape is due to the above mentioned voltage hysteresis of the Q(V) IRE function.

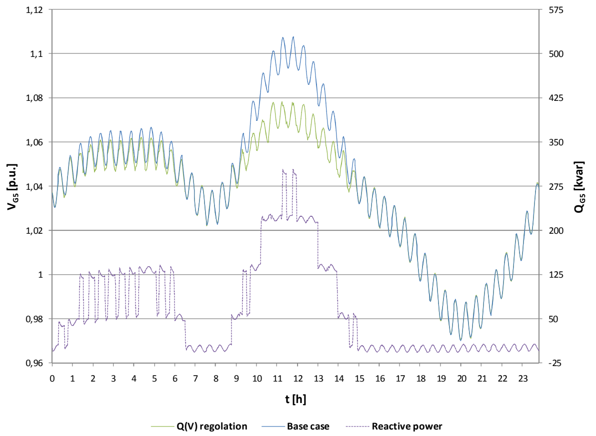


Figure 9. G5 voltage without voltage regulation and with the Q(V) voltage function in active state.

CONCLUSIONS AND FUTURE DEVELOPMENTS

After the experimentation phase and pilot projects, it is very likely that each power plant will be equipped with a device or a control system implementing IRE functions.

Of course, IRE should not be a device provided by Enel, but a unified interface built-in all commercial power plant controller. In this way the cost of the equipment, in charge of the client, will be very low and comparable with the cost of a simple data logger or remote control system.

The producer will have to provide these functions or "network services" according to a specific network code to be stated by the Regulator.

This is why, after the real field test, a new regulatory framework must be proposed to operate the network with the new technologies, on a daily base.

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