#4 MV grid voltage control and anti-islanding systems in the Demo4

<table>
<thead>
<tr>
<th>Type of solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Equipment / Hardware / Firmware</td>
</tr>
<tr>
<td>• Information system</td>
</tr>
</tbody>
</table>

**Manufacturer(s) implied (for equipment or hardware)**
SIEMENS Italia

**Work Stream considered**
• DER integration
• Storage
• Islanding

**Location / Topology (with regards to distribution grid)**
• HV/MV Substation
• MV
• DER
• Other Centralized system (calculations, information system)

**Thematic(s)**
• Grid Monitoring / state estimation
• DER Integration / increased grid capacity
• Anti Islanding protection

**Use Case(s)**
• Voltage control on MV grids (with high DER penetration)
• Anti-islanding protection on MV grids

**Key figures**
• Distributed energy resources (DER) available:
  - 4 photovoltaic generators
  - 1 energy storage system
• Control resources available in the HV/MV Substations:
  - 4 OLTC for 2 Primary Substations (2 per each HV/MV Substations)

---

**Objective and technical requirements**

**Context & Objective**
Electrical network has been historically designed for mono-directional power flows (from large power plants to loads). Today we are seeing the introduction of a new paradigm related to distributed generation which provides two-way power flows. A massive penetration of distributed generation can cause problems related to power quality, network protections, imbalances generation / load and overload thus deteriorating the quality of power supply. These facts have led to a reconsideration of the classic power grid control systems.

An adequate and dedicated evolution of control system, which could cope with the widespread diffusion of distributed generation, can be achieved through the use of coordinated resources on a decentralized system architecture as shown in the **figure 19**.

---

The control system realized aims at increasing MV grid hosting capacity through:

1. Implementing Voltage Control (at all nodes) and Power Flow Control in the MV network (including the use of storage systems);
2. Managing efficiently and reliably the Disconnection of DER units in the event of unwanted islanding operations;
3. Enabling Ancillary Services for Network operation provided by DER

Regarding the first point, the objectives of the algorithms developed in the framework of the Demo4, consists in minimizing the overall ‘cost’ of the dispatching actions needed to satisfy the technical constraints, first of all the voltage magnitude at nodes.

In case of voltage limits violation due to the strong penetration of DER, the voltage control function regulates the voltage profile computing appropriate set point commands for the distributed energy resources. Shown in **figure 20**, calculation algorithms main interconnections.

---

**Requirements**

Instead relatively to the second point, the anti-islanding algorithm goal is to disconnect from the grid all the generators that are localized along a MV line/lines that are no more energized from the main power network (this can happen because of faults or maintenance works on those MV lines).

The algorithm assigns to each grid element (Primary Substation switch, Secondary Substation switch) a unique identifier (called “tag”) to describe the position of the element on the grid topology. When a switch is opened, the identifier of that element is sent via the communication network (using IEC 61850 GOOSE messages)
to all the devices of the MV network; each device, comparing the received identifier with its own identifier, is able to determine autonomously its position on the grid (if the MV plant, along the feeder, is before/after the opened switch) and decide if the generator disconnection is necessary. Details shown on figure 21 and 22.

Figure 21 - Goose tag dispatching logic for Anti-islanding

Figure 22 - Electrical network graph generated for 61850 tagging

Development and implementation

Architecture and technical characteristics

Starting from the overall system architecture developed in Demo4 and shown in figure 23, main sub-systems involved in MV voltage control and anti-islanding use cases can be grouped in three main parts (level) of the entire system (DSO Operative Control Center, HV/MV - Primary substation and MV/LV - Secondary Substation). Some of these sub-systems are totally new, while other parts are upgrades of the current systems installed.

The Network Calculation Algorithm System (NCAS) (shown in figure 24) is the core system SW implementing the calculation algorithms. It is designed to be open and modular with standard interfaces (HTML/SOAP). Main components are:

- Network Manager
- Topological Processor
- Plug-In Algorithm Manager
- Load/Generation Profiles Manager

DSO Operation Control Center ➞ Substation Control System remote controlling and monitoring functions introduction (A.1)

Primary Substation evolutions ➞ Local SCADA system introduction (A.2)

Secondary Substation and Customer evolutions ➞ Energy Regulator Interface introduction (F)

The Network Calculation Algorithm System (NCAS) is the core system SW implementing the calculation algorithms. It is designed to be open and modular with standard interfaces (HTML/SOAP). Main components are:

- Network Manager
- Topological Processor
- Plug-In Algorithm Manager
- Load/Generation Profiles Manager
**TPT2020.** This device is the RTU installed in the HV/MV substation and allows the communication among SCS, OCS and MV field devices (wired or using 61850 protocol). It is able to process the voltage regulation set points transmitted by the NCAS and manages the anti-islanding algorithm. Details shown on figure 23.

**DV7500 (PIT).** This is the integrated HV/MV transformer protection device, compliant to IEC 61850 protocol, which manages primary substation MV busbar voltage regulation.

**DV7300.** This device interfaces the generators protection system; it converts and transmits messages from the MV central control system to the local customer protection system.

**RGDM.** The RGDM (acronym of “Rilevatore di Guasto Direzionale e Misura”) is an intelligent electronic device for measurements acquisition (on MV side) and fault passage indication; it is installed in the MV/LV substations and in the “DSO side” of the generator’s MV substations.

**IRE.** This device is the energy regulation interface that is able to realize active/reactive power regulation for each MV generation plant.

The devices installed at secondary substation & generators level are briefly described below and figure 26 shows the connections between them.

**Lab tests**

The whole Demo4 system architecture has been replicated in Enel’s laboratories in order to perform the overall system integration tests, before field commissioning and tests. Figure 27 depicts all the components used for the laboratory set up, in details:

1. A Rack provided with Central SCADA and Load & Generation Forecast system;
2. A Rack provided with primary substation control sub-systems (Local SCADA, Network Calculation Algorithm system and Remote Terminal Unit-TPT2020);
3. An Integrated Transformer Protection (DV7500);
4. An Energy Regulation Interface (IRE);
5. A Directional Fault Detector/Measurements acquisition device (RGDM);
6. RTDS® system (Real Time Digital Simulator).

Thanks to this set up it was possible to go through different kinds of integration tests, related to:

- Data and commands exchange between systems and devices (measures, db alignment, forecast data, etc);
- Single devices and overall system functionalities (IRE, RGDM, voltage regulation, etc);

The Simulation of the electrical network field was possible thanks to the use of Real Time Digital Simulator RTDS®, which is used to provide the real system response during closed-loop testing.

**Field implementation**

The following systems were deployed in field:

- 2 SCS (1 for each Primary substation) – see figure 28 for internal architecture details
- 2 workstations in Operation Center
- 1 OCS system enhanced with new functions
- 4 IRE on MV plant producers

Internally, an SCS has 2 physical nodes consisting of:

- 1 PC PANEL (Siemens SIMATIC)
- 1 TPT2020 (Primary substation RTU)

On PC PANEL, to implement a local (SCADA), have been provided 3 environments:

- 1 UEL as Elaboration Unit
- 1 SOZ as Operation HMI
- 1 FERP as Primary Substation Front End

In addition to above, another environment has been created to grant algorithm calculations:

- 1 NCAS (Network calculation algorithm system)
The Substation Control System (figure 29) has the following functionalities:

- Local Supervisory Control And Data Acquisition (SCADA).
- Network topology management.
- Algorithms for power flow management and DER control (voltage regulation, active power flows control, anti-islanding procedures) and storage device dispatching.
- Human Machine Interface.
- Configuration of local database.
- Communication with Distribution Control Center (OCS).

The OCS integration with SCS is completed by the presence of remote HMI’s of primary substation systems (figure 30) for monitoring the operations and for allowing the operators to enable/disable the SCS functionalities in case it is necessary.

Tests

On Network Calculation Algorithm System (NCAS) side

Calculations have been held on field and realized by the Substation Control System installed in the Quarto Primary Substation considering an autumn weekday; in detail, results of the Multi-period Voltage Regulation algorithm are shown in Figure 31 (the considered time horizon is 24 hours).

The algorithm considers the On Load Tap Changer of the HV/MV Primary Substation transformers, MV generation plants and the Storage system. Figure 31 shows:

- the calculated MV bus-bar set points trend (those set points were not applied on field) and the real field MV bus-bar measures (without any Voltage Regulation control action – VR off)
- the “Quarto” Primary Substation Active and Reactive Power trends estimated by the Voltage Regulation algorithm (obtained if all the set points would have been applied on field – VR on)

Reactive power set points are calculated by the Voltage Regulation algorithm installed in the Quarto Primary Substation, then they are sent to the Primary Substation RTU (TFT2020); at the end they are transmitted to the MV generation plant.

Locally (at generator’s side), the received set point is managed by the Energy Regulation Interface (IRE) and sent to the data logger that is responsible for the final split of the set point between the different inverters of the plant. In addition, an example of two MV feeders (connected to two different Primary Substation MV bus-bars) with the comparison between the “baseline” voltage trend and the “Smart Grids solution” trend (Figure 32); in this case, the Voltage Regulation (VR) algorithm increases as much as possible the feeder’s voltage profile (according to all the technical constrains) to minimize network losses.

Calculations Platform stability tests, held in laboratories (in simulation mode), have shown a system robustness which can assure 6 months operation without interruption. The iterated elaborations are:

a. Power grid topology update + Measures/states elaboration
b. State Estimation execution
c. Voltage Regulation execution

On field, each complete iteration takes 200 seconds considering that Voltage Regulation runs on a time horizon of 24 hours per day to include storage (96 Voltage Regulation algorithm runs per day).

Details about NCAS performance figures are shown on figure 34.
Figure 32 - Reactive power set points for the four photovoltaic plants connected to the Quarto Primary Substation MV network + Feeders voltage trend

Figure 33 - Active power set points for the Storage system and the State of Charge trend provided by the algorithm to optimize the network operation on the considered time horizon (24 hours)

<table>
<thead>
<tr>
<th>Test Mode</th>
<th>Elaboration type</th>
<th>N.Iterations</th>
<th>N.days</th>
<th>Max memory occupation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation</td>
<td>Power grid topology and measures/states update (one iteration) + Complete State Estimation + Voltage Regulation</td>
<td>96 per day (Total - 17280)</td>
<td>180 gg</td>
<td>1.222.340 Kilobyte</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test Mode</th>
<th>Elaboration type</th>
<th>N.Iterations</th>
<th>N.secs</th>
</tr>
</thead>
<tbody>
<tr>
<td>On field</td>
<td>Complete State Estimation + Voltage Regulation (on Multiperiod) (96 VR runs per complete execution)</td>
<td>1</td>
<td>200 secs</td>
</tr>
</tbody>
</table>

Figure 34 - NCAS Performance figures

On Energy Regulation Interface (IRE) side
IRE test procedures held on field included the following steps:

- Writing a reactive power request directly into the input process variable of IRE (with a dedicated programming tool). NOTE: the reactive power request received by IEC61850 protocol is written into the same variable; this makes this test very reliable and close to the behavior of the completely integrated system.
- Check of the correct computations into the IRE CPU (from percentage (with sign) of nominal apparent power - $S_{MAX}$ - to $\cos \phi$. NOTE: $S_{MAX}$=4108=432 kVA
- Check of the current value passing from the IRE analog output board to the I/O module
- Check of the correct acquisition of the current value by the MV plant data-logger
- Verifying the imposed $\cos \phi$ (and the reactive power of the plant) considering the measurements acquired by IRE

Replication, next steps and up scaling
The entire NCAS platform (State Estimation and Voltage Regulation) has demonstrated to be a good starting point for implementing the Demo functionalities, but it requires further developments in order to be applied to other DSO’s networks with different distributed generation penetration, different grid topology (MV feeder composition, number of Primary/Secondary Substations) and different critical issues to solve.

About IRE, the Energy Regulation Interface was developed according to specific requirements and adopting a 61850 profile set by ENEL to be compliant with all the other devices already installed on field. All this guaranteed a quite easy integration of IRE device in the system and is a solid base for replicability and scalability of the system.

Intellectual property (IP)
SIEMENS developed, in collaboration with Politecnico di Milano, core network calculation algorithms (Power Flow / State Estimation) whose intellectual property exclusively owns.

Regulatory challenges
The massive distributed generation connection that during recent years was carried out according only to the “fit & forget” principle brought to some critical issues about observability and control of the electrical grid.

Some first steps were already done by the Italian regulatory authority about new connection rules and protection systems of those plants: from a perspective point of view, a very strict cooperation among TSO and DSO is needed (data exchange and common goals).
Conclusion and key messages

The idea of this project appeared very ambitious, not only to have evolved the operation control system with a new SCADA system, but also to have implemented Smart Grid logics in the primary substations.

This project was meant to improve power grid on certain electrical key parameters. First results have shown benefits of using voltage regulation of the On Load Tap Changer of the HV/MV transformer, generators and Electric Energy Storage System. In addition this experience gave the possibility of acquiring skills and technologies for the development of new systems (smart-grid oriented) in order to face power grid “revolution” challenges.

Most of the system parts (devices, software, etc) are very innovative and this brought to additional work especially during the field deployment phase due to some issues that didn’t emerge during the laboratory tests. However all this work brought to a lot of improvements able to deal with “real field” problems.