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Italian demonstrator - DSO support to the transmission network operation

Deliverable 6.8

EU-SysFlex

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TABLE OF CONTENTS

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

AB	Advisory Board
ADMS	Advanced Distribution Management System
BESS	Battery Energy Storage System
BUC	Business Use Case
CA	Consortium Agreement
CEI	Comitato Elettrotecnico Italiano (Italian Electrotechnical Committee)
DoA	Description of Action
DB	Demonstration Board
DER	Distributed Energy Resource
DSO	Distribution System Operator
DV7203	Medium Voltage Feeder Fault Detector
DV7500	Integrated Protection of the High to Medium Voltage Transformer
EC	European Commission
EC-GA	Grant Agreement
EU-SYSFLEX	Pan-European System with an efficient coordinated use of flexibilities for the integration of a large share of Renewable Energy Sources (RES)
GA	General Assembly
GOOSE	Generic Object Oriented Substation Event
GSP	General System Protection
HC	Hosting Capacity
HMI	Human Machine Interface
HV	High Voltage
IEC	International Electrotechnical Committee
IED	Intelligent Electronic Device
IRE	Energy Regulation Interface
KPI	Key Performance Indicator
LV	Low Voltage
MO	Management Office
MV	Medium Voltage
NCAS	Network Calculation Algorithm System
OLTC	On Load Tap Changer
O&M	Operation and Maintenance
P	Active Power
PC	Project Coordinator
PF	Power Factor
PMB	Project Management Board
PV	Photovoltaic
PWM	Pulse Width Modulation
Q	Reactive Power
Q&A	Questions and Answers
RES	Renewable Energy Source
RGDM	Secondary Substation Fault Detector
RMS	Root Mean Square
RTDS	Real Time Digital Simulator

RTU	Remote Terminal Unit
SCADA	Supervisory control and data acquisition
STATCOM	Statci Synchronous Compensator
SUC	System Use Case
TM	Technical Manager
TPT2020	Remote Terminal Unit of Primary Substation
TSO	Transmission System Operator
V	Voltage
VSC	Voltage Source Converter
WP	Work Package

EXECUTIVE SUMMARY

The EU-SysFlex H2020 project aims at a large-scale deployment of solutions, including technical options, system control and a novel market design to integrate a large share of renewable electricity, maintaining the security and reliability of the European power system. The project results will contribute to enhance system flexibility, resorting to both existing assets and new technologies in an integrated manner, based on seven European large scale demonstrators. In particular, the following document deals with the detailed description of the Italian Demonstrator, whose objective is analyzing and proving the exploitation of decentralized flexibility resources connected to MV distribution grid for system services provision to the TSOs.

This demonstration suggests innovative approaches in flexibility management in order to support transmission system operators' (TSO) and distribution system operators' (DSO) needs and their related services, identified within the EU-SysFlex H2020 funded project.

This deliverable analyses the results coming from the Italian demonstrator, which, through the implementation of the recent improvements in the DSO control and monitoring system. It introduces the general technical scenario and the innovative and advanced devices used for the development of the smart grid infrastructure.

The main aspect that will be shown in this document is how laboratory simulations and field tests have led to the satisfaction of the set objectives and the achievement of the relative benefits, proving that the DSO is able to increase the distributed system observability having the possibility to control local assets directly owned or not (like Storages, STATCOM and Dispersed Generators) through an upgraded remote control systems, pursuing an evolved distribution grid operations.

In addition, the results collected from the field tests and laboratory simulations demonstrated that the DSO is able to implement the efficient provision of the information regarding the aggregated network capability at the interface with the TSO, which in the Italian demonstration is represented by the HV/MV substation. This is necessary since the DSO needs to manage renewable energy sources by itself in order to avoid violations in its network and to maintain a safe and secure network. In general, the deliverable was structured by proposing an overview on the Italian Demonstrator, illustrating the challenges, the relevant innovative aspects and the expected results from its operation.

Subsequently the Demonstration features has been analyzed focusing on systems developments and updates, installed or run during the project activities, giving a structure as detailed as possible of the impacted network and a knowledge of the overall actors contributing to the commissioning of the entire smart grid infrastructure.

Then, an analysis of the demo results was carried out while the relative KPIs deduced from considerations related to the experience gained. In particular, the real field Demonstration test was carried out in order to verify the effectiveness of the entire solution: central and local systems – devices – communication standards, in terms of optimized management of distributed resources finalized to enhanced network operations.

The grid analyzed scenario involved the 3 controllable PV generators (SANNA FTV 1, SANNA FTV 2 and QUARTO FTV) and the OLTC of the HV/MV Green Transformer, while the OTLC of the Red Transformer was excluded from the automatic voltage regulation for MV network operation needs.

As expected, the main achieved results are related to the automatic voltage regulation effect which allows to operate the involved network at a voltage level closer to the nominal value, with significant advantages in terms of network operation and increased hosting capacity.
On the other side, relevant observations have been carried out from the reactive power capability range rise point of view, by considering further results from a preliminary test held on February 3, 2022, when the contribution of controllable resources was analyzed.

1. INTRODUCTION

The main objective of the EU-SysFlex project is to enable the European power system to make use of efficient, coordinated flexibilities to integrate high levels of Renewable Energy Sources (RES) with the final goal of increasing the flexibility of the future European system.
First of all, the project aims at analysing the European power system, on which a huge part of the generated electricity comes from distributed sources such as wind and solar.
Therefore the EU-SysFlex project aims at a large-scale deployment of solutions, including technical options, system control and a novel market design to integrate a large share of renewable electricity, thus guaranteeing a high level of security and reliability.

In order to achieve the project's objectives, the EU-SysFlex consortium identified technical shortfalls with new subsequent network needs, designed new market scenarios to provide incentives for these solutions and how to perform the demonstration of a range of innovative solutions. The project approach involves detailed studies about different activities such as data management, innovative tools development and integration and testing of new functionalities. The results of this project contribute to enhance system flexibility, resorting both to existing assets and new technologies in an integrated manner, based on seven European large scale demonstrators in Germany, Italy, Finland, Portugal (2), France, and the Baltic states (WP 6, 7, 8 and 9).

In particular, the mentioned activities and objectives are considered in the Work Package (WP) 6 *"Demonstration of flexibility services from resources connected to the distribution network",* which analyses the opportunities arising from decentralized flexibility resources connected to the distribution grid, to serve the needs of the overall power system, in coordination between DSOs and TSOs, thanks to three demonstrators located in Germany, Italy and Finland.

1.1 WP6 AND DEMONSTRATOR OBJECTIVES

The primary objective of WP6 is to analyse and test the exploitation of energy resources connected to the distribution grid in order to provide flexibilities and ancillary services to the TSO, according to the needs of DSOs and TSOs.
Nowadays, the current policies for the decarbonisation of the energy systems are leading to an increase of RES capacities, especially in the distribution network, and to a corresponding decrease of the amount of energy produced by conventional generators. As a consequence, the DSO has to technically validate the aggregation of flexibility resources in the distribution grid, in order to satisfy the needs of both TSO and DSO by avoiding congestions and constraints violations and operating the DSO grid in a more secure and resilient way so that the cooperation between TSOs and DSOs becomes essential.
In detail, three sub-objectives have been identified:

- Improve the TSO-DSO interaction;
- Provide ancillary services to the TSOs from flexible units connected to the distribution grid;
- Investigate how these flexibilities could meet the needs of both TSOs and DSOs

The Italian Demonstrator takes advantage of a constantly evolving infrastructure in order to create a developed smart grid. This is possible by integrating the SCADA with a new generation of Intelligent Electronic Devices (IEDs), fully involving the DSO assets and the RES connected to the distribution network into the provision of ancillary services to the TSO (e.g. congestion management, balancing and voltage support), taking into account the TSO and DSO's needs and constraints mutually.

The provision of the listed ancillary services, provided by the RES and DSO assets, is fully supported by the improvement of TSO-DSO data exchange, by a higher observability of MV network for the DSO, thanks to new requirements for capability aggregation at the Primary Substation interface. Furthermore, a platform of network calculation algorithms is exploited, performing an optimization procedure with some techno-economic constraints in order to maximize and optimise the involvement of RES and DSO assets.

1.2 SCOPE AND OBJECTIVES OF THIS DELIVERABLE

This document (Deliverable D6.8) presents the necessary information regarding functionalities implemented in the Italian Demonstrator.
In particular, the scope of this deliverable is to point out the Italian demonstration's purposes, innovative elements, both laboratory testing and real field implementation and obtained results. It highlights that the approach is always oriented towards the improvement of the data exchange between DSO and TSO with the aim of providing power modulation at HV/MV substation level for TSO requirements.

WP 6 addresses the objectives stated in chapter 1.1 through five interlinked tasks. Task 6.1 is related to needed Work Package coordination. Task 6.2 is focused on the definition of System Use Cases (SUC) based on the Business Use Cases (BUC) defined in WP3. Within Task 6.3 systems and tools were developed in order to set up the SUC. In Task 6.4 the demonstrators are being set up and performing. The resulting field tests are carried out. Furthermore, the results of these field tests will be also analysed and common conclusions will be drawn in Task 6.5.

The list below includes all the deliverable which were drafted in WP6 activities:

- Deliverable 6.1 "*Demonstrators Use Cases description*" presents the description of all the system processes (and corresponding functionalities) which support business activities, defined in the Business Use Cases (developed in Task 3.3 and presented in Deliverable 3.3 "Business Use Cases for Innovative System Services");
- Deliverable 6.2 "*Forecast: Data, Methods and Processing. A common description*" presents the description of requirements of the DSO/TSO interface, in order to harmonize the data formats and models for all the trials;
- Deliverable 6.3 "*Grid simulations and simulation tools*" presents the first results about network models and simulations from the demonstrators;
- Deliverable 6.4 "*General description of the used data as a basis for a general data principle*" presents the description of communication interfaces between the actors involved in the demonstrators;

- Deliverable 6.5 "*Optimization tools and first applications in simulated environments*" presents the description of the optimization tools and the range of flexibilities used in the demonstrators;
- Deliverable 6.6 "*Demonstrators for flexibility provision from decentralized resources, common view*" presents the deployment plan, including technical specifications, procurement procedures fortechnical equipment, timeline for installations, and monitoring procedures.

Their outcomes have been taken into account and analysed in the present document.

A schematic overview of the relationships between tasks is presented in Figure 1-1:

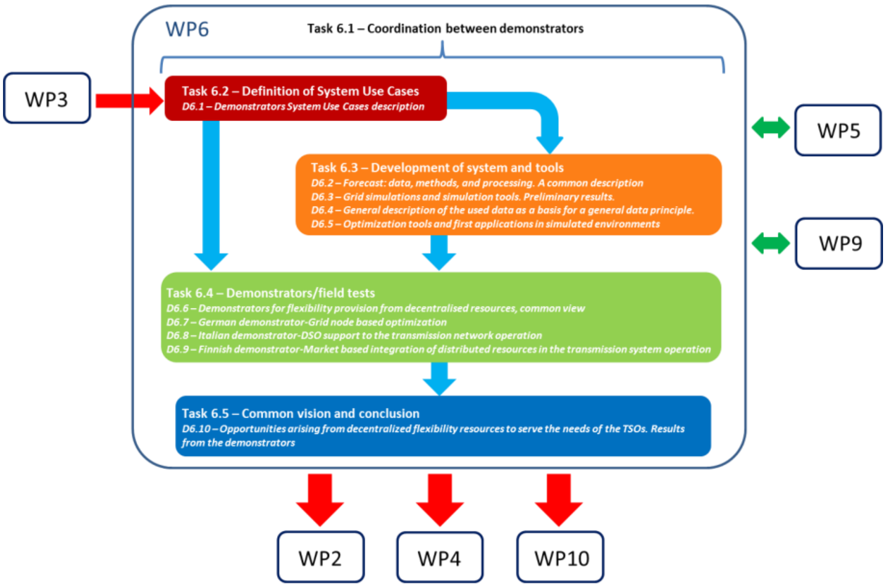


FIGURE 1-1 – WP6 OVERVIEW AND RELATIONSHIPS WITH OTHER WORK PACKAGES

The other deliverables for Task 6.4 are shortly listed below:

- Deliverable 6.7 *"German demonstrator - Grid node based optimization"* presents the information about the German demonstrator results, including the description of the working framework;
- Deliverable 6.9 *"Finnish demonstrator – Market based integration of distributed resources in the transmission system operations"* presents the information about the Finnish demonstrator results, including the description of the working framework.

Within Task 6.5 "Common vision and conclusion" will be drafted Deliverable 6.10 *"Opportunities arising from the decentralized flexibility resources to serve the needs of the TSOs. Results from the demonstrators"*, which will presents common conclusions and recommendations from the demonstrators' activities, in order to contribute to the WP objectives and overall Project results.

1.3 STRUCTURE OF THE DOCUMENT

The structure of the deliverable is as follows:

- Chapter 2 presents an overview of the Italian Demonstrator, illustrating its challenges, the relevant innovative aspects and the expected results;
- Chapter 3 deals with the demonstrator functionalities and systems that have been developed, updated, installed or run during the project;
- Chapter 4 presents and analyses the results of the demo;
- Chapter 5 carries out important considerations and recommendations related to the acquired experiences and the results of the demonstration and the exploitation plan with further research questions;
- Chapter 6, as a conclusive chapter, recaps Task 6.4 and Italian Demonstrator activities with the achieved objectives.

2. GENERAL OVERVIEW OF THE DEMONSTRATOR

The Italian Demonstrator analyses the DSO infrastructure evolution, through the integration of the SCADAs and platforms with advanced smart grid devices, in order to provide flexibilities and ancillary services (e.g. voltage control, congestion management, frequency balancing) to the TSO, always considering both TSO and DSO needs and constraints.
The demonstration aims to improve the data exchange between the TSO and the DSO and to perform power modulation at the HV/MV substation level for TSO requirements, thanks to:

- the development and integration of tools, systems and devices within the DSO infrastructure;
- the development of new actions needed for a better coordination between the TSO and the DSO;
- the improvement of network observability and forecasting systems for network state estimation issues;
- the development of a platform of network calculation algorithms, based on an optimization process with some techno-economic constraints, which allows to maximize the involvement of DERs and DSO assets.

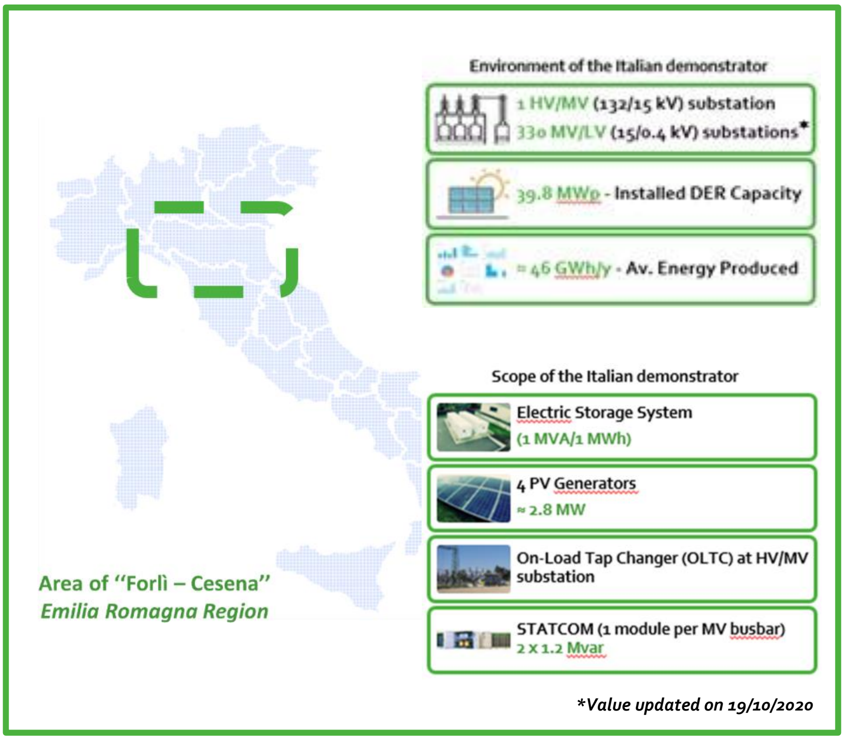


FIGURE 2-1 - LOCATION OF THE ITALIAN DEMO SITE.

As illustrated in Figure 2-1, the demonstration site is located in the area of Forlì-Cesena (Emilia Romagna region) which is characterized by a strong penetration of renewable generation (mainly PV) and low load consumption thus causing frequently back-feeding phenomena from MV to HV network. The involved portion of the distribution grid includes:

- 1 HV/MV (132/15 kV) substation and all 8 MV feeders connected to the substation;
- About 330 MV/LV (15/0.4 kV) substations;
- Installed DER Capacity: 39.8 MWp

- Average energy produced per year: ~46 GWh/y.

The involved flexible resources are:
- 1 Electric Storage System (1 MVA/1 MWh);
- 4 remote controlled PV generators;
- 2 On-Load Tap Changers at HV/MV substation;
- 2 STATCOMs (1,2 MVAr for each MV busbar).

2.1 STATUS-QUO, DRIVERS AND CHALLENGES ADDRESSED BY THE DEMONSTRATOR

The distribution networks in Italy are characterised by a high penetration of RES (about 24 GW of RES connected to the distribution network level in Italy, for about 120GW of total installed electricity production capacity), which can cause voltage violations and congestions. The DSO must guarantee a high quality of distribution network services, by adopting some actions such as the replacement of lines and transformers, even if this kind of solutions is not always reasonable so that the implementation of a smart grid architecture represents a step ahead within network operations.
For this reason, in the last years, advanced control solutions, in addition to improved and innovative network automation technologies, have started to be adopted for the management of the DSO network.
Nowadays, the increase of energy generated by RES and the decrease of generation from traditional plants, cause a lack of resources which were used to regulate frequency and voltage in the transmission network. This causes higher probabilities to have congestions. As a consequence, the Italian TSO (Terna) needs to take some measures such as planning new connections between the north, where the load is concentrated, and the south, where the generation is higher and by installing compensation devices (e.g. STATCOM). This forces the TSO in involving conventional generators in the ancillary services market.
In this framework, the Italian Authority incentivizes the adoption of smart grid solutions by DSOs in order to improve the operations of distribution networks and also acts to support the management of transmission network, encouraging the aggregation and the access of RES to the ancillary service market. For this reason the project aims at showing how the DSO designs and implements network functionalities, considering all the technical aspects and regulatory restrictions.
This may allow the DSO to exploit DERs in contingency situations and to guarantee determined levels of continuity of supply and quality of energy.
This need to guarantee service continuity and to solve problems related to typical electrical disturbances, like voltage variations or interruptions due to extreme weather conditions, pushes the Italian demonstrator to foresee and analyse new scenarios in which DERs are exploited to solve blackouts, enabling the concept of resilient network.
The DSO needs to operate always in security and safety on the distribution network.

2.2 GOALS OF THE DEMONSTRATOR AND CONTRIBUTION TO THE WP6 AND PROJECT'S OBJECTIVES

The Italian Demonstrator functionalities are directed to the following purposes:

- Including RES, Storage, STATCOMs and OLTCs in congestion management, balancing and voltage support;
- Setting up a new coordinated process for ancillary service provision to the TSO;
- Developing automated tools for Network State Analysis, Network Optimization and Reactive Power Management;
- Integrating improved forecasting for RES generation and load.

The above mentioned objectives brings the DSO to the possibility to aggregate the available distributed resources thus providing flexibility and ancillary services to the TSO for a general better management of both transmission and distribution networks.

2.3 INNOVATION OF THE ITALIAN DEMONSTRATOR

The Italian Demonstrator innovative approach focuses on using RES, Storage, STATCOMs and OLTCs in the congestion management, balancing and voltage regulation for both DSO and TSO needs.
The project, based on the experience from Grid4EU, in order to improve the previous results, introduces the innovative elements that are shown below:

- The installation of the STATCOM which is a new device in the distribution network for voltage support, reactive power regulation and power factor correction.
- The aggregated reactive power capability calculation which allows the DSO to make available to the TSO the amount of reactive power that can be provided by local resources.
- An improved network calculation platform for network state estimation and optimization issues, thus obtaining the evaluation of the reactive power capability at the Primary Substation (HV/MV substation).
- The development of data exchange between DSO and TSO for a better observability for the TSO of the aggregated decentralized resources at the primary substation interface.

Except for the integration of RES and Storage for congestion management and frequency balancing services that has been simulated, all the available resources are involved in voltage regulation which is tested in the field by interfacing RES and DSO devices (Storage, STATCOMs and OLTCs) with the existing infrastructures.
Within the Italian Demonstration, the STATCOMs are tested to perform Reactive Power compensation and Voltage Support. Positive results from this experimentation encourage:

- A new kind of service at the TSO/DSO interface;
- A new approach to network operation aimed at maintaining a high quality voltage profile in each node of the distribution network;
- A massive installation of new tested assets in the distribution network with high penetration of DERs, long MV feeders and distribution Hubs.

The SCADA systems, which are already able to evaluate network state, thanks to real-time measurements acquired by Smart Grids devices, and to perform optimisation calculations, sending control commands to the available

resources, have been developed in order to maximize the provision of services to the TSO by distributed energy resources.
This has required an improved Distribution Network Observability, which in the Italian Demonstrator is updated to set up a new coordinated process with the TSO. In particular, by integrating improved forecasting for RES generation and load, allowing best performance within the calculation of the reactive power capability of each resource and aggregating this information at the Primary Substation interface.

The Italian Demonstrator tests also an automated coordination process between DSO and TSO by using an IEC 104 protocol simulator, which should act as a substitute in the transmission of some specific signals and measurements between the DSO and the TSO.
In particular, considering that the Italian TSO Terna does not join EU SysFlex project, E-distribuzione simulates the data exchange between DSO and TSO SCADAs. Indeed, the Italian Demonstration innovative approach will lead to the possibility for the DSO to calculate and send the network capability to the TSO, in addition to the Active and Reactive Power measurements at the Primary Substation interface.

2.4 EXPECTED RESULTS AND KPI

The aim of the Italian demonstration is to prove that E-distribuzione is able to implement an efficient solution in order to provide an aggregated information of network capability at its interface with the TSO, which in the Italian demonstration is represented by the Primary Substation of medium voltage network. This is necessary since the DSO needs to manage RES by itself in order to avoid violations in its network and to maintain a safe and secure network.
In addition, the DSO can provide to the TSO a better observability of DERs making use of forecasting tools for an enhanced network state estimation and computation of reactive power capability, thus improving data exchanges between the two System Operators to guarantee safety in the operation of the electrical system.
Therefore, the demonstration analyzes how much the designed solutions are efficient and the acquired experience can be used to describe new requirements for Operation and Maintenance (O&M) procedures and to update the SCADA system for implementing new requests from the Authority.
Since the STATCOM is a new device in e-distribuzione infrastructure, the project tests its usefulness in terms of reactive power management and its operation can provide the following benefits:

- Limitation of reactive power flows at the Primary Substation;
- Meeting TSO requests at TSO/DSO interface;
- Supporting Voltage Control;
- Power factor compensation.

The specific indicators to be considered for evaluating the Italian Demonstrator efficient performance are related to the following parameters and will be widely explained in chapter 3.6:

- Analysis of the tracking error, that is the resulting error between the requested Reactive Power Set-point and the measured one, at TSO-DSO interface as well as in relation to each employed resource, thus proving the effective implementation of the required set point;
- Evaluation of the PV Forecast performances which is mainly processed by taking into account the error of PV plants, expressed in kW, as the difference between the exchanged active power and the forecast of generated power based on weather forecast.
- Estimate of the increase in reactive power capability at primary substation.

3. DEVELOPMENTS DURING THE PROJECT

The launch of EU-SysFlex project has required a list of actions necessary to find the best design solution, starting with all the developments and bureaucratic procedures and ending with the technical and physical implementation of the Italian Demonstration.

The whole Italian Demonstration infrastructure puts its basis on the existing hardware and system functionalities, developed within GRID4EU project. The main innovation introduced within EU-SysFlex project is then represented by the installation of the new device STATCOM, which will be fully described in chapter 3.3, which has required respectively:

1) Scouting within power converters, static compensators and storages market;
2) Technical specification writing and revisioning;
3) Vendors workshop for best technical compliance;
4) Launch of call for tenders;
5) Technical and economical offers analysis, performed in collaboration with procurement team;
6) Award of contract;
7) Device and system integration;
8) Installation in field;
9) Commissioning and starting of STATCOM operations.

The device integration between the STATCOM and the Primary Substation Remote Terminal Unit (RTU) TPT2020 has been possible after technical compliance of STATCOM IEC 61850 profile to the E-Distribuzione technical specification and the following development programmed for the RTU, in order to guarantee a correct transmission of events, commands and measurements from field to the SCADA located in Bologna.

As a consequence, a development of SCADA functionalities for STATCOM monitoring and management has been necessary in order to define the configuration procedure for operating the new network asset connected to the DSO network.

The remote control system has required also other developments for:

- State Estimation platform, addressed to its integration with Vocant for the optimization function, reactive power capability calculation and set points management;
- Arrangement for data exchange between DSO/TSO SCADAs;
- Nowcast for Network Observability.

3.1 OVERVIEW OF THE DEVELOPMENT WORK REALIZED IN THE DEMONSTRATOR

Although the aforementioned macro-activities started almost immediately after the internal kick off, the difficulties that arose during the entire project period were considerable and which slowed the start-up of the demonstrator in its most complete form.

First of all, it should be underlined that the STATCOM envisaged for the project also represents the first example of STATCOM ever for E-Distribuzione. In order to procure it and make sure that its characteristics were fully compatible with the distribution network involved according to the project objectives, the first activity that required a strong effort by the project team (especially in terms of technical coordination of all the company functions involved) consisted in the drafting of the technical specification.
Before the release of this document, an intense scouting was also carried out among the main solutions available on the market in order to identify the most appropriate technologies for the project purposes.
This activity also saw the involvement of various E-Distribuzione technical functions including, among others, Operation & Maintenance. This aspect is crucial as the project demonstrator (and with it the STATCOM operation) is implemented on a portion of real network with all possible implications in terms of safety and quality of service during installation and subsequent operation.

The drafting of the technical specification led to the release of the first complete version of the document in 07/2018 and, on its basis, it was possible to prepare the European call for tenders which took place in October 2018. In March 2019 the pre-qualification phase was closed with the sending of the Request for Offer to the candidate suppliers and the planning of the first on-site inspections aimed at the preparation of the technical offers. This call for tenders, despite intense Q&A sessions between candidates and E-Distribuzione, was closed without successful bidders in June 2019 due to non-compliance of the offers received with the technical specification.
This event led to the introduction of a first delay of almost a year to the activities which made necessary to proceed with the preparation of a new European call for tenders. This time, in order to minimize the risk of receiving non-compliant offers again, Enel Global Procurement organized a workshop with potential candidates with the aim of improving possible pain points of the specification without obviously altering the main characteristics, necessary to achieve the project goals.

The observations collected after the workshop led, in August 2019, to the issue of a more updated version of the technical specification document and the subsequent publication of a second call for tenders.
This time, further delays due to the outbreak of the health emergency, which involved all the parties due to the need to reorganize work activities, were added to the normal timing for this type of process.
Despite the difficulties related to the management of the COVID emergency, in April 2020 the activities for the preparation of the secondary substation, functional to the connection of the STATCOMs to the distribution network in compliance with the electrical regulations in force, began.
At the end of the analysis phases of the technical and economic offers, after a series of evaluations which also saw the involvement of the E-Distribuzione Central-North territorial unit for the management of aspects relating to safety, Jema Energy SA was appointed as the successful tenderer and the contract letter was issued on 23/12/2020.

Following the signing of the contract, it was possible to start with the supplier all the activities aimed at issuing the executive project and the documentation necessary to proceed with the authorization process with the local authorities.

At the same time, the design and development activities aimed at realizing the interface, through the adoption of the IEC 61850 standard, between the two STATCOM modules and the RTU of the Primary Substation, the TPT2020, also started, together with the current developments on Enel SCADAs.
During the development and design activities, it was necessary to review the entire planning again and several times due to the inevitable delays (also attributable to the consequences of the health emergency) on the procurement of materials. The most critical case was undoubtedly represented by the supply of the MV external switchgears: their delivery took place with a delay of 17 weeks compared to the initial schedule. In order to guarantee also the safe operation of the entire system, this strong delay was also affected from the need to perform switchgears internal arc tests, that were held at the beginning of July 2020.

In the meantime, in March 2020, the secondary substation was completed and the authorization process for the STATCOMs started. It required a dense cross-document exchange between Jema, the Italian local authorities and E-Distribuzione.
The STATCOM preparation and FATs activities therefore continued at the Jema facilities until the opening of the construction site at the Quarto Primary Substation on 26/10/2021.
The main activities carried out since this last date include: civil works, building of the Statcom concrete basement, the laying of cables for the MV and LV interconnections and of the optical fiber for communications up to the laying of the STATCOM modules, which took place on 21/12/2021.
Starting from 24/01/2022 it was possible to start in parallel both the commissioning of the STATCOM and the one of the local remote control system installed in the primary substation, needed for the final field tests.

3.2 GRID ASSESSMENT

As stated in chapter 2, the Italian demonstrator is located in the area of Forlì-Cesena (Emilia Romagna region), in Quarto Primary Substation. This area is characterised by a high penetration of RES (mainly PV) in comparison with low consumption.
The involved distribution network portion includes one HV/MV (132/15 kV) substation and all the 8 MV feeders connected to it. This portion of distribution network, which can be considered a model of the Smard Grid concept as others already in operation in e-distribuzione, is then managed by the Operating Center located in Bologna.

Therefore, the Italian Demonstration is implemented in a real portion of distribution network which feeds, as included in Table 3.1, 66 MV customers and 11633 LV customers. The total amount of MV and LV customers with generation is 212 (Last update, 19/10/2020).
Different types of flexible resources are managed by the DSO within the demonstration: four PV generators, a Battery Energy Storage System (BESS), two modules of Static Synchronous Compensators (STATCOMs) and the OLTCs of the two Primary Substation HV/MV Trasformers.

Italian Demonstrator	
DSO operating voltage	15 kV
Operating voltage at TSO/DSO interface	132 kV / 15 kV
Feeders	8
MV customers	66 (41 with generation)
LV customers	11633 (157 with generation)
DSO assets	• 2 OLTCs • 2 STATCOMs (2x1,2MVAr) • 1 BESS (1MVA)
Controllable resources	4PV generators • Quarto FTV: 1MW • S.Anna 1: 0,5 MW • S.Anna 2: 0,5 MW • Ca Zeno: 1 MW

TABLE 3.1 - MAIN CHARACTERISTICS OF THE ITALIAN DEMONSTRATOR.

The BESS and the STATCOMs are controlled by the DSO, within the limits of the present Italian regulations. The activities of the Italian demonstrator will investigate the potential of these assets in supporting the ancillary services provision from distributed resources.

The management of the RES and DSO assets is facilitated by an enhanced quality of real time measurements of electrical quantities and the forecast of the monitored MV generators. The demonstrator also includes a communication infrastructure which is based on some standard protocols, like the IEC 61850, targeted to a better devices integration.

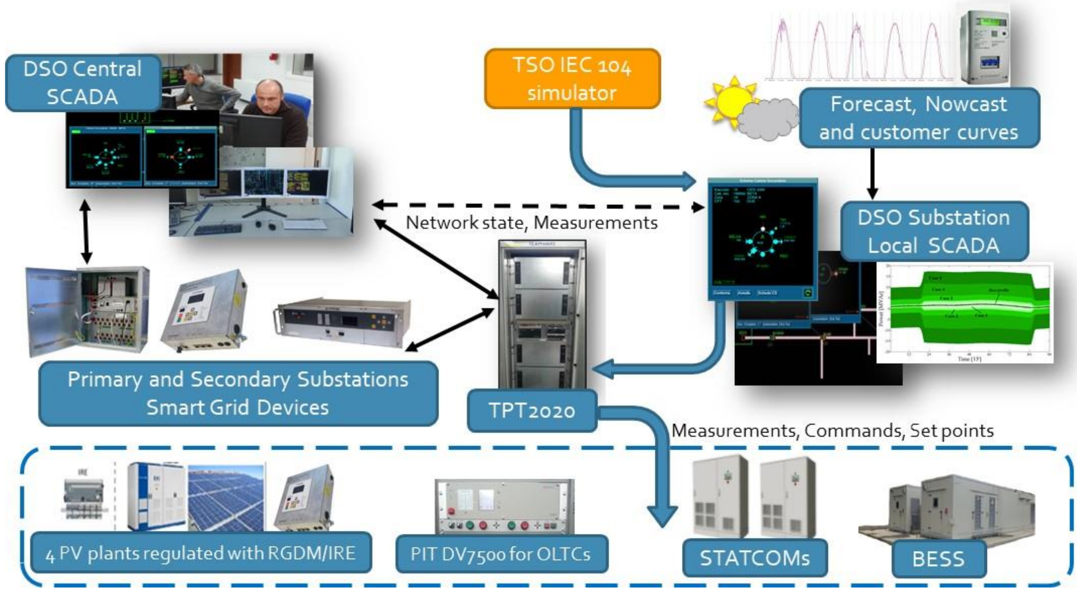


FIGURE 3-1 - ITALIAN DEMONSTRATION ARCHITECTURE.

Figure 3-1 shows the Italian Demonstration architecture, which includes many network elements, Smart Grid devices and SCADAs [1].

The HV/MV substation RTU TPT2020 implements standard remote-control features and manages advanced voltage regulation functions. In compliance with IEC 61850 standard, it sends commands and setpoints to Primary and Secondary Substation IEDs (Intelligent Electronic Devices) which are amongst others:

- **DV7500**, the Integrated Transformer Protection performs automatic voltage regulation, acting on the OLTCs of HV/MV Transformers
- **DV7203**, the HV/MV Substation feeder protection panel, with advanced network automation features;
- **RGDM**, the MV/LV Substation advanced fault detector, able to guarantee advanced network automation features.

This new generation of IEDs is also called to collect measurements of voltage, current, active and reactive power, power factor and so forth, with a high accuracy, along the whole distribution network, thanks to an always-on communication infrastructure [2].

RGDMs can communicate with **IRE** (Interface for Energy Regulation) [3], exploiting GOOSE messages publishing and subscription, in order to implement set-points on full controllable PV plants involved in the experimentation, and to acquire from the active users all the local measurements, with a time step of 10s, to be sent to the TPT2020 and then to the DSO SCADA.

The SCADA system allows to control, monitor and manage the Medium Voltage network [4]. Within the Italian Demo, two different SCADA systems are operating.

The **Central SCADA**, located in the Operating Center in Bologna, is the monitoring and remotely control system of the regional distribution network. It includes the database of the electrical network and can acquire events both from the Primary and Secondary Substations RTUs and measurements from the Primary Substations RTUs; it sends commands to the devices in the Primary Substations and to the remotely controlled Secondary Substations.

The **Local SCADA**, located in Quarto Primary Substation, is synchronized with the Central SCADA; it collects field measurements, routes the local set-points to be implemented by TPT2020 at each resource or DSO asset, and runs the **NCAS** (Network Calculation Algorithm Systems) which performs State Estimation and Network Optimization calculations [5].

For the EU-SysFlex project purposes, the SCADA system has undergone extensive improvements, related to the update of the BESS monitoring functionalities and of the optimization and calculation functionalities, to the implementation of new functionalities for STATCOMs management and to the introduction of the new **Nowcast** functionality, together with the already implemented **Forecast** functionality.

The Italian Demonstration architecture takes also into account the TSO coordination aspects, since the SCADA systems are interfaced with a **TSO protocol simulator**.

3.3 NEW TECHNOLOGIES AND FUNCTIONALITIES INVOLVED IN EU SYSFLEX PROJECT

As introduced in paragraph 2.3, the Italian Demo - developed for the purposes of the EUSysFlex project - introduces some innovative elements and functionalities which represent, together with the use of advanced smart grid devices, the original and experimental aspect of the project itself.

In detail, the features of the mentioned elements and functions are described below.

Static Synchronous Compensator (STATCOM)

The STATCOM is an electrical device that provides reactive power to the network to which it is connected.
A DC capacitor, capable of storing the energy required, is used as a voltage source. It is connected to the distribution network by PWM inverters, exploiting IGBT (Insulated Gate Bipolar Transistor) technology, and an insulating LV/MV transformer.
The output of the STATCOM consists of a sinusoidal waveform operated at 50Hz and obtained from the DC voltage source with a chopping frequency of approximately 1 kHz.
The output parameters can be then varied to control specific variables of the power system at the point of connection; in particular the LV/MV transformer includes an internal series reactance which allows to couple the 3-phase STATCOM voltages to the corresponding 3-phase Network voltages and, as a result, to obtain a Reactive Power flow, from the higher to the lower voltage magnitude source. Since the 2 STATCOM modules are operated at the MV level and directly connected to the MV busbars of the Primary Substation, this can guarantee Reactive Power compensation at the TSO/DSO interface.
From a physical point of view, the effects of a Statcom on the network are equivalent to a rotative syncronous compensator. Since it is not a rotative device, it has not any kind of mechanical inertia and it has a fast response on the electrical quantities.
Figure 3-2 shows the equivalent model of the STATCOM, in which the VSC is represented and connected to the network with the coupling transformer. In this representation the Statcom voltage is called V_{VR} while the Network Voltage is called V_K.

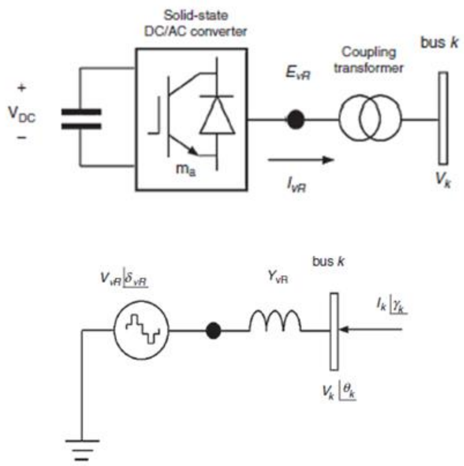


FIGURE 3-2 – ELECTRICAL EQUIVALENT MODEL OF THE STATCOM.

If the Statcom Output Voltage is:

- Higher than Network Voltage, the STATCOM generates Capacitive Q (over-excitation);
- Lower than Network Voltage, the STATCOM generates Inductive Q (under-excitation).

As a result, this device is able to generate and/or absorb reactive power, in order to perform power factor correction and voltage stabilization [6].

Improvement of forecast functionality

The Nowcast functionality, introduced in Deliverable D6.2 *"Forecast: Data, Methods and Processing. A common description"* [7], translates temperature and solar irradiation collected by mean of a weather station in the calculation of Active and Reactive Estimated Power of PV generators.

This functionality is implemented in the Primary Substation Local SCADA and provides data for all MV production plants not equipped with IRE and all the MV/LV transformers inside the demo grid; for the solar sources, this upgrade of forecast tool allows the acquisition of weather data from weather stations with "near real time" frequency.

The Local SCADA, through the Remote Terminal Unit installed in the Primary Substation, acquires also Active and Reactive Exchnaged Power sent by the 4 MV PV plants equipped with Energy Regulation Interface. This data is then aggregated every 20 seconds, considering respectively:

- the generation from multiple sources (PV plants on one side and others on the other)
- the loads connected to every branch of secondary/tertiary for all those HV/MV transformer in which observability is available and activated.

Flexibility aggregation and aggregated reactive power capability calculation

The optimization and calculation functionalities are carried out by a dedicated software tool, developed by RSE SpA, embedded in the NCAS (Network Calculation Algorithm System) module of the SCADA.

Through the optimization tool, the system operator can manage its own assets and other controllable resources, minimizing the dispatching costs, avoiding network violations and RES curtailment. Different types of constraints can be considered in the optimization problem, including power exchange constraints at the HV/MV primary substation node: this feature allows to model the constrained profile of active and reactive power flows resulting from a specific request from the TSO.

Regarding calculation features, specific functionalities have been developed and integrated in the SCADA for the Project activities: the flexibility aggregation, the reactive power capability calculation and the cost-active power parametric curve.

The **flexibility aggregation** feature is essential for calculating the correct set-points for assets and flexible resources, respecting both the constraints of the distribution network and the constraints shared between the DSO and the TSO at connection node.

The **reactive capability calculation** and the **parametric curve calculation features**, are computed with the same algorithm, whose objective function is set to optimize the power exchange with the transmission network.

The integration of these functionalities in a single algorithm allows a more efficient calculation process, guaranteeing also that the consequent flexibility activations respect the network constraints, avoiding the need to run another optimization process after the flexibility selection from the TSO.

Data exchange between DSO and TSO

After the calculation of data obtained by the Nowcast of network observability, all this aggregated data is saved into a DSO central system database and then sent to the TSO central system, together with all the other measurements related to the Primary Substation.

Data exchange between DSO and TSO is simulated by using a dummy system which emulates the TSO SCADA and the communication with the DSO SCADA, respecting the same kind of standards.

The automated coordination process between DSO and TSO is tested by using an IEC 104 protocol simulator, which acts as a substitute in the transmission of specific signals and measurements between the two System Operators.

In case of failure in updating the aggregated data to be transmitted to the TSO, it is expected that a null value "invalid" is sent, as required by the TSO central system. There is also the possibility for the TSO to activate/deactivate the delivery of aggregations for observability.

3.4 LABORATORY TESTING RESULTS OF ALL THE DEVICES AND SCADA SOLUTIONS

In a preliminary phase to the installation in field, a series of integration tests have been performed within the Lab **"Grid-in-the-loop"** Test System in Milan [8], by using the RTDS (Real Time Digital Simulator). RTDS is a technology based on a multi-rack architecture that numerically simulates an electrical network, allowing the observation of real-time electrical transients and steady-state phenomena.The simulated distribution network is the same of the field demonstration and includes all the electrical components characteristics and significant parameters, such as resistance, inductance and general composition of the MV feeders.

Figure 3-3 and Figure 3-4 show a generic example of a single circuit PI-Section model, necessary to build the distribution network on the RTDS and its mask including general electric parameters.

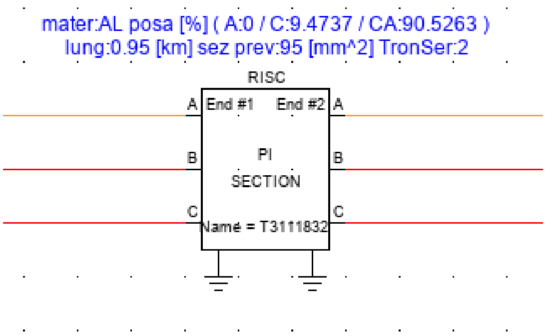
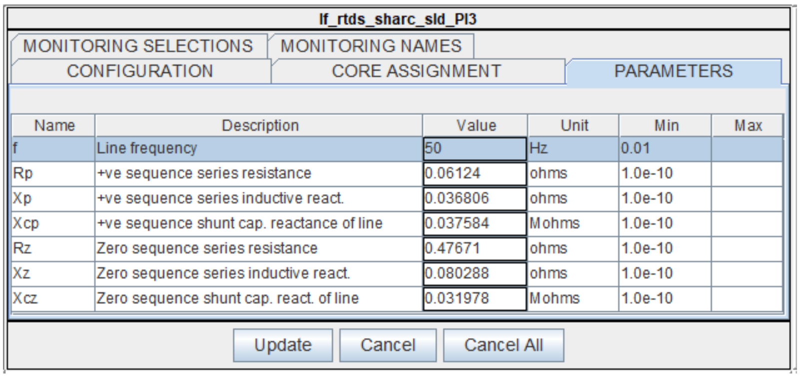


FIGURE 3-3 - SINGLE CIRCUIT PI-SECTION MODEL FROM THE REAL TIME SIMULATION.



lf_rtds_sharc_sld_PI3

MONITORING SELECTIONS | MONITORING NAMES | CONFIGURATION | CORE ASSIGNMENT | PARAMETERS

Name	Description	Value	Unit	Min	Max
f	Line frequency	50	Hz	0.01	
Rp	+ve sequence series resistance	0.06124	ohms	1.0e-10	
Xp	+ve sequence series inductive react.	0.036806	ohms	1.0e-10	
Xcp	+ve sequence shunt cap. reactance of line	0.037584	Mohms	1.0e-10	
Rz	Zero sequence series resistance	0.47671	ohms	1.0e-10	
Xz	Zero sequence series inductive react.	0.080288	ohms	1.0e-10	
Xcz	Zero sequence shunt cap. react. of line	0.031978	Mohms	1.0e-10	

Update | Cancel | Cancel All

FIGURE 3-4 - ELECTRICAL PARAMETERS INCLUDED IN A PI SECTION.

The simulated digital and analog quantities are imported/exported from and to the real IEDs.

Figure 3-5 highlights how the electrical simulated quantities might be exported through a GTAO block to an external hardware; in details, the exported quantities in the figure are related to the HV/MV transformer and take into account of the amperometric and voltmetric coefficient for the transduction to the IED.

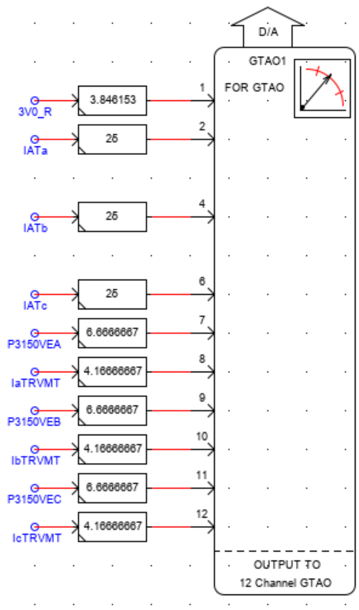


FIGURE 3-5 - GIGABIT TRANSCEIVER ANALOGUE OUTPUT CARD (GTAO) BLOCK TO INTERFACE ANALOGUE SIGNALS.

The output quantities from the RTDS are amplified through many Voltage and Current amplifiers (as shown in Figure 3-6) and then sent to the Smart Grid Devices.

FIGURE 3-6 - RTDS RACKS IN LAB FACILITIES CONNECTED TO VOLTAGE AND CURRENT AMPLIFIERS.

The real time simulation could be built step by step, based on the test to perform.
Figure 3-7 includes a view of the Human Machine Interface of the real time simulation which has been built.

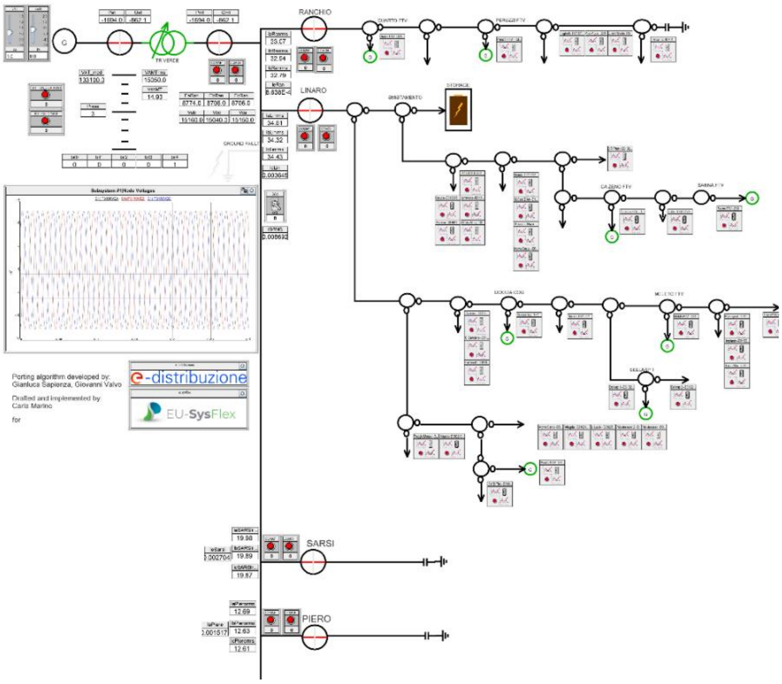


FIGURE 3-7 - HMI OF THE SIMULATED QUARTO DISTRIBUTION NETWORK FED BY GREEN TRANSFORMER.

The Human Machine Interface (HMI) of the real time simulation is used for the management and monitoring of the simulated scenarios, in order to analyze the dynamics of the distribution network fed by the Green HV/MV transformer of Quarto Primary Substation. In details, the tool allows to:

- analyze all the waveforms of the distribution network;
- implement commands to the external IEDs and acquire any feedback from the hardware, such as the actual simulated breaker positions;
- monitor the evolution of the simulation itself, with a time step of 50µs.

The simulated distribution network includes the characteristics of any single feeder and customer. For this issue, in the simulation all the active and passive customers load curves have been implemented; the tool allows to acquire a typical customer curve profile, in particular for this analysis a working day on summer has been considered.

Since the simulation may be interfaced with external devices, it is possible to act directly on a simulated OLTC and a controlled generator. The position of the OLTC is properly acquired by the Transformer Integrated Protection DV7500 while the Reactive Power Regulation on the simulated PV generator is performed by the interfaced IRE.

A configured RGDM is integrated within the simulation test setup, in order to monitor the simulated DSO secondary substation to which the regulated PV generator is connected and to acquire the measurements from the active customer itself. In the mean time, it has also the role to receive the Q set point from the Primary Substation RTU TPT2020 and to send it to the IRE, which will actuate the requested reactive power on the simulated generator.

In addition, a protection DV7203 is configured in order to acquire the measurements and the actual status of the breaker of one MV feeder.

The table below includes a summary of the smart grid devices infrastructure used within the simulation setup.

Device	Role	Function	Monitored quantities and status
DV7500	Integrated Transformer Protection	Fault Detector OLTC regulation	V, I, P, Q etc… OLTC position HV and MV breaker positions of the Transformer
DV7203	Feeder Protection	Fault Detector	V, I, P, Q, etc… MV breaker position
RGDM	Secondary Substation Protection	Monitoring Fault Detector PV generator set point transmission to IRE	V, I, P, Q etc… of the DSO secondary substation P, Q of the PV generator
IRE	PV generator interface	PV generator set point implementation	P, Q of the PV generator

TABLE 3.2 – SUMMARY OF THE ROLES AND FUNCTIONALITIES OF IMPLEMENTED SMART GRID DEVICES IN LABORATORY TEST SETUP

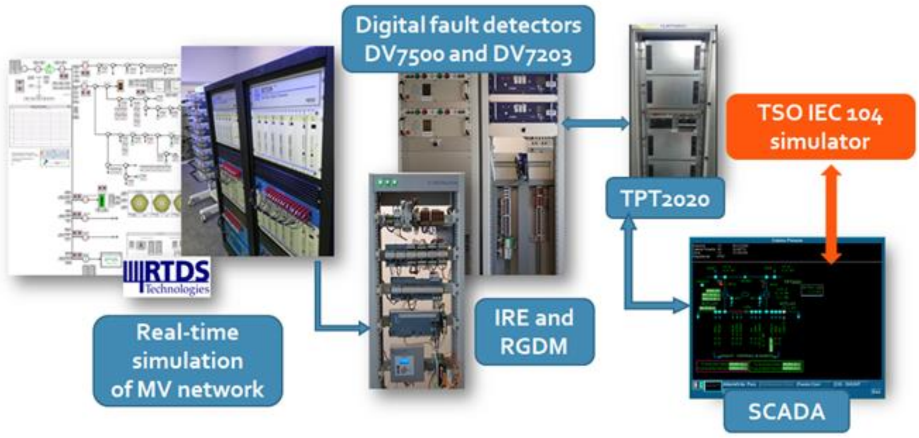


FIGURE 3-8 - GRID IN THE LOOP INTEGRATION TEST SETUP OF THE ITALIAN DEMONSTRATION.

Figure 3-8 shows the block diagram of the implemented test environment, whose details are deeply described in the following section.

Thanks to an optic fiber connection between all the devices, TPT2020 acquires events and measurements from each configured IED (DV7500, DV7203 and RGDM) connected to the simulated MV network; then it sends all significant data to the SCADA, that can perform state estimation and optimization functionalities on a distribution network database identical to the one of Quarto used in Bologna Control Room. Both DSO network optimization and a TSO external request of capability can drive the DSO SCADA to implement the State Estimation and the Optimization functionalities, generating optimal set-points to each involved resource.

For the second issue, an IEC 104 protocol simulator atcs as the TSO SCADA and sends a capability request to the DSO SCADA; once the set-points are calculated, they are sent to each flexibility from TPT2020, which receives after the regulation the corresponding feedback from all the IEDs. This methodology allows to carry out advanced integration tests, in which the elements of the entire chain are included, and the functionalities can be performed as well as in real field.

These integration tests have been carried out in order to evaluate SCADA functionalities related to State Estimation, Optimization and Nowcast functionality arrangement in a Pre-Statcom Scenario.

Secondly, the Statcom IEC 61850 profile has been considered for testing monitoring and management SCADA features of the new DSO asset.

3.4.1 PRE STATCOM SCENARIO

The results from the integration tests show that the SCADA acquires all the measurements and signals from the configured smart grid devices and sends all the commands, such as the Q set points to the simulated PV plant and the V set points to the DV7500.

Figure 3-9 shows the HMI SCADA of the Primary Substation of Quarto tested in Milan, with the measurements and the breaker positions collected by the DV7203 configured on the feeder Linaro and by the DV7500 configured on the HV/MV transformer TRV. The automatic voltage regulation of the OLTC managed by the SCADA is active (AUT P3).

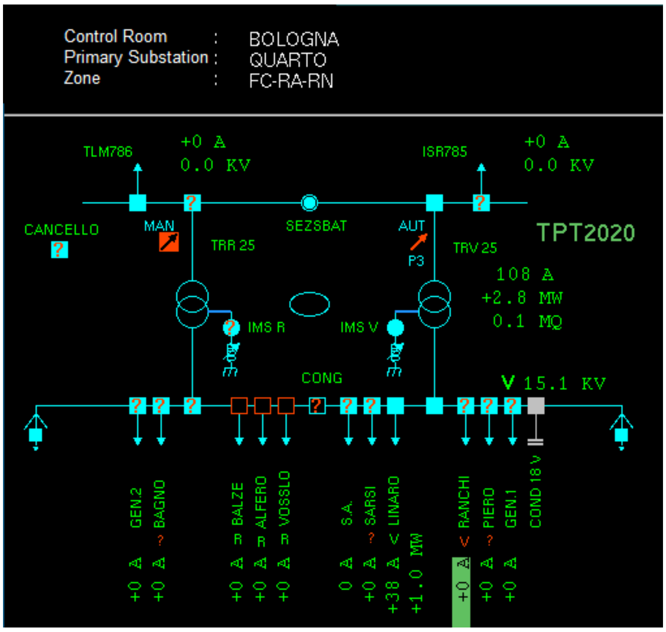


FIGURE 3-9 - OVERVIEW OF QUARTO PRIMARY SUBSTATION SCHEME ON SCADA.

As stated in chapter 3.4, the SCADA acquires real time measurements from field devices installed in the laboratory facilities and interfaced with the real time simulation of the examinated distribution grid.

Figure 3-10 and Figure 3-11 consist of the active and reactive power profiles under the Green Transformer of Quarto Primary Substation on 1st of June 2021.

Through the analysis of these curves, it is possible to validate the simulation equivalent model of the network and to check that the P, Q historical trends, which have been implemented in the simulation itself, are coherent to the one recorded in field in the same season of the year.

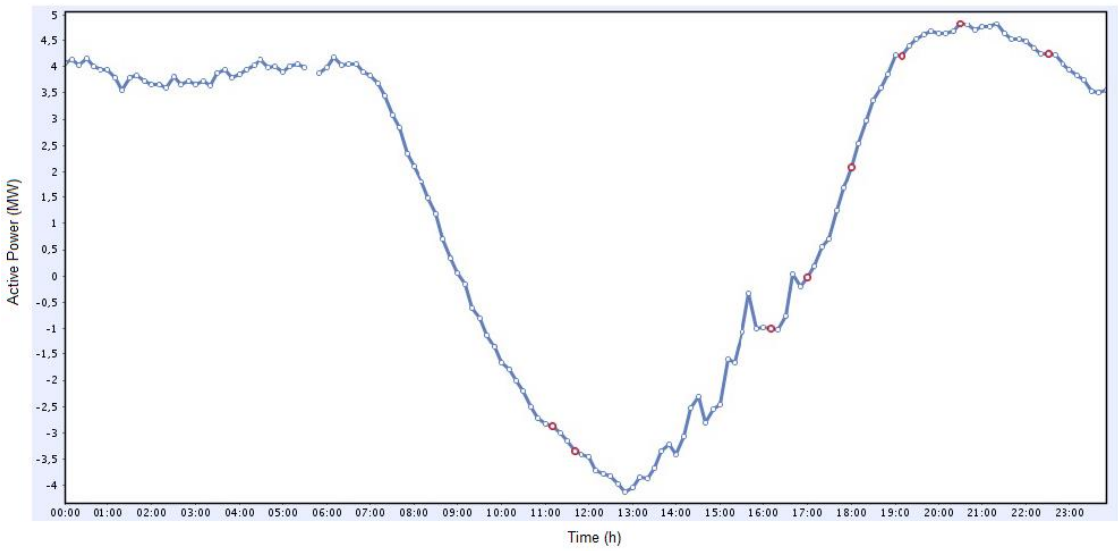


FIGURE 3-10 - ACTIVE POWER PROFILE OF THE GREEN TRANSFORMER OF QUARTO RECORDED ON 1ST JUNE 2021.

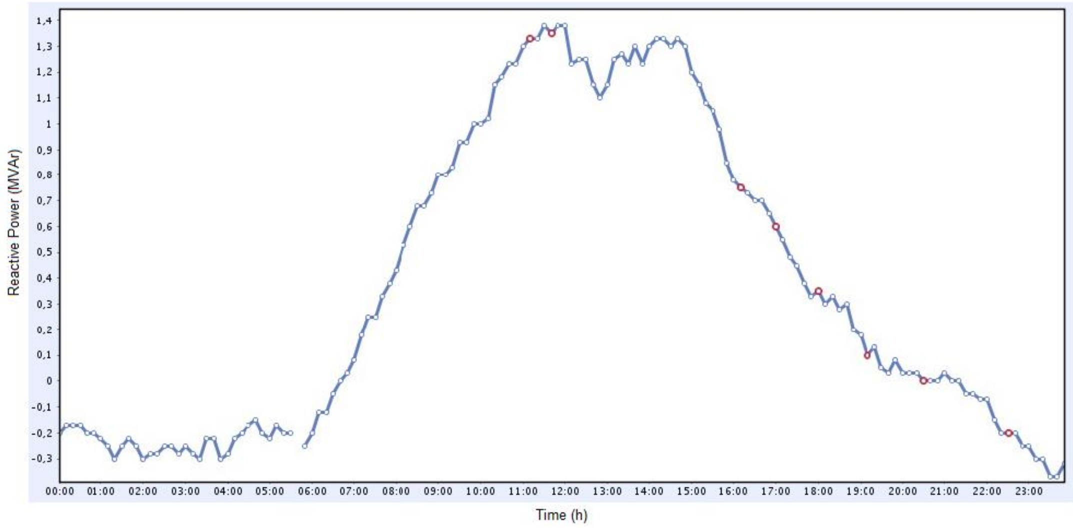


FIGURE 3-11 - REACTIVE POWER PROFILE OF THE GREEN TRANSFORMER OF QUARTO RECORDED ON 1ST JUNE 2021.

In order to check the consistency of the injected Q profile, the HMI SCADA allows also to visualize the measurements at the DSO side and the measurements at the customers' side (see Figure 3-12). The exchanged P, Q at the DSO Secondary Substation are collected, together with the busbar voltage Vsca, by the RGDM; on the other hand, the power injection Pgen and Qgen at the simulated PV plant are sent by IRE, so a comparison between the corresponding measurements is possible.

Once all the prelimiar conditions of connectivity and data acquisition have been checked at any level, then the integration tests for the regulation features were performed. Therefore, the EUSysFlex solution exploits an already existing SCADA architecture, adding also the fields related to the provision of the aggregated information of network capability at the DSO/TSO interface and the TSO aggregated set point request of Voltage and Reactive Power.

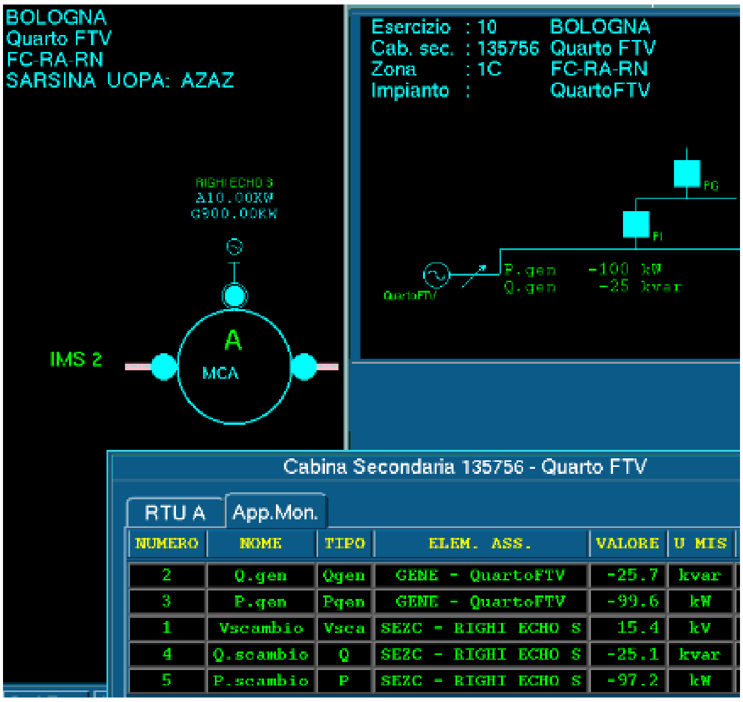


FIGURE 3-12 - SCADA VIEW OF THE REGULATED PV GENERATOR.

Within the integration tests, the functionalities were checked in the following order:

1. The virtual capability generation for a HV/MV Transformer;
2. HV Voltage Regulation attuation after a TSO Voltage set point request;
3. HV Voltage Regulation attuation after a TSO Reactive Power set point request;
4. Nowcast for Observability.

Virtual capability generation for a HV/MV Transformer

Within this test, it was observed that the Local SCADA may correctly activate the NCAS for the capability calculation, by considering all the dispatchable MV elements under the examinated HV/MV transformer.

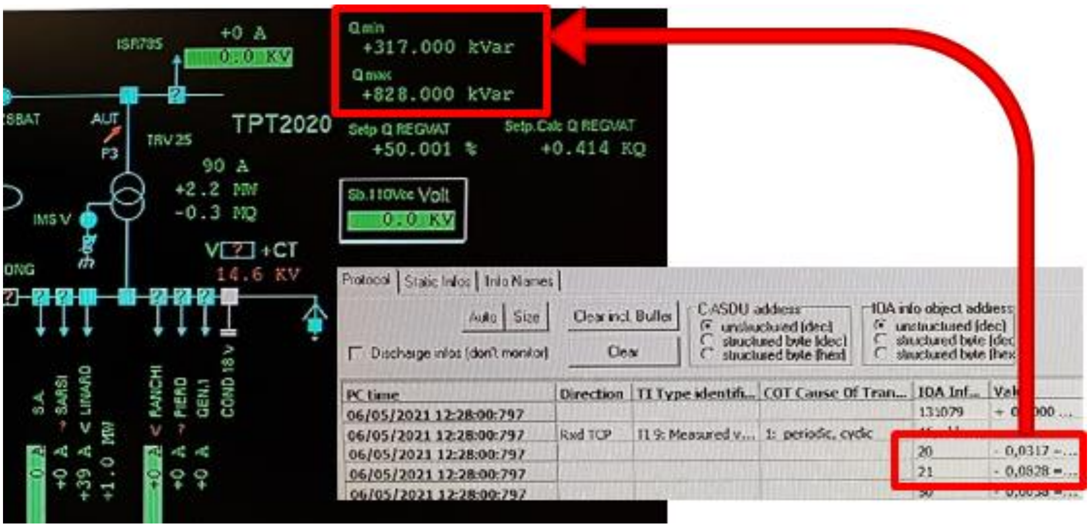


FIGURE 3-13 - CALCULATED REACTIVE POWER CAPABILITY ON SCADA VIEW AND TSO SIMULATION TOOL.

As a consequence, the Local SCADA might show the capability and send every 20s the values to the TSO SCADA simulator, with the proper sign convention.

Figure 3-13 shows an example of calculated Reactive Power Capability $Q_{min} \div Q_{max}$ and the corresponding interval with the opposite sign in the TSO simulator.

HV Voltage Regulation attuation from a TSO Voltage set point request

Within this test, it was observed that the Local SCADA may correctly receive the Voltage setpoint from the TSO simulator and convert it in a Reactive Power setpoint at the HV/MV Transformer through Q(ΔV) curves.

Then the NCAS is triggered to calculate and send the voltage setpoint for the MV Primary Substation bubsar and the dispatchable resources for Voltage regulation.

Figure 3-14 shows on the right side of the picture the HV setpoint which consists of a percentage respect to a normalized value; in particular the TSO requests the 91,04% of normalized value of voltage of 145kV.

Then the Reactive Power setpoint to implement within the dispatchable resources is shown to the operator.

FIGURE 3-14 - TSO VOLTAGE SETPOINT REQUEST.

HV Voltage Regulation attuation from a TSO Reactive Power set point request

Within this test, it was observed that the Local SCADA may correctly receive the percentage value of Reactive Power setpoint from the TSO simulator and convert it in an absolute Reactive Power setpoint at the HV/MV Transformer.

Then the NCAS is triggered to calculate and send the voltage setpoint for the MV Primary Substation bubsar and the dispatchable resources for Voltage regulation.

Figure 3-15 shows on the right side of the picture the reactive power percentage requested from the TSO simulator with the proper sign convention.

Then the Reactive Power setpoint to implement within the dispatchable resources is shown to the operator.

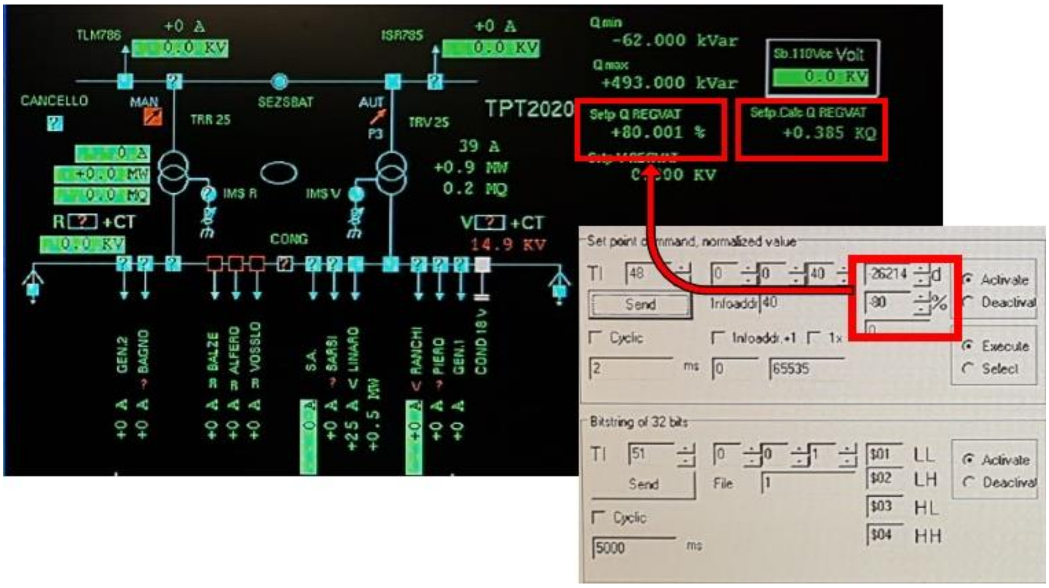


FIGURE 3-15 - TSO REACTIVE POWER SETPOINT REQUEST.

Nowcast for Observability

Nowcast for Observability functionality has been arranged in order to make available Active and Reactive Power from Nowcast for Observability and to merge the weather data elaboration with the corresponding measured values calculated by the updated forecast algorithms.

The upgraded SCADA includes the labels which corresponds to this additional information needed for the improving of network observability, as shown in Figure 3-16.

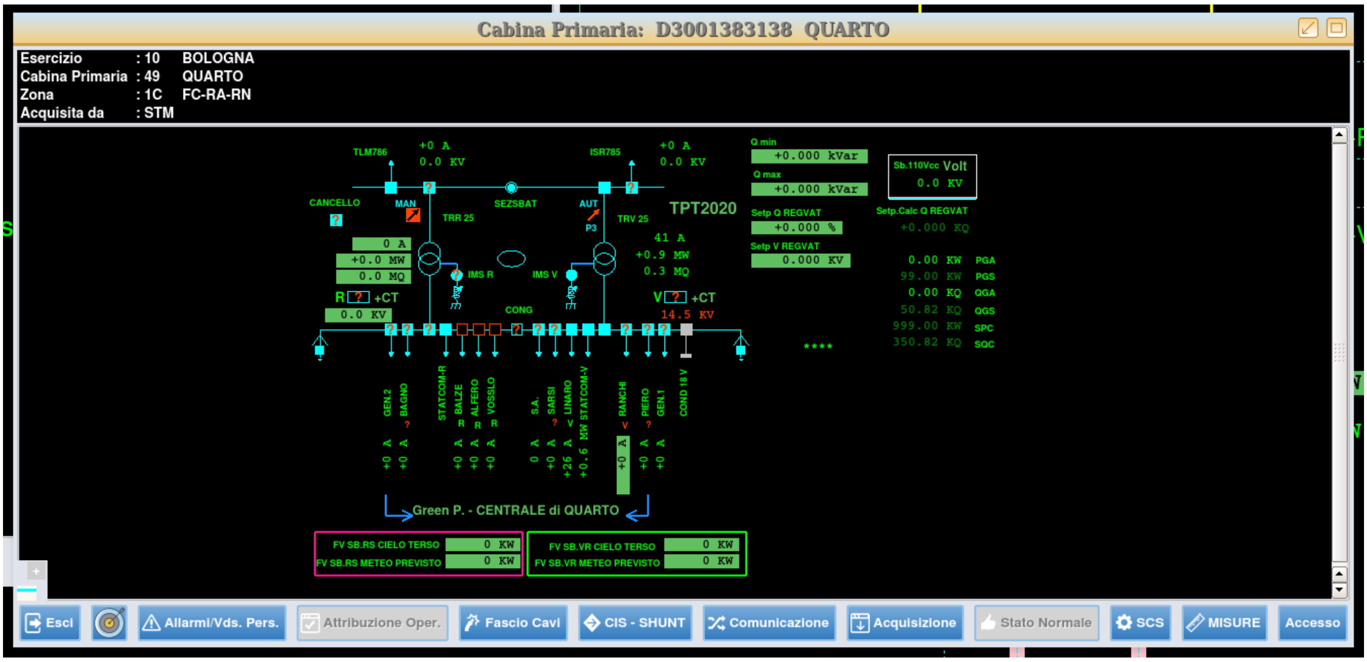


FIGURE 3-16 – QUARTO PRIMARY SUBSTATION SCHEME INCLUDING AGGREGATED NOWCAST RESULTS.

3.4.2 POST STATCOM SCENARIO

In this paragraph, the needed activities for the STATCOM integration within the distribution grid of Quarto Primary Substation and for its correct management together with field devices and Enel remote control systems are illustrated.

Figure 3-17 shows the Statcom connection scheme to the distribution grid both from an electrical point of view and from a communication architecture side; in detail, following the ordinary convention of Enel electrical schemes, each STATCOM has a specific naming as "Green STATCOM" and "Red STATCOM", associated to the corresponding busbar and HV/MV Transformer.

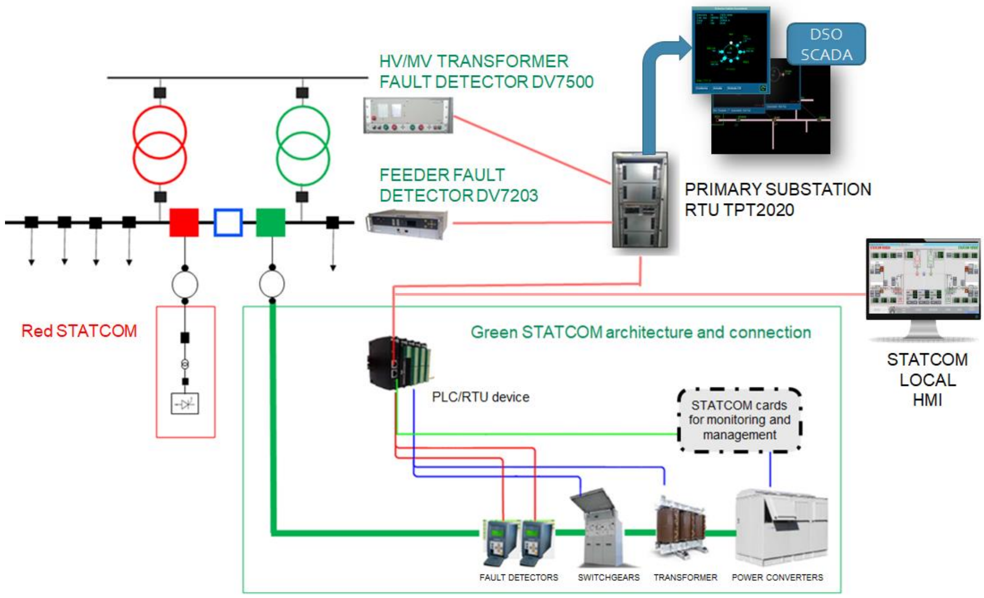


FIGURE 3-17 - ELECTRICAL CONNECTION AND COMMUNICATION ARCHITECTURE SCHEME OF THE STATCOM.

The figure includes in detail a focus of Statcom designed components, as listed below:

- Power Converters;
- Switchgears;
- Insulation Transformers;
- General Protection System (GPS) according to CEI 0-16 prescriptions

and of the Primary Substation architecture in which Statcom is included.

As it can be seen from the figure, the STATCOM can be managed both from its specific local HMI and remotely thanks to Enel Central and Local SCADAs, through the Primary Substation RTU TPT2020.

It is important to specify that the local HMI and the Local SCADA play two different roles and don't perform the same functionalities: the local HMI consists of a management software provided by the Statcom manufacturer limited to the operations of the single Statcom commands, signals and measurements, in order to provide a safe and reliable instrument for those operators who need to exploit the Statcom during field works and maintenance

activities. On the other hand, the Local SCADA is an Enel remote control system located inside the Quarto Primary Substation needed for EuSysFlex functionalities upgrade referred to Network State Estimation, Nowcast for Observability and management of the involved resources as DERs, OLTCs, Storage and the Statcom itself.
From an electrical point of view, Figure 3-18 shows the solution adopted in e-distribuzione to implement the STATCOM connection to the distribution network.

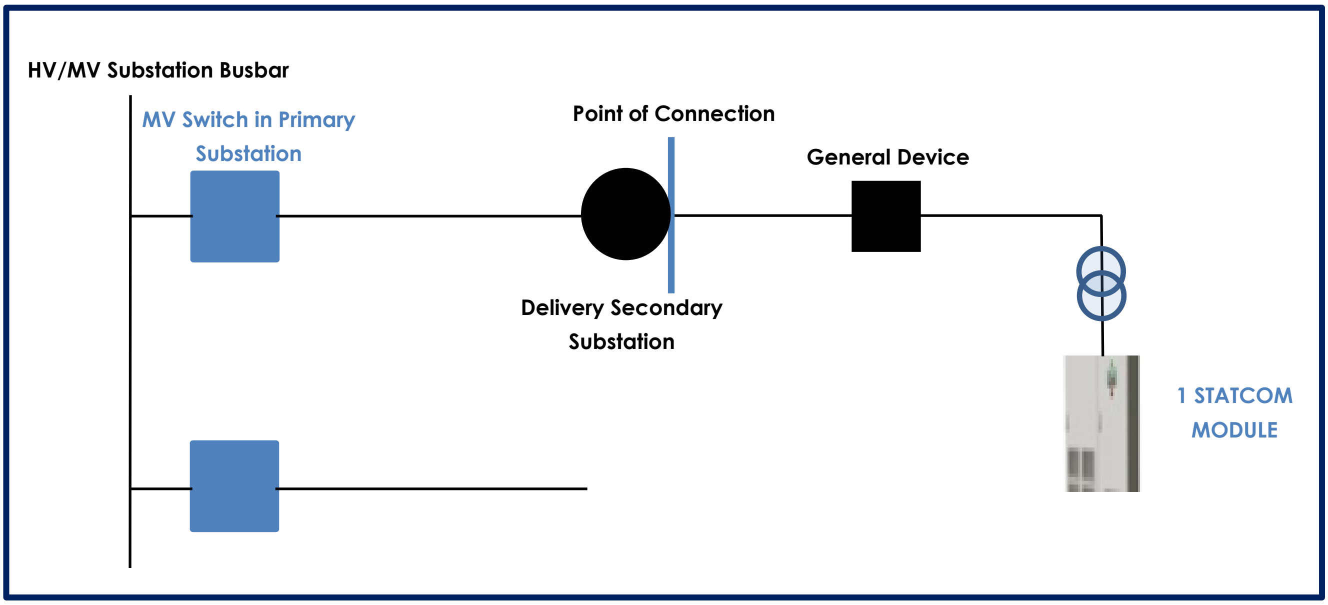


FIGURE 3-18 – CONNECTION SCHEME OF THE STATCOM TO THE DISTRIBUTION NETWORK

The connection of the two STATCOM modules (one for each busbar in Quarto Primary Substation) to the distribution network has been realized through a dedicated delivery secondary substation, in compliance with the recommendations provided by the CEI 0-16 standard: "Technical reference regulation for the connection of active and passive Users to the HV and MV networks of distribution companies". Indeed, as already described in paragraph 2.3, considering the innovation represented by the installation of the STATCOM in the distribution network and, consequently, the lack of experience in its operation, it has been established, for the functionalities tested within the EUSysFlex project, to configure the device as a passive user and, as such, it has to guarantee the installation of a General Protection System associated with the User General Device, the protection requested from the Italian technical requirement CEI 0-16 for active and passive customers connected to the MV network.
In particular, the General Protection System includes a relay which provides the following fault detection levels.

Three-thresholds phase overcurrent protection

- First threshold (51.S1), optional, for the detection of minor overload events originating within the user system;
- Second threshold (51.S2, with intentional delay) for the detection of polyphase short-circuit on impedance events within the user system;
- Third threshold (50), istantaneous, for the detection of polyphase short-circuit with no impedance events within the user system;

Two-thresholds homopolar overcurrent protection

It is correctly referred to the operating status of the neutral of the involved MV network::

- First backup threshold (51N.S1) for the detection of the phase-to-earth faults within the user system;
- Second threshold (51N.S2) for the detection of the double phase-to-earth faults, with one of the fault points on the STATCOM wiring;

Two-thresholds directional earth protection

- First threshold (67N.S1) for the detection of the phase-to-earth faults during the operation of the MV network with neutral grounding with impedance;
- Second threshold (67N.S2) for the detection of the phase-to-earth faults during the operation of the MV network with neutral not connected to ground.
-

GENERAL PROTECTION SYSTEM ACCORDING TO CEI 0-16 STANDARD		
Protection	**Threshold**	**Delay Time**
50	600 A	120 ms
51.S1	-	-
51.S2	250 A	500 ms
51N.S1[1]	2 A	450 ms
51N.S2	1,4 I_{GMT}[2] (56 A)	170 ms
67N.S1 (wattmetric)	2 A; 5 V	450 ms
67N.S2 (varmetric)	2 A; 2 V	170 ms

TABLE 3.3.3 SETTING VALUES OF THE GPS, IN COMPLIANCE WITH CEI 0-16 STANDARD, FOR THE CONNECTION OF THE TWO STATCOM MODULES TO E-DISTRIBUZIONE NETWORK.

The general protection regulation values, for the different above-mentioned protective functions, are shown in Table 3.3.3.

IEC 61850 Integration tests and SCADA features for STATCOM management

As mentioned in the introduction of this chapter, a communication architecture has been realized and upgraded in order to manage commands, signals, alarms and measurements related to the Statcom, in compliance with the Standard IEC 61850.

As a consequence, the Central and the Local SCADA have been developed in order to define this new network device within Enel remote control systems, providing also the necessary graphical view to the network operators.

[1] Adopted in absence of 67N.S1 and 67N.S2.
[2] It has to be considered the earth-fault current for the operating status of the neutral of the involved MV network.

Figure 3-19 shows how the Statcom connection is represented on the SCADA interface: going in detail, the two Statcom modules, called Statcom-R (Red Statcom) and Statcom-V (Green Statcom), are characterized by the symbol of an electronic component, thus being uniquely identified.

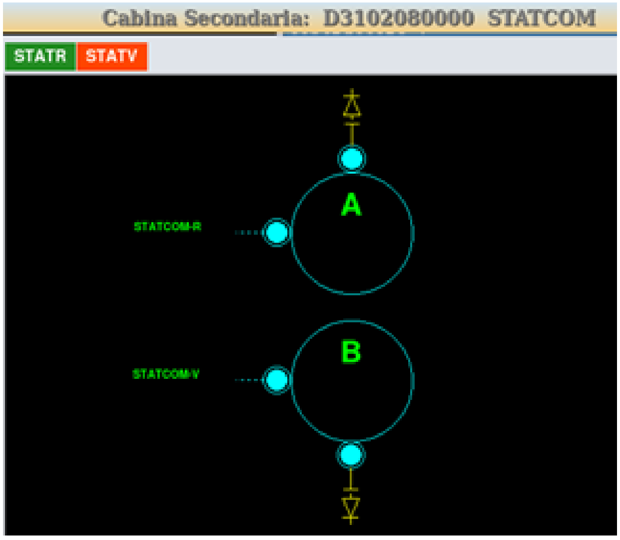


FIGURE 3-19 - GRAPHICAL REPRESENTATION OF THE TWO STATCOMS CONNECTION TO THE DSO NETWORK.

The most significative measurements of the Statcom element are shown in Figure 3-20, in which there is the detail of the exchanged Active and Reactive Power together with the information of the Root Mean Square (RMS) operating Voltage. Since the Statcom does not exchange active power with the network to which it is connected, the corresponding value on the SCADA view PatM is correctly equal to zero.

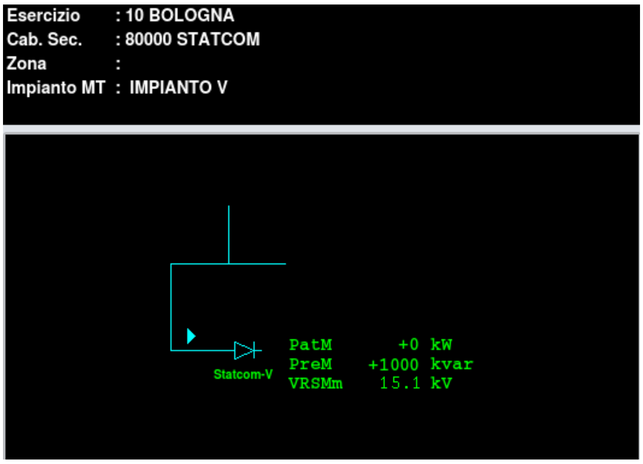


FIGURE 3-20 - FOCUS ON GREEN STATCOM MONITORED MEASUREMENTS.

It is possible to monitor the operating point of the Statcom, included in its working area, thanks to a specific graphical representation included in Figure 3-21, in which the horizontal axis represents the active power, while the vertical axis represents the reactive power.

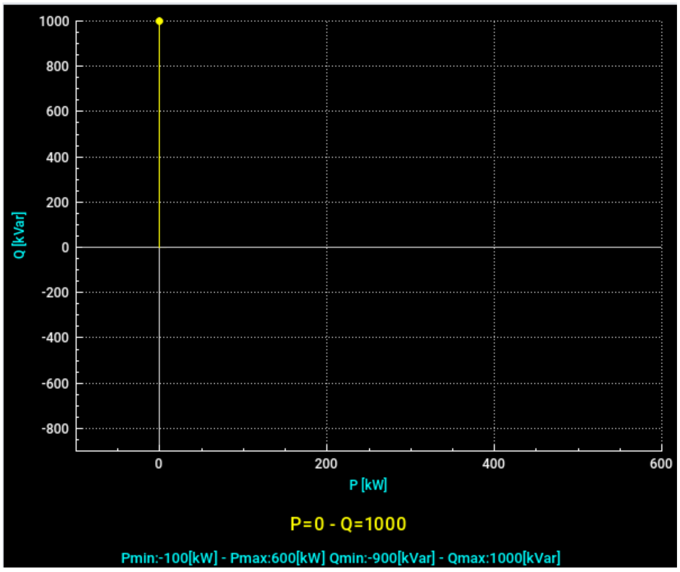


FIGURE 3-21 - GRAPHICAL REPRESENTATION OF THE STATCOM IMPLEMENTED SETPOINT WITHIN THE TEST SETUP

Within the SCADA upgrade performed for the integration of the STATCOM, a State Machine has been develop to manage the different working modes during the STATCOM operation, as illustrated in Figure 3-22.

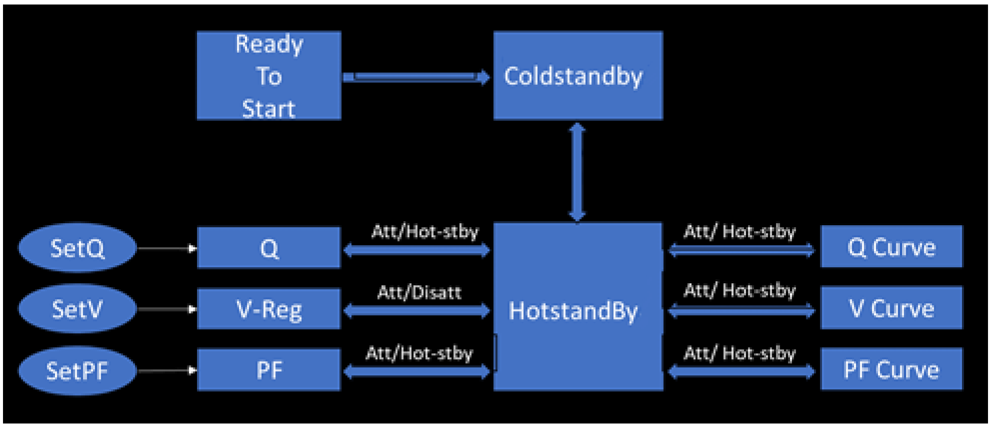


FIGURE 3-22 - STATE MACHINE OF THE STATCOM WORKING MODES.

The State Machine works considering the possible status, as following:

- Ready to Start: it is the status in which the Statcom is ready to be connected to the network;
- Coldstandby: it is the status related to the command through which is possible to disconnect the Statcom from the network;
- Hotstandby: it is the status in which the Statcom is connected to the network and ready to receive any regulation request;
- Setpoint regulation (Q, V, PF): the Statcom may receive a specified setpoint from an operator request or as an outcome of the optimization algorithm; the setpoint can be expressed in terms of reactive power, voltage and power factor;
- Curve regulation (Q, V, PF): it is possible to preset a regulation curve locally within the Statcom HMI, then through the SCADA the operator may activate any regulation curve, acting on reactive power, voltage and power factor.

3.5 REAL FIELD RESULTS OF ALL THE DEVICES AND SCADA SOLUTIONS

The real field results of all the devices and SCADA solutions are collected dividing the activities in two macro-blocks:

- Pre STATCOM scenario;
- Post STATCOM scenario.

Within the pre STATCOM scenario the Central and Local SCADA solutions, including the update of state estimation algorithm tested during Factory Acceptance Tests in Milano Flexibility Lab, are set up in order to be used within the real field network of Quarto Primary Substation, whose architecture was explained in chapter 3.2 and illustrated in Figure 3-1.

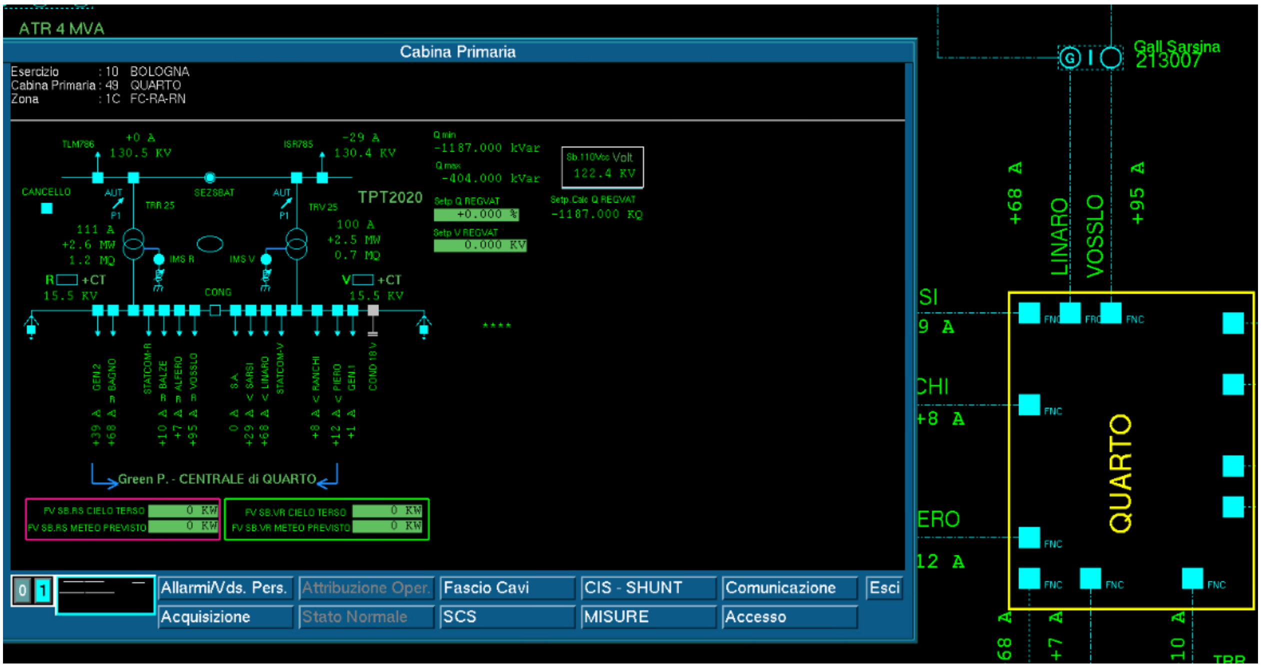


FIGURE 3-23 - LOCAL SCADA VIEW DURING PRELIMINAR FIELD TESTS.

Figure 3-23 shows the Local SCADA view acquired during real field preliminar tests. The main difference between this picture and the equivalent Local SCADA view acquired during FATs in Flexibility Lab consists in the visualization of a greater number of measurements coming from the real field devices of the MV network of Quarto Primary Substation, shown in Figure 3-24 and Figure 3-25, needed for grid operations.

FIGURE 3-24 – VIEW OF THE FEEDER PROTECTIONS DV7203 PERFORMING FAULT DETECTION AND MEASUREMENTS COLLECTION.

FIGURE 3-25 – VIEW OF THE INTEGRATED TRANSFORMER PROTECTIONS DV7500 PERFORMING FAULT DETECTION, MEASUREMENTS COLLECTION AND AUTOMATIC VOLTAGE REGULATION ON THE OLTC$_S$ OF HV/MV TRANSFORMERS.

The post STATCOM scenario includes the involved resource of the pre STATCOM one, with the additional contribution of the two STATCOM modules within the flexibility regulation.

3.5.1 PHASE 1: PRE STATCOM INSTALLATION SCENARIO

The pre STATCOM installation scenario of the Italian Demonstration includes the real field tests performed with the available resources and the O&M needs of Quarto distribution grid.

The real field demonstration tests were performed on 8th February 2022 by using Central SCADA located in Bologna and Local SCADA located in Quarto Primary Substation through the support of the Operational Centre personnel and, in details, the test session included the following controllable resources:

- 3 PV Generators (SANNA FTV 1, SANNA FTV 2 and QUARTO FTV);
- The OLTC of the Primary Substation HV/MV Green Transformer.

The Storage and the 4th PV plant located in CA ZENO were not available during test activities cause to extraordinary maintenance and fixing of network communication outages.
The OLTC of the Primary Substation HV/MV Red Transformer was excluded by the automatic voltage regulation in order to guarantee specific safety and network operation needs within the fed MV network.

The operational tested scenario had the purpose to verify the implementation of commands in order to satisfy a specific request from the TSO in terms of Q exchanging level at HV/MV interface, taking into account the capability of controllable resources and containment of voltage variation on MV network directly connected to the HV/MV transformers. The activities foreseen during the test are listed below:

1. Assuming to receive a command from the TSO in order to support voltage regulation on HV side, a fixed request of Rreactive Power level is set on the TSO simulator;
2. The system converts the Q setpoint into a corresponding setpoint related to the necessary Reactive Power transit on the HV/MV Green Transformer for obtaining the required regulation;
3. After the request, the optimization algorithm provides as output the setpoints to all the controllable resources, according to their priorities;
4. The actual sending from the Local Scada and DSO Primary Substation RTU TPT 2020 and consequent receiving of the setpoint for each flexibility resource is verified through the analysis of the measurements of the involved electrical quantities.

In detail, all the steps which have been performed during the test are described below in chronological order, illustrating details, graphs and measurements useful for verifying the effectiveness of the entire Demonstration.

Real Field Test Execution

First of all, in order to prove the visualization of the calculated Reactive Power capability at HV/MV level on the Local Scada, a view of Quarto Primary Substation has been acquired.

In particular, Figure 3-26 – shows the view of the operator in the Local Scada located in Quarto Primary Substation in which it is possible to appreciate the information of “Qmin” and “Qmax” equal to -1,566 MVAr ÷ -1,039 MVAr, that represents the range of reactive power that could be available for regulation issues at the Primary Substation interface.

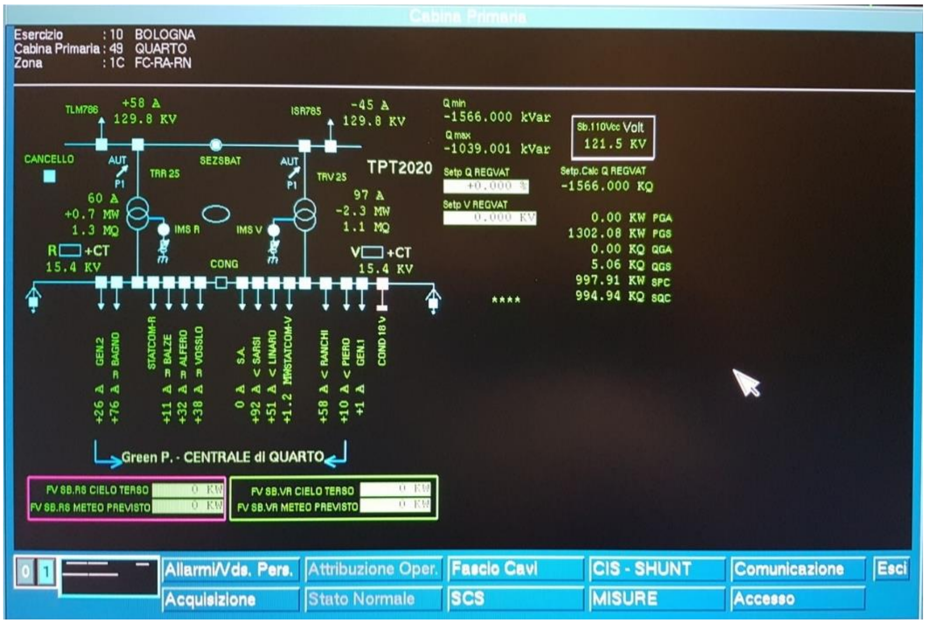


FIGURE 3-26 – VIEW OF THE PRIMARY SUBSTATION ON THE LOCAL SCADA.

The objective of the following step was to display on the Central Scada a view of each PV generator involved in the demonstration.

Figure 3-27, Figure 3-28 and Figure 3-29 show the detailed Central Scada view of each PV plant, in which it is possible to notice the interesting electrical quantities which include, in particular, the exchanged Q curve at the point of Connection level for each Power Generating plant.
After having carried out the checks described above, the operating personnel proceeded to enable the automatic voltage regulation on the Quarto Primary Substation Green Transformer, by means of the specific command on the Local Scada, maintaining the regulation already set on the Red Transformer.

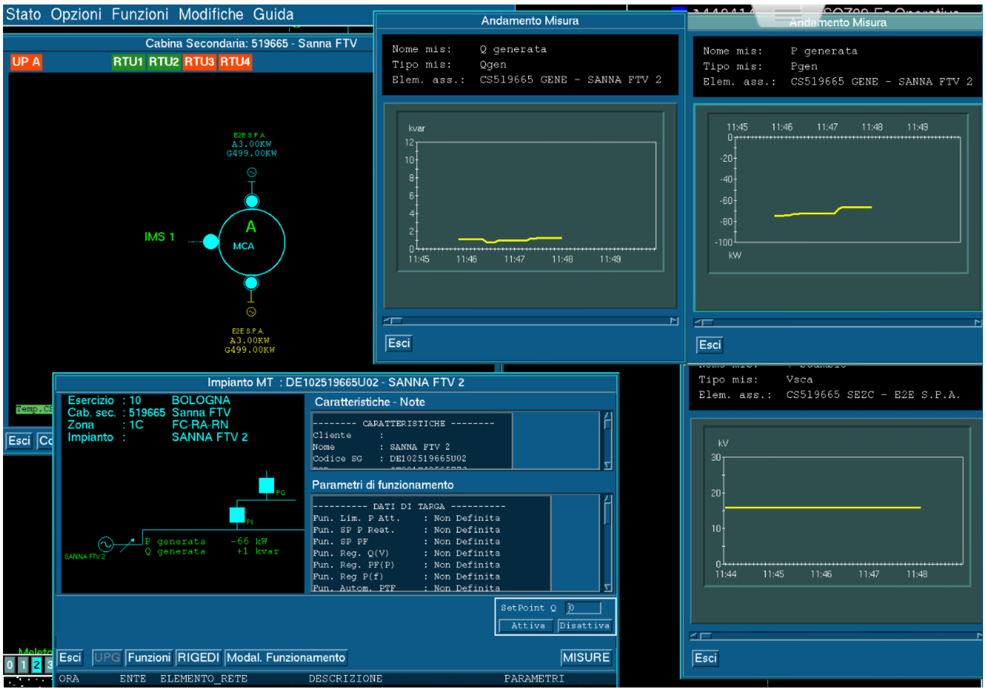


FIGURE 3-27 – CENTRAL SCADA VIEW OF SANNA FTV 1 PV GENERATOR.

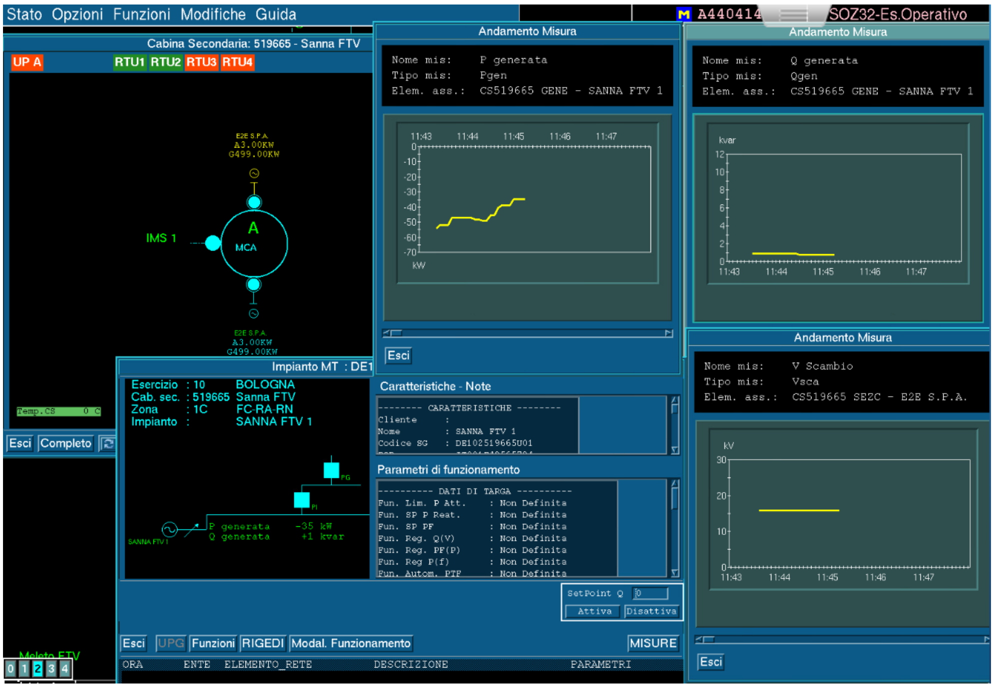


FIGURE 3-28 - CENTRAL SCADA VIEW OF SANNA FTV 2 PV GENERATOR.

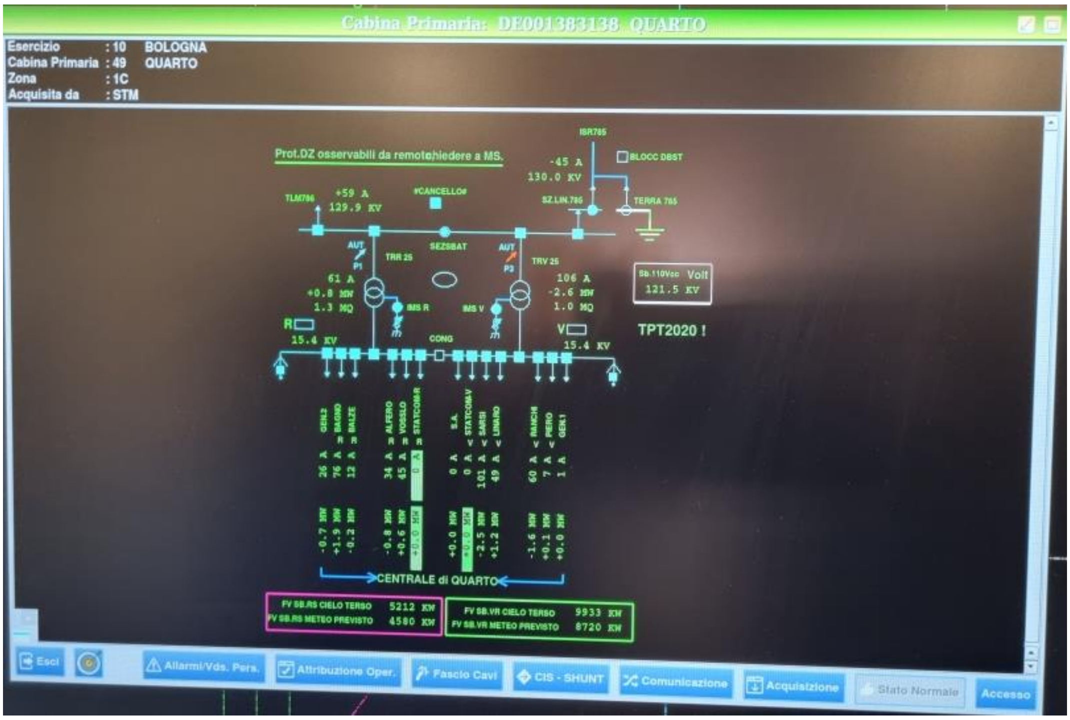


FIGURE 3-30 – DETAIL OF THE ACTIVATION OF AUTOMATIC VOLTAGE REGULATION ON GREEN OLTC.

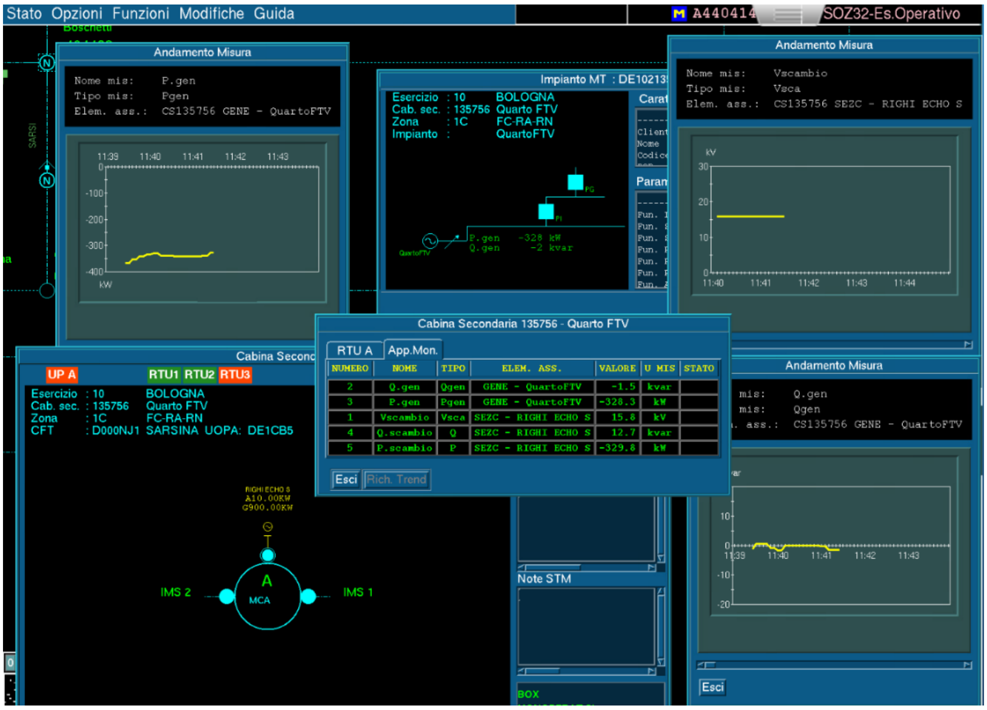


FIGURE 3-29 - CENTRAL SCADA VIEW OF QUARTO FTV PV GENERATOR.

In Figure 3-30 is represented a Central Scada view of Quarto Primary Substation, in which it is possible to appreciate the activation of the automatic voltage regulation on the Green OLTC (AUT P3). On the Red OLTC, the automatic voltage regulation is locally enabled but it is performed independentely from the network calculation because of network operation and safety needs.

Once these steps are done, the procedure requires to enable the Local Scada calculation algorithm, as shown in Figure 3-31, thus providing the suitable setpoints to the flexibility resources.

In order to verify the correct setpoint delivery to each involved resource, it has been needed to monitor the measurements of the electrical quantities involved in the regulation. Figure 3-32 and Figure 3-33 show the variation of the Reactive Power - measured and provided by each IRE - during the time interval in which the test has been performed and the corresponding results have been extracted.
The recorded measurements are averaged every 10 minutes; this does not affect the entire analysis of the scenario.

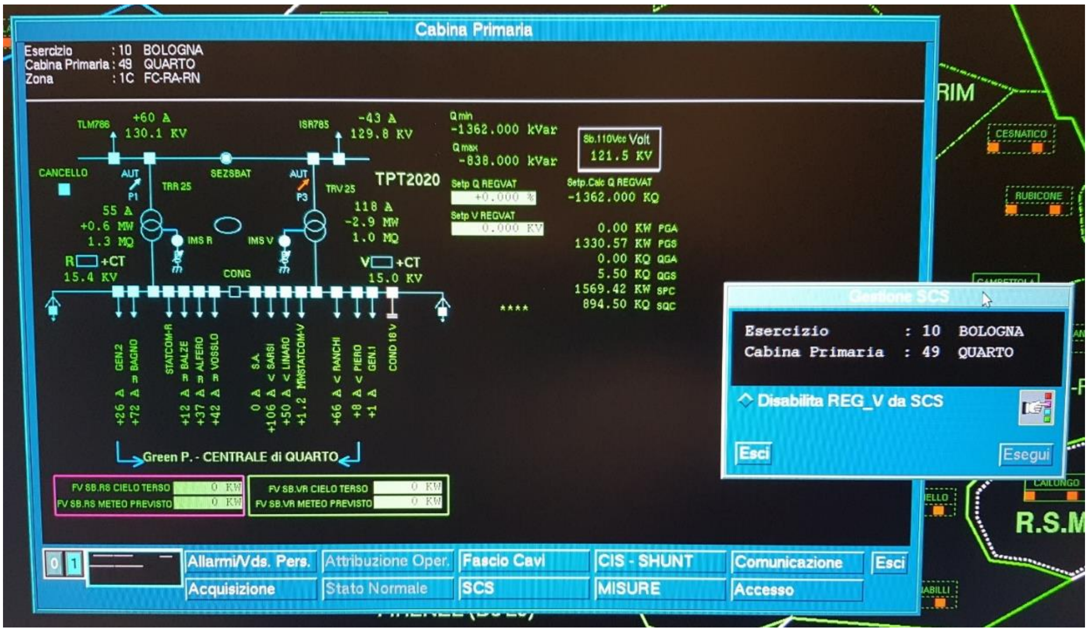


FIGURE 3-31 – VIEW OF THE ENABLED LOCAL SCADA CALCULATION ALGORITHM.

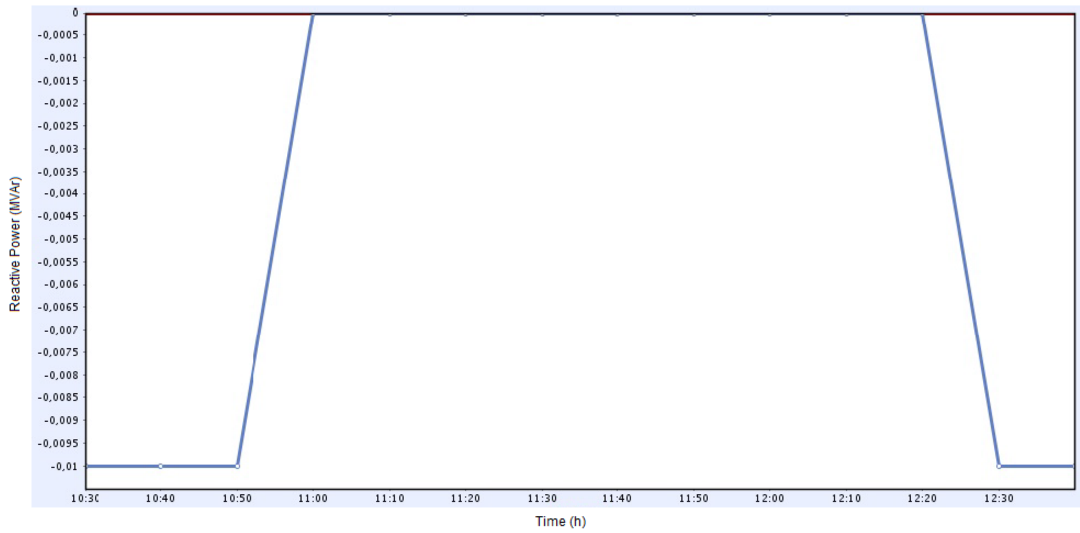


FIGURE 3-32 - REACTIVE POWER PROFILE OF QUARTO FTV PV GENERATOR RECORDED ON 8TH FEBRUARY 2022.

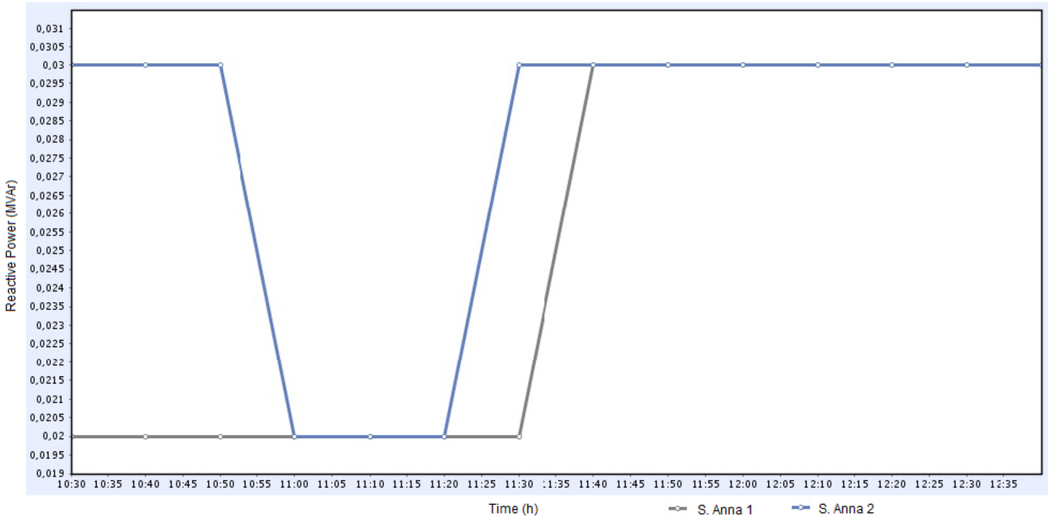


FIGURE 3-33 - REACTIVE POWER PROFILE OF S. ANNA 1 AND S. ANNA 2 PV GENERATORS RECORDED ON 8TH FEBRUARY 2022.

In order to verify also the Voltage variation at Quarto Primary Substation, the monitored measurements on central Scada HMI are shown below in Figure 3-34.

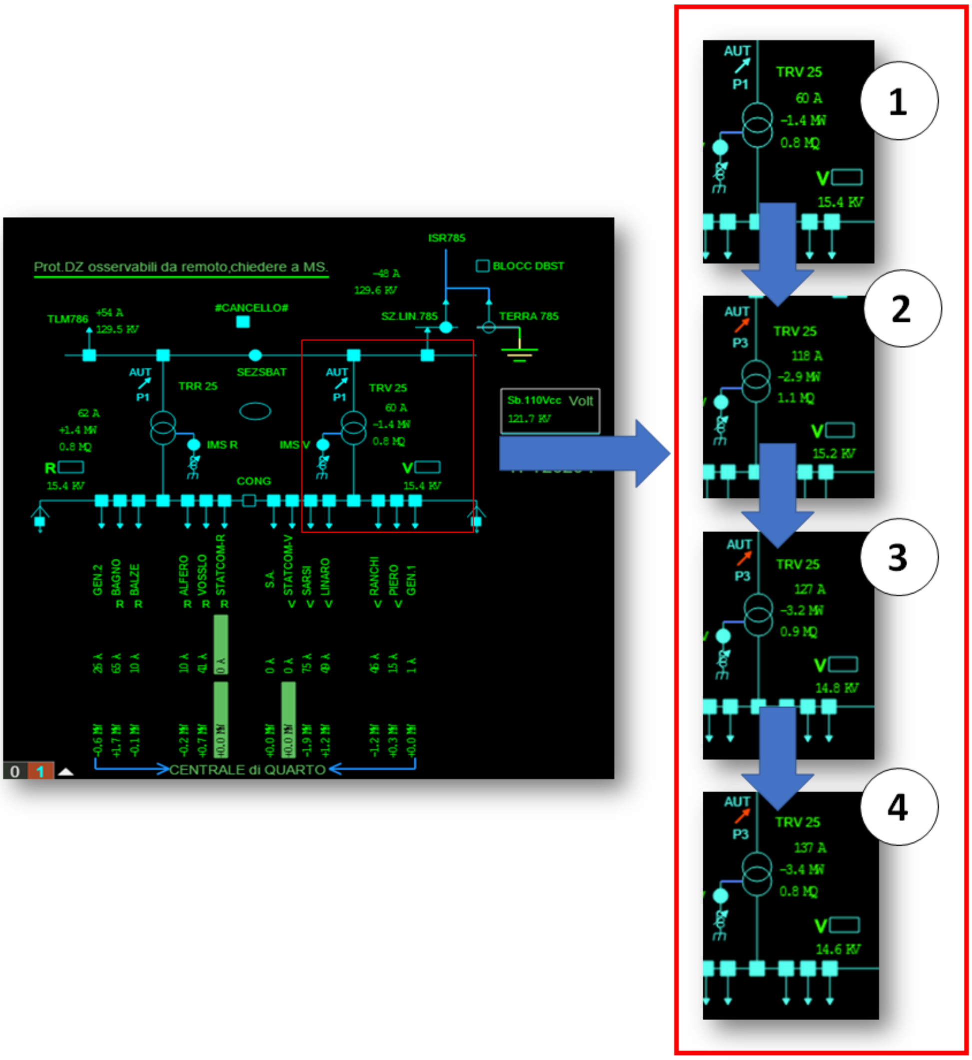


FIGURE 3-34 - QUARTO PRIMARY SUBSTATION OVERVIEW ON BOLOGNA CENTRAL SCADA DURING THE TEST OF 8TH FEBRUARY 2022.

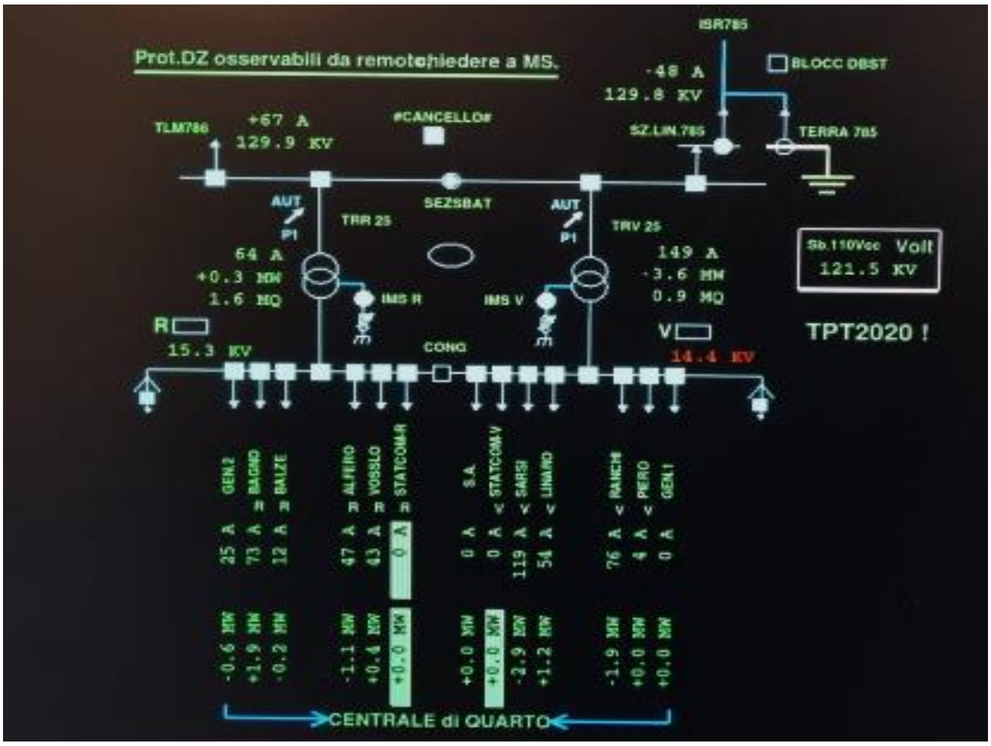


FIGURE 3-35 – LOWEST BUSBAR VOLTAGE VALUE REACHED DURING THE TEST OF 8TH FEBRUARY 2022.

Figure 3-35 shows the lowest voltage busbar measurement acquired during the test procedure, before excluding the automatic voltage regulation.

After the testing activity, the Central Scada Database has been used in order to acquire the graphs with the recordings of the operating busbar voltage and the reactive power total amount at Primary Substation interface with the TSO.

Since the Local Scada and the DSO Primary Substation RTU TPT 2020 have correctly provided the setpoint to the involved resources, Figure 3-36 shows the time window in which the test has been performed.

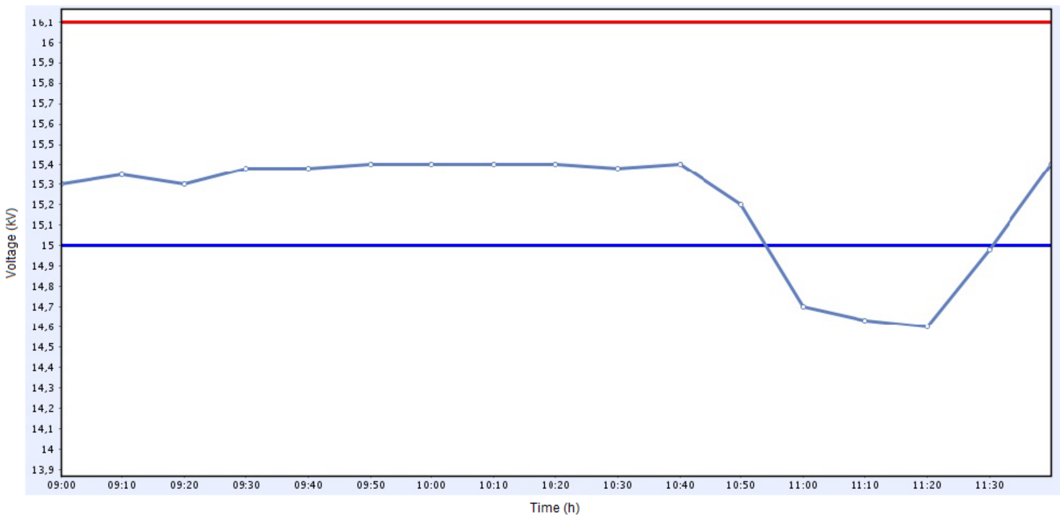


FIGURE 3-36 - VOLTAGE PROFILE OF THE GREEN TRANSFORMER OF QUARTO RECORDED ON 8TH FEBRUARY 2022.

The shape of the busbar operating voltage, which shows a significative reduction close to time 10.45 corresponding to the activation of Local SCADA automatic calculation, allows to identify an increasing of the network Hosting Capacity and helps to evaluate a voltage range, lower than the actual one used for normal operations, confirming offline simulation results illustrated in the Deliverable D6.3 *"Grid simulations and simulation tools" presents the first results about network models and simulations from the demonstrators"* [9] and D6.5 *"Optimization tools and first applications in simulated environments"* [10] presents the description of the optimization tools and the range of flexibilities used in the demonstrators. It suggests also a different approach within distribution network operations, due to a more optimized management of the resources connected to the distribution grid.

It is possible to appreciate the effect of the automatic regulation, mostly due to the OLTC activity during the tests, also in the voltage profiles recorded at the secondary substations in which the PV generators are connected.

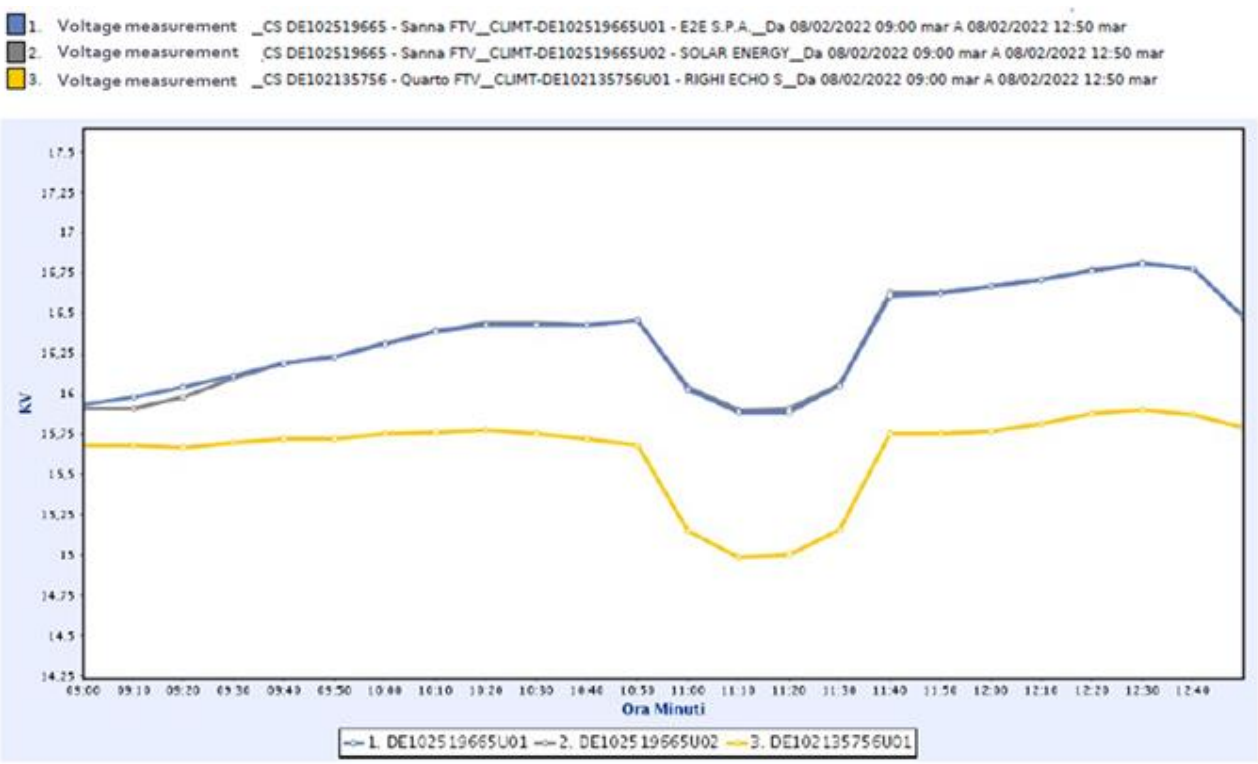


FIGURE 3-37 - VOLTAGE VARIATION OF THE THREE PV GENERATORS RECORDED ON 8TH FEBRUARY 2022.

Figure 3-37 shows that the voltage profiles of the three generators go down in an equivalent way of the busbar voltage profile during the test. It was observed that the optimization algorithm try to push the operating voltage of the network to a lower level than the usual one; indeed, the usual operating voltage of each PV generator is close to higher values as 15,75kV or 16kV.
In particular, for the two PV groups fed by SANNA FTV, it can be highlighted that the operating voltage is very close to che maximum limit admitted from the general power quality prescriptions (±10% of the operating voltage).

3.5.2 PHASE 2: POST STATCOM INSTALLATION SCENARIO

The need to exploit STATCOM functionalities within EUSysFlex project required significant changes within Quarto MV network, as the building of the Secondary Substation which implements the physical connections of the two STATCOM modules to the two separated MV feeders.
The realized secondary substation was built in compliance with the recommendations provided by the CEI 0-16 standard stated in chapter 3.4.2 and shown in Figure 3-38.

FIGURE 3-38 – SECONDARY SUBSTATION FEEDING STATCOMS.

Each STATCOM is an outdoor solution which have been installed on dedicated skids which integrates the power converters, the insulation LV/MV Transfomers and the MV outdoor switchgears, as shown in Figure 3-39.

FIGURE 3-39 – VIEW ON THE TWO STATCOM MODULES INSTALLED IN QUARTO PRIMARY SUBSTATION.

Below is proposed an exploded view of each STATCOM module in which it is possible to appreciate any significant component of the supply.

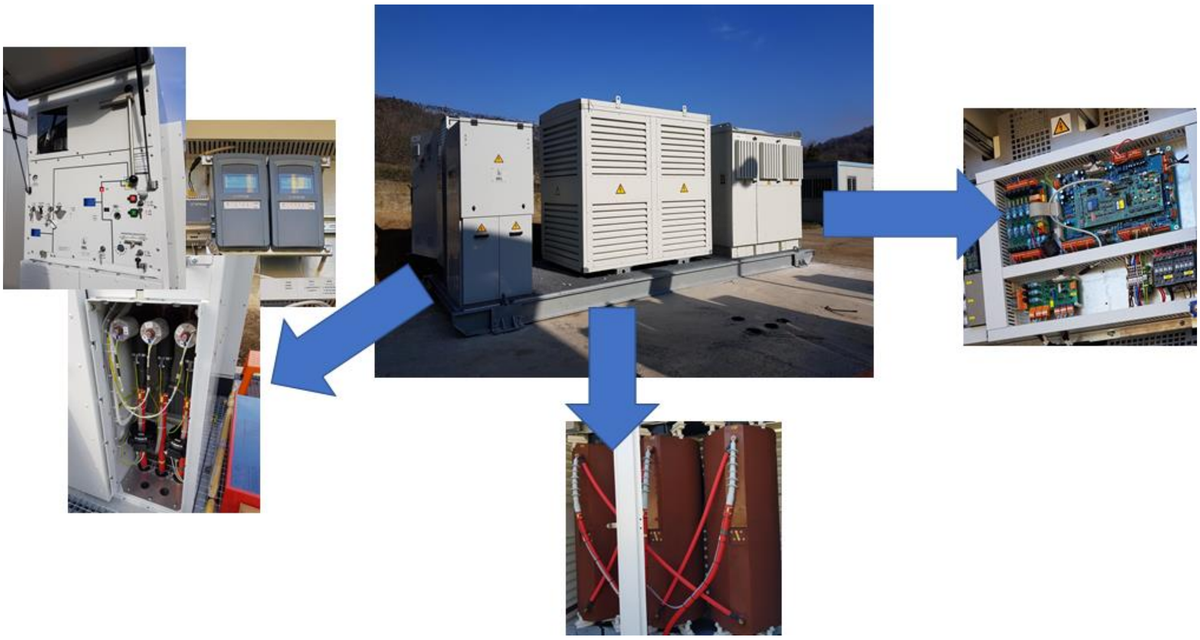


FIGURE 3-40 – EXPLODED VIEW OF A STATCOM MODULE.

Figure 3-40 shows on the right side a partial view of the processing system of the power converters, in the middle the installed insulation transformer and on the left de detailed views of the MV switchgears with the current and voltage sensors and the fault detectors required by Italian prescription CEI 0-16.

3.6 KPIS EVALUATED

The technologies and functionalities implemented within the Italian Demonstrator include the improvement of data exchange between the DSO and TSO and an optimized management of DSO network in order to meet DSO and TSO mutual needs, through automatic voltage regulation and reactive power modulation.
After the execution of the real field Demonstration tests, the following KPIs have been evaluated, as described in D10.1: "The report on the selection of KPIs for the demonstrations" [11].

- Tracking error measured at TSO/DSO interface [%]:

$$e_{TSO/DSO}(t) = \frac{|Q(t) - Q^*(t)|}{Q^*(t)}$$

- Tracking error measured at DER interface [%]:

$$e_{DER}(t) = \frac{|Q(t) - Q^*(t)|}{Q^*(t)}$$

- Increase of Hosting Capacity at primary substation [%]:

$$\Delta HC\% = \frac{HC_{SG} - HC_{base}}{HC_{base}} * 100\%$$

- Increase of reactive power capability at primary substation [%]:

$$\Delta C_{RP}\% = \frac{\sum_t (\Delta Q_{SG} - \Delta Q_{base})}{\sum_t \Delta Q_{SG}} * 100\%$$

- Line Voltage profile [%]:

$$\Delta V(t) = |V^*(t) - 1|$$

Where:

$$V^*(t) = \frac{V(t)}{V_n}$$

Tracking error measured at TSO/DSO interface

The tracking error measured at TSO/DSO interface should be calculated assuming to receive a command from the TSO in order to support the HV side voltage regulation.

The field tests have been performed by setting on TSO simulator a certain request in terms of Reactive Power at the TSO/DSO interface and subsequently trying to verify the satisfaction of the specific setpoint through the measurement of Reactive Power at HV/MV Substation. In this context, it can be pointed out that the activity has been carried out successfully from a communication protocol side, with the correct implementation of the setpoint in the Local Scada as an absolute Q setpoint referred to the HV/MV Green Transformer.

However, since the actual weather and climate conditions of the specific day when the field test has been performed did not allow a significant production from the PV plants, the measurements collected from the field devices, even if they demonstrate that the TSO request has been received (and the system has been triggered), they can not be used to prove, mainly because of the weather conditions, the full achievement of the requested setpoint at Quarto Primary Substation.

Tracking error measured at DER interface

The tracking error measured at DER interface has been calculated at a simulation level by using the Central Scada System. In particular a simulation regarding the implementation of different specified reactive power setpoints has been carried out on the IRE of Quarto FTV PV generator and the resulting reactive power measurements have been aquired.

The error in the implementation of each set point level has been calculated, as shown in Table 3.4 in which the evalutated error Is referred the corresponding percentage setpoint as well as the consequent Reactive Power request. In detail, the calculation has been performed considering 1 MVA power plant with a generated active power of 100 kW. The % setpoint - sent to the resource - represents a defined request in terms of Reactive Power which the power plant has to exchange with the MV network.

Setpoint (%)	Pmeas (kW)	Power Factor	Q setpoint (kVAr)	Qmeas (kVAr)	Error
-5	-100	-0,89	-49,92	-50,5	0,01
-4	-100	-0,93	-39,936	-37	0,07
-3	-100	-0,96	-29,952	-25	0,17
-2	-100	-0,98	-19,968	-15	0,25
-1	-100	-1,00	-9,984	-10	0,00
0	-100	±1	0	0	0,00
1	-100	1,00	9,984	10	0,00
2	-100	0,98	19,968	17	0,15
3	-100	0,96	29,952	26,4	0,12
4	-100	0,93	39,936	38	0,05
5	-100	0,89	49,92	51	0,02

TABLE 3.4 - CALCULATED ERROR AT DER INTERFACE FOR DISCRETE REACTIVE POWER SETPOINTS

In particular, Figure 3-41 shows the trend of the percentage error referred to the requested Q setpoint, in which it can be highlighted how the calculated error decreases as the requested Q value increases.

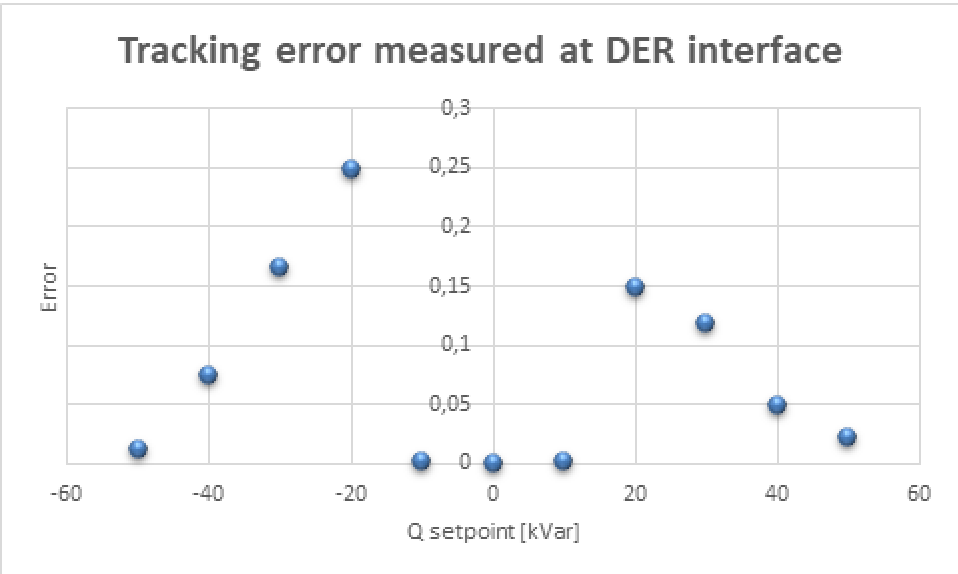


FIGURE 3-41 – TRACKING ERROR TREND MEASURED AT DER INTERFACE

Figure 3-42 shows the laboratory implemented limit for power factor values related to the required Q setpoints.

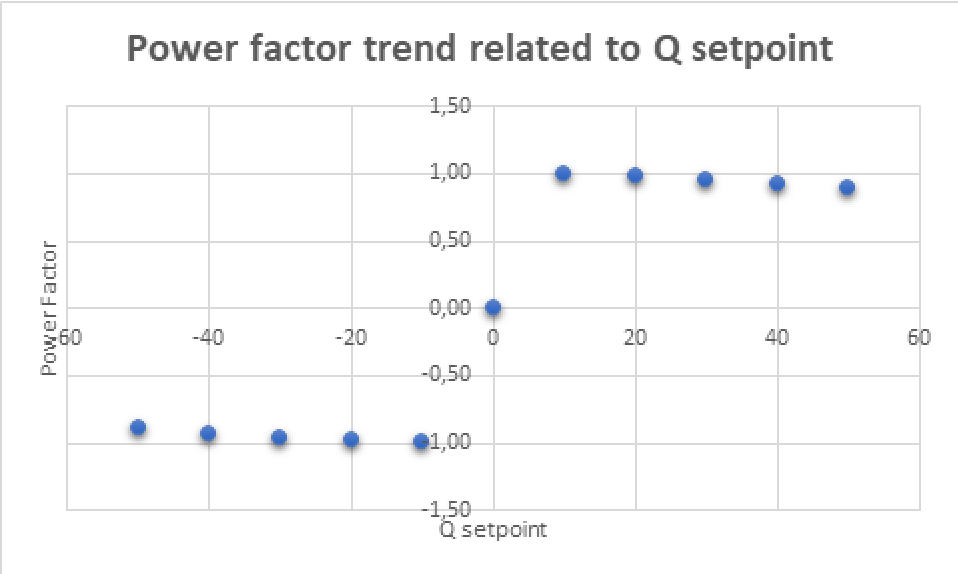


FIGURE 3-42 – POWER FACTOR TREND FOR THE CORRESPONDING Q SETPOINT AT DER INTERFACE

Increase of Hosting Capacity at primary substation

The Hosting Capacity increase at Quarto Primary Substation is calculated to estimate the rise in the potential connectable power to the distribution network as part of the improvement enabled by the EUSysFlex Project. One of the most important constrains to be considered for the connection of new Distributed Generators to the MV grid is the network voltage quality, which depends on the fact that the connection of DERs causes a change in the voltage profiles along the network itself. Since the voltage must always be between 90% and 110% of Vn (in accordance with CEI EN 50160) and in order to keep the voltage in all network nodes within the previous limits during all operating conditions, one of the main interventions is the voltage regulation that allows an increase in the connectable DG, suitably regulating the voltage on the MV side of the HV/MV transformer and the reactive power on DER. Holding the voltage level within the before mentioned range, it will be guarantee the continuos connection and operation of Power generating modules (in accordance with connection rules CEI 0-16, Annex A.70 of Grid national Codes and European standard EN 50549).

Therefore, a simulated computation has been developed thanks to the Advance Distribution Management System software (ADMS), where the ***"Base Scenario"*** is characterized by the absence of automatic voltage regulation, while the ***"Smart Grid Scenario"*** refers to the state where the voltage regulation is activated.

Considering the MV node with the most relevant level of criticality from the voltage rise point of view - Sanna FTV under the SARSI MV feeder - in the day of 2021 year (06/06/2021) when maximum production and minimum load can be noticed, a calculation simulation was carried out. In the ***"Base Scenario"***, the results show that it is not possible to connect further DERs on the considered MV node (where the two PV generators are connected) as the voltage level is already at the higher limit (16,5 kV as confirmed by the measurements recorded during field test and illustrated in paragraph 3.5.1); then the initial Hosting Capacity is assumed equal to the one currently installed under the whole SARSI feeder. In the "***Smart Grid Scenario***", the demonstration proves that operating the network at a lower voltage level allows to connect further Distributed generators on that specific Secondary Substation and, in this context, the connectable DG value is not more limited by the voltage level.

In conclusion, it can be estimated an $\boldsymbol{HC_{base}}$ approximately about ***7,4 MVA*** and an $\boldsymbol{HC_{SG} = HC_{base} + HC_{V\_regulation}}$ equal to **8,7 MVA**, with a consequent $\Delta\boldsymbol{HC}\%$ **= 18%.** It should be noticed that in this computation a conservative approach has been adopted since the benefit in terms of HC increase is only referable to the contribution of the Primary Substation OLTC, not having considered the contribution to the voltage regulation of the two Statcoms, Storage and the variation of reactive power on the three PV dispatchable generators.

Increase of reactive power capability at primary substation

The expected variation of reactive power capability at primary substation level can be calculated thanks to the Q measurements acquired during the Demo operation.

In detail, the resulting Reactive Power Capability variation ($\Delta C_{RP}\%$) must necessarily be analyzed by taking into account, on one side, the meteorological conditions of the season where the test has been executed - which do not support the production from PV plants – and, on the other hand, the limited dispatchable resources involved in the simulation itself which does not contemplate the two Statcom modules and the Storage.

Therefore, as the Q capability changed from **524 kVar** in the ***"Base Scenario"*** (absence of automatic voltage regulation) to **518 kVar** in the "***Smart Grid Scenario***", the calculated $\Delta C_{RP}\%$ is about **-1%.**

Line Voltage profile

In order to evaluate the KPI related to voltage quality, the voltage profile - function of time V(t) – on Sanna FTV MV node has been analyzed since it can be considered the most critical involved secondary node from the voltage rise point of view, due to production of energy from distributed generation. In detail, the difference in the voltage values measured during the execution time of the demonstration - which took place on 08th February - and the comparable time window of the corresponding day of the previous week - 01st February – has been evaluated.

In detail, Figure 3-43 shows the difference between the nominal voltage value and the effective operational one on SANNA FTV MV node during the time window of the demonstration test and the corresponding interval of the comparable day of the previous week. As expected, it is clear that the calculated $\Delta V(t)$ [%] decrease for each instant – during the time affected by the field test - for which measurements are available.

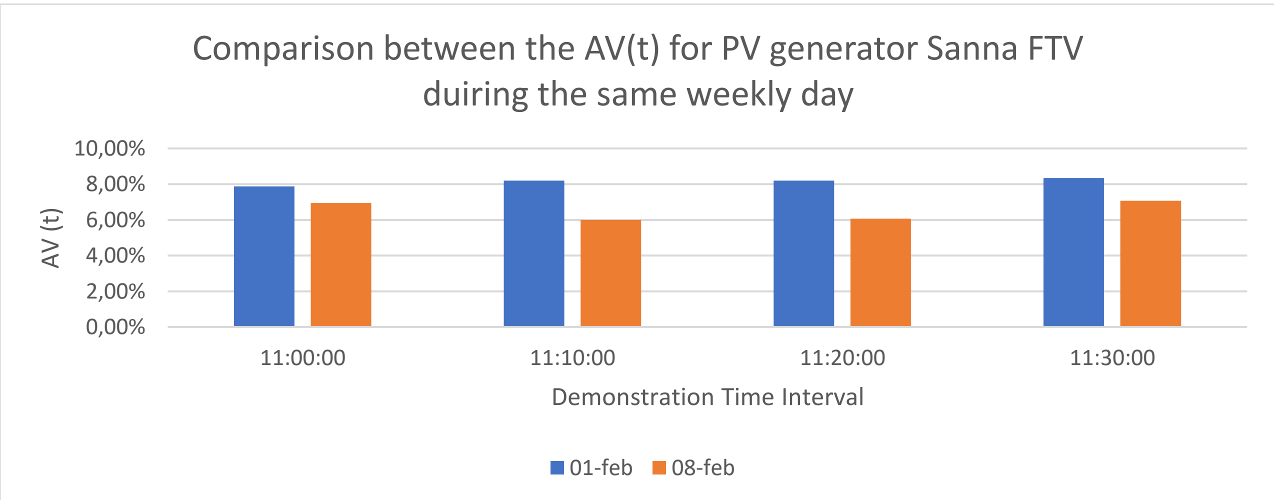


FIGURE 3-43 – COMPARISON BETWEEN UPPER OPERTAING VOLTAGE LIMIT ON SANNA FTV REACHED DURING REAL FIELD TEST AND THE CORRESPONDING DAY OF THE PREVIOUS WEEK.

4. INTERPRETATION OF LABORATORY TESTS AND FIELD RESULTS

The real field Demonstration test, held on 08 February 2022, was the opportunity to test the entire chain of systems - devices - communication protocol developed within the EUSysflex project. In particular, the activity focused on evaluating the effectiveness of Central and Local SCADA solutions, including the evolved calculation, state estimation and optimization algorithm. The flexibility resources - connected to the MV network under Quarto Primary Substation – involved within the test have been the 3 controllable PV generators (SANNA FTV 1, SANNA FTV 2 and QUARTO FTV) and the OLTC of the HV/MV Green Transformer, excluding instead the OTLC of the Red TR for requirements related to the MV network operation.

In this scenario, the most significant results in terms of benefits in the operation of the MV network are illustrated below.

Automatic Voltage Regulation

As already described in detail in paragraph 3.5.1, one of the most significant effects recorded during the demonstration operation was surely the reduction of the operating voltage on the green busbar, occurred in correspondence with the activation of the Local SCADA automatic calculation, which took place around 10.45, as shown Figure 4-1. The optimization algorithm encourages a more optimized management of the resources connected to the distribution network, guaranteeing benefits in terms of increased hosting capacity on the MV networks involved in the demonstration.

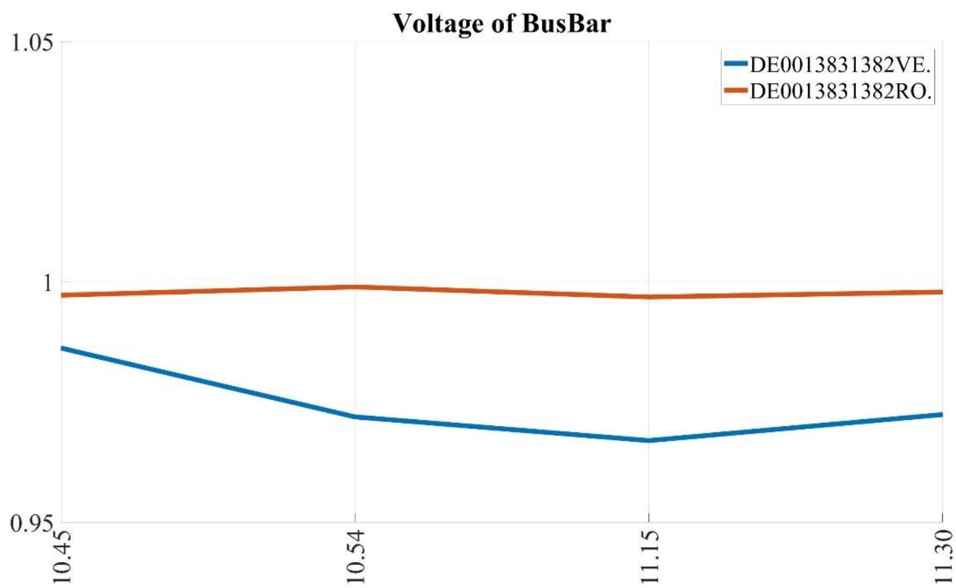


FIGURE 4-1 VOLTAGE PROFILE OF THE GREEN SND RED TRANSFORMERS OF QUARTO RECORDED ON 8TH FEBRUARY 2022 DURING THE TEST TIME INTERVAL.

The automatic voltage regulation effect - mainly due to the activity of the OLTC on the Green busbar - is also clear at the level of each secondary node where the controllable PV generators are connected. Figure 4-2 offers a comparison between the voltage trend on the Sanna FTV node during the time interval of the test and the corresponding time window of the same day of the previous week. The demo pushes the operating voltage -

normally close to the upper limit allowed by power quality standards - to a lower level, closer to the nominal value with the consequent benefits in terms of network operation and connection of additional flexibility in the specific node.

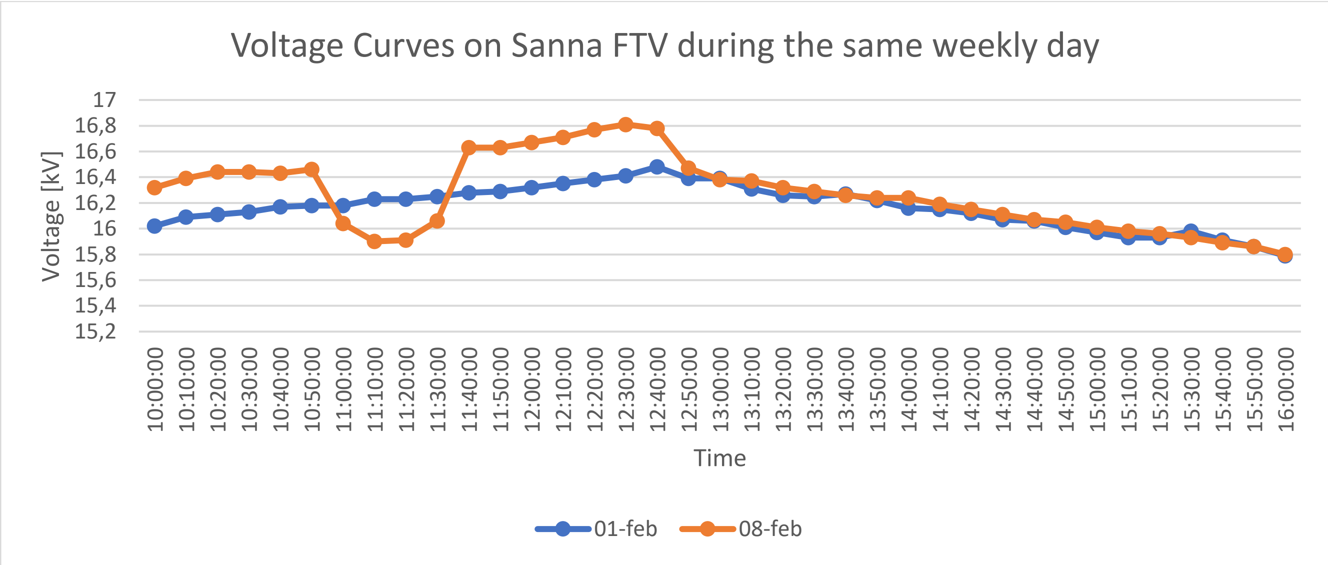


FIGURE 4-2 COMPARISON BETWEEN VOLTAGE MEASUREMENTS ON SANNA FTV DURING REAL FIELD TEST AND THE CORRESPONDING DAY OF THE PREVIOUS WEEK

Increase in Reactive Power Capability at Quarto Primary Substation

Regarding the increasing in the reactive power capability at Quarto primary substation Green busbar, where the dispatchable elements involved within the demonstration are connected, two different results are proposed below, deriving respectively from a test on 3rd February 2022, in which set point actuation on resources was disabled, and the real test carried out on 8th February 2022.

In detail, Figure 4-3 shows the reactive power capability range rise during the preliminary test conducted on 03rd February 2022, when the contribution of controllable resources was monitored.

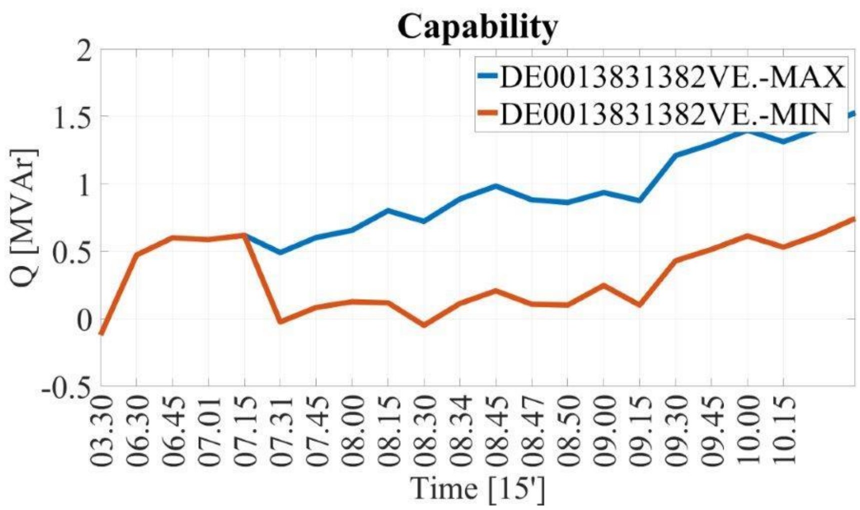


FIGURE 4-3 REACTIVE POWER CAPABILITY TREND ON THE GREEN TRANSFORMER OF QUARTO RECORDED ON 3RD FEBRUARY 2022.

On the other hand, during the real Demo operation, no increase in the reactive capability at green busbar level was recorded during the test execution time window, but actually a constant trend was observed (even a slight decrease), as shown in Figure 4-4.

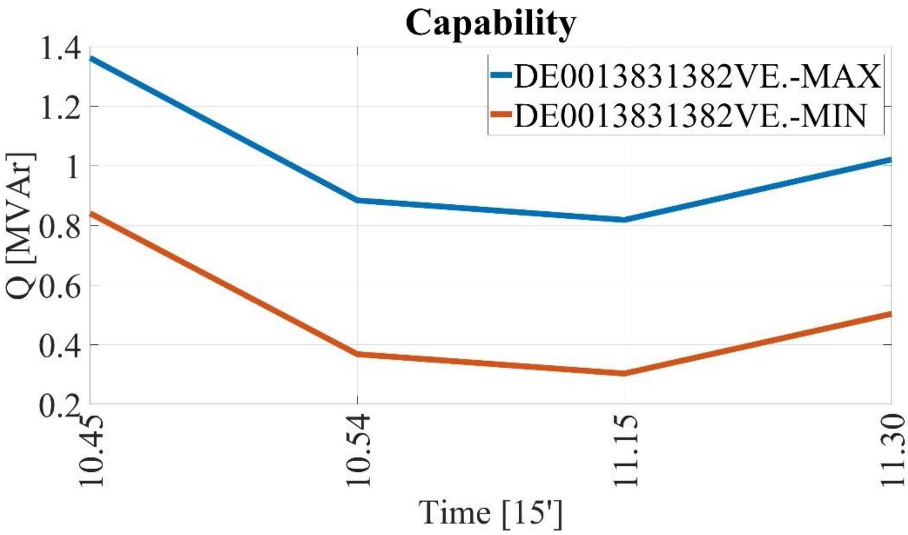


FIGURE 4-4 REACTIVE POWER CAPABILITY TREND ON THE GREEN TRANSFORMER OF QUARTO RECORDED ON 8TH FEBRUARY 2022.

This result has to be necessarily referred, on one side, to the meteorological and climate conditions which characterized the season of the year in which the test was performed – when the PV plant production is not at significant levels – and, on the other hand to the limited dispatchable resources involved in the field test which does not include the two STATCOM and the Storage.

More relevant results are clearly expected from the field test execution during the summer season and with the entire contribution of the other resources involved in the Demonstration, as the two Statcoms and Storage. Additional tests need to be performed with the Nowcast for Observability in order to better evaluate the effectiveness of the solution.

5. EXPLOITATION PLAN, OUTLOOK AND FURTHER RESEARCH QUESTIONS

Analyzing the results coming from the Italian Demonstration field test and monitoring the KPIs related to each implemented functionality, it has been proved that the infrastructure implemented by the DSO has a relevant set of requirements thus being replicated and scaled on others network, taking into account the necessity related to an efficient communication network and to the real network conditions.

The advanced functionalities implementation, as the automatic voltage regulation, has a significant impact on the standard operation of the distribution grid. Each analyzed portion of network is characterized by different criticalities and constraints, so that the possible scalability and replicability can be carried out from an infrastructural point of view, but it has to take into account the experience about the operation of each single network.

Moreover, in order to expand the adoption of this technology it is necessary to realize a training plan for the operating personnel who operate on the distribution grid, trying to make the developed tools as user friendly as possible, considering that the final purpose is always to guarantee high quality and continuity of electrical service.

In addition to the advanced smart grid infrastructure, which has already exploited in the projects listed below:

- Puglia Active Network (PAN);
- PON;
- POR;
- Replicate;
- POI MV Smart GRID;
- RES Novae;
- GRID4EU;
- Isernia Project;
- Firenze Smart City.

The system implemented within the EUSysFlex project are fully part of a set of tools related to the ADMS DERMS family which are necessary for the management of the flexibility on the distribution network in a logic integrated to a market model in which balance service providers can participate.

So far, the Italian regulatory framework does not contemplate a local flexibility market accessible for the resources connected to the distribution network neither a remuneration mechanism for active and reactive power modulation for the benefit of the DSO, while pilot projects for the provision of ancillary services to the TSO by the DERs have been underway for four years. However, according to ARERA Resolution 352/2021/R/eel published on 03/08/2021 [12], DSOs will be allowed to launch new pilot projects aimed at testing, ensuring coordination with the TSO, the procurement of flexibility services from DERs as foreseen by Directive 944/2019. In this direction, the EUSysFlex experience puts the basis for encouraging the participation of local resources to different ancillary services. In particular, within the demonstration, the 4 controllable PV plants are regulated using a DSO-owned device (IRE), but in this context an aspect which has to be explored concerns the implementation – for the producers within the Observability project – of the Power Plant Controller (Controllore Centralizzato di Impianto, CCI) which will be necessary in order to interact with TSO network. In detail, the innovative device will allow to implement controllability requirements and eventually to take part in the dispatching service market.

Therefore, as illustrated in the O and T Annexes of CEI 0-16 Standard, the possible functionalities to be implemented through the PPC are:

- Data exchange between producer and DSO (observability);
- Automatic voltage regulation and active power limitation (controllability);
- The participation of the power plant to the dispatching service market (flexibility services).

The PPC can be considered part of an enhanced context of advanced network regulation which is finalized at more efficient distribution network operation and able to explore concepts as the network resilience in emergency conditions. Indeed, the DSO has a strong necessity to exploit DERs in contingency context. Nowadays DSO has to guarantee determined levels of continuity and quality of energy, solving problems related to typical operational needs or interruptions due to extreme weather conditions or contingencies in the electrical system. Consequently, this demo allowed the study of new scenarios in which DERs are exploited to solve the abovementioned problems and where systems monitoring capability is improved.

Finally, an appropriatre regulatory framework could support a new kind of network operation which involves also the active power regulation, so that the control of each resource could allow to overcome the use of customers remote disconnection during critical context.

6. CONCLUSIONS AND RECOMMENDATIONS

The results from the tests carried out during real-time simulation in laboratories and real field operations of the Italian Demonstrator show that the SCADA systems acquire all the field measurements and signals, from the configured smart grid devices, and sends all the commands to the involved controlled resources.

The challenge of the Italian Demonstrator to implement the proposed solution in real field has allowed to have an awareness on the replicability of the solution, from laboratory environment to real DSO network, and to face critical situations due to internal and external variables in inserting innovative technologies as the STATCOM within the operated real network.

The adopted methodology allows to show how the network monitoring can become very detailed during distribution grid operations, focusing on the connected active customers, exploiting an upgraded SCADA system and an extended Smart Grid architecture, based on standard IEC 61850.

The real time simulation results and integration tests represent the mid-step before scaling the proposed solution to the real field distribution network, giving an overview even if partial of the potentials of the DSO technological solutions. One significative result of the experimentation allows to confirm that the network communication infrastructure - implementing the proposed technologies - based on communication protocols for IEDs at electrical substations, needs to have a good communication infrastructure always efficient and reliable, in order to transmit significant data to centralized systems and to correctly implement specific flexibility requests on field, by respecting cybersecurity requirements.

Both during the laboratory and the real field tests, it was highlighted also that the DSO is able to provide suitable reactive power flexibility at its interface with the TSO and to interface dynamically with this external stakeholder, by respecting the existent communication protocols. As a consequence, an improvement in the quality of relevant exchanged data can be guaranteed, including the availability of the Reactive Power Capability at the Primary Substation, in addition to the Active and Reactive Power measurements at the HV/MV Transformers.

From the measurements in the field it was possible to verify that the evolved voltage regulation allows to maintain the voltage levels below threshold in the critical nodes of the network, in order to allow the correct operations even in limit situations (high production or high load) and facilitate the integration of additional DERs on the network portion affected by the project.

Even if the control of RES by the DSO today is not allowed, a result of this experimentation proves that the DSO is capable to implement network observability thanks to power grid user interface installed at the generation plants and to the arrangement of Nowcast functionalities on SCADA systems; on the other hand it is proved that the DSO can perform controllability of connected generators involved in the experimentation.

It is needed to point out that the RES involvement during the automated process of flexibility provision from the DSO to the TSO is widely affected from PV production seasonality and the physical limits of capability curves while performing reactive power regulation. This suggests that is needed to increase the number of participants to flexibility services and to define a wider flexibility service portfolio implementing also the active power regulation, to repeat additional tests according to the effective reaching of proposed KPI, to study deeply the contribution of STATCOMs within DSO operations and to integrate new technologies promoted by Italian Electrotechnical Committee which meet the most recent regulatory guidelines from Italian local authority ARERA.

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