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Flexible energy systems Leveraging the Optimal integration of EVs deployment Wave

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Deliverable 6.2

# System level definition and hardware in the loop simulation

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# List of Acronyms

| Acronym | Meaning |
|---|---|
| AC | Alternate Current |
| ADMS | Advanced Distribution Management System |
| DC | Direct Current |
| DR | Demand Response |
| DSO | Distribution System Operator |
| EV | Electric Vehicle |
| EVSE | Electric Vehicle Supply Equipment |
| FSP | Flexibility Service Provider |
| HIL | Hardware-in-the-Loop |
| MCTS | Modular Charging Test System |
| OCPP | Open Charge Point Protocol |
| OMIE | Operador del Mercado Ibérico de Energía |
| PGUI | Power Grid User Interface |
| PHIL | Power Hardware-in-the-Loop |
| RTDS | Real-Time Digital Simulator |
| SOC | State of Charge |
| V1G | Unidirectional Smart Charging |
| V2G | Vehicle-to-Grid |
| WP | Work Package |


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# Executive Summary

The D6.2 deliverable presents the results of Task 6.2, conducted within the framework of the FLOW project. The task focused on verifying the technical feasibility and performance of integrated systems supporting Demand Response (DR) programs using electric vehicle supply equipment (EVSE) as flexible assets. The validation process involved both physical hardware and software platforms, including charging emulators, grid simulators, backend systems, and standard communication interfaces.

The main goal of the task was to demonstrate system interoperability across all actors in the DR value chain and to verify that such integration enables flexibility services in response to grid conditions.

Two laboratory-based test environments were developed to replicate real-world field scenarios:

- The Rome Demo Laboratory focused on DSO direct control of an emulated EVSE using Modbus protocols. The EVSE emulator was operated under various test scenarios to simulate real charging sessions in AC and DC, and to receive setpoint commands representing DR settings. These tests validated the ability of DSOs to observe and control EVSEs as flexible resources in near real-time.
- The Menorca Demo Laboratory tested the end-to-end integration between an aggregator platform and a backend EV charging platform (CPO) using OpenADR and OCPP 1.6J protocols. The MCTS was configured acts as an EVSE emulator and test procedures were designed to emulate the communication flow from aggregator to vehicle, verifying DR program triggering and power modulation.

To complement the physical testbeds, real-time digital simulations were executed using RTDS (Real-Time Digital Simulator) to evaluate the grid impact of DR interventions on a distribution network. Two use cases were modelled: one assessing voltage recovery under load congestion, and another testing the frequency support potential of V2G services. These simulations, conducted by considering potential future scenarios with large fleets of EVs charging simultaneously, demonstrated that aggregated EV flexibility can contribute to grid stabilization, although with performance strongly dependent on the scale of participation.

Overall, the work conducted in Task 6.2 confirms the technical viability of integrated DR services using EVSEs and highlights the key architectural and functional considerations necessary for field deployment (Task 7.2 and Task 7.3, Rome and Menorca Demos). The results represent a key step towards large-scale demonstration activities and provide valuable insights into how the flexibility of electric vehicles can be orchestrated to support energy transition and grid flexibility.



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# 1. Introduction

The increasing penetration of electric vehicles (EVs) into the energy system introduces both opportunities and challenges for the operation of electricity distribution networks. EV charging infrastructure, if properly managed and integrated, can provide flexibility services that support grid stability and optimize energy flows. One of the most promising applications in this regard is the implementation of Demand Response (DR) programs, where EV charging processes are dynamically adjusted in response to grid needs, market signals, or system constraints.

Within the FLOW project, Task 6.2 addresses the validation of system integration necessary to enable such DR programs through the involvement of multiple stakeholders such as the Distribution System Operators (DSOs), aggregators, Charging Point Operators (CPOs), and EVSE (Electric Vehicle Supply Equipment) manufacturers or operators. This task focuses on testing technological and functional interoperability across the whole value chain, ensuring that all involved systems can effectively exchange control signals, telemetry, and setpoints to activate and regulate flexibility services.

To achieve this, a laboratory-based validation environment was established, combining real and emulated EVSE assets, backend platforms, and digital grid simulation tools. The Modular Charging Test System (MCTS), a flexible and programmable EVSE emulator, was used to replicate various charging scenarios. On the network side, real-time simulation tools were used to model the electrical grid and to evaluate the response of the system under different loading and control conditions.

Two main laboratory environments were set up to reflect the distinct contexts of the field demonstrations: one in Rome, focusing on DSO-side direct control of EVSE via Modbus protocols; and one in Menorca, where the full integration of backend platforms was explored through standard protocols like OpenADR and OCPP 1.6J, allowing the activation of DR programs through aggregator-to-CPO-to-EVSE communication chains.

The goal of these activities was twofold. First, to verify the technical feasibility of remotely controlling EV charging processes via standardized communication interfaces. Second, to evaluate the grid-level impact of such controls when applied to multiple EVSEs operating concurrently. The insights gained are critical to de-risking future field deployments and supporting the implementation of scalable DR programs leveraging electric mobility as a distributed flexibility resource.

This deliverable outlines the architecture, test cases, validation procedures, and results obtained in the scope of Task 6.2. It serves to demonstrate how the integration between flexible EVSE systems and energy service platforms can be achieved and which technical configurations, communication flows, and coordination mechanisms are required to support DR-based flexibility in real-world applications.



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# 2. Scope and Objectives

This deliverable presents the activities and results related to Task 6.2, within the FLOW project. The main scope includes:

- Testing and validating the interoperability and control capabilities of EVSE systems in simulated lab charging environments.
- Demonstrating integration with aggregator and CPO platforms for the activation and execution of DR programs.
- Verifying that communication and control interfaces support accurate and near real-time modulation of EV charging loads.
- Implementing real time simulations using RTDS to replicate grid conditions and assess the impact of DR events on grid stability at different levels of network aggregation.
- Supporting the large-scale field demos (WP7) by identifying possible issues, problems or configuration challenges in advance. In particular, this task is strictly related to the on-field DEMO of Menorca Island and of Rome, present in the WP7 (Task 7.2 and Task 7.3).

Through the activities carried out in this task there will be a strong basis for the successful completion of on field DEMOs by proving that EV-based flexibility can be securely integrated into existing grid architectures and DR mechanisms.


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# 3. Gridspertise Flexibility Laboratories

## 3.1. Overview

Flexibility Labs are a center of excellence that can boast of resources with highly qualified expertise, advanced systems, and state-of-the-art instrumentation capable of replicating real-world and complex power grid management scenarios, thanks to the know-how in "smart grids."

The flexibility labs operate in an international context, with two locations present in Italy, in Milan and Bari.

The Milan flexibility lab is mainly focused on tests of technology adopted in Medium Voltage network while the Bari flexibility lab is mainly focused on tests of technology adopted in Low Voltage network. Here are performed tests on the functionality of a single device and integration tests of the device inserted in the entire chain of the distribution grid.  Moreover, both labs offer the possibility of real-time digital simulation, stress-testing, system integration of various flexibility resources, such as monitoring and regulation systems for distributed generation, electric vehicle charging infrastructure, and storage systems.

The facilities of the lab are constituted by:

- MV SCADA called STM (Milan and Bari).
- LV SCADA called STB (Milan and Bari).
- TLC network equipped with firewall and router as in the real field (Milan and Bari);
- Digital HV/MV and MV/LV substations without power equipment, having only the digital protections interfaced to the RTU and SCADA (Milan);
- Digital device simulators to simulate large scale outages (Milan);
- MV area to test sensors interfaced with protections (Milan);
- LV network reproduction (Bari);
- RTDS (real time digital simulator) (Milan and Bari);
- Electric mobility test area (Bari).

To perform integration tests related to new functionalities the devices are connected to the simulated electrical network implemented in RTDS that allows to perform “Hardware in the loop” simulations. In RTDS, it is possible to simulate all types of electrical networks and test the devices’ functionalities with all the possible scenarios of an electrical grid. Moreover, the devices are connected to the simulated grid and inserted in the entire environment of the MV and LV grid technologies. This is called “Grid in a building” facility.

The services available in the Flexibility Labs allow testing the compatibility of devices and resources with the delivery of flexibility services, operating parameters under different network configurations or extraordinary operating conditions (e.g., network congestion, large-scale load reductions in emergency situations, widespread failure events) as well as simulating different regulation scenarios and possible impacts on networks.


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## 3.2. Gridspertise e-mobility Lab Description

This section provides a description of the equipment and of the potentialities that can be implemented in the GSP e-mobility lab.

The lab is equipped with a Grid Emulator and an EV/EVSE Emulator (MCTS System), that combined can emulate different scenarios including both real and emulated devices.

- Completely emulated scenario: Grid emulator + EVSE emulator + EV emulator;
- Partially emulated scenarios:
    - Grid emulator + EVSE emulator + real EV;
    - Grid emulator + real EVSE + EV emulator;
    - Grid emulator + real EVSE + real EV;

The Grid emulator includes both AC and DC power modules, in order to emulate both AC and DC charging. It can communicate with MCTS (Modular Charging Test System) via User Interface, Modbus commands or OCPP.

MCTS is a modular emulator for electric vehicles and charging stations which enables testing of charging communication protocols and power exchange dynamics.

The Gridspertise e-mobility lab is specifically designed to address these objectives, particularly by testing the entire chain of mobility infrastructure from the DSO perspective to the end-user. The lab covers various use cases, including:

- Implementation of the electrical network of the real-time digital simulation (RTDS) to simulate different use cases. This includes examining the behavior of the grid under different scenarios, such as creating critical situations or congestion related to electric mobility. The aim is to evaluate the performance of flexibility algorithms and their impact on grid operations.
- Hardware-in-the-loop (HIL) emulation with real power flow to verify the effectiveness of flexibility algorithms. This involves emulating electric vehicles (EVs) and grid criticalities using the Grid Emulator connected to EVSE/EV emulators.
- Testing different models of EVSE (either real or emulated) including:
    - V1G EVSEs up to 30 kW (AC)
    - V1G EVSEs up to 36 kW (DC)
- Testing the communication protocols for charging infrastructure.
- Testing V2G technologies for flexibility services.
- Testing different tools and software required to enable flexibility services.
- Testing the communication and command capabilities between the Charge Point Operator (CPO) and EVSE.


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## 3.3. Lab Devices Description

### 3.3.1. Real Time Digital Simulator (RTDS)

The Real-Time Digital Simulator (RTDS) is an advanced simulation platform that allows real-time digital modeling and analysis of electrical power systems. It plays a very important role in modern power system engineering to study the behavior of electrical networks under both steady-state and transient conditions.

One of the primary features of the RTDS is its capacity to model electrical network components such as generators, transformers, transmission lines, and loads with high accuracy. These models allow for the simulation of a wide range of operational scenarios including electrical transients, overload conditions, and short circuits.

What distinguishes RTDS from traditional offline simulation tools is its ability to operate in real time. Unlike conventional simulators, which may require significant time to compute and process complex network interactions, RTDS delivers immediate results, mirroring the real-time responses of the actual grid.

A major advantage of RTDS is its support for hardware-in-the-loop (HIL) simulations.

In summary, the RTDS is a powerful tool that can help studying power systems and validating several use cases before their on field application .


**Figure 1. Real Time Digital Simulator (RTDS) Rack, Ref: www.rtds.com**

### 3.3.2. Modular Charging Test System (MCTS) – EVSE and EV Emulator

The Modular Charging Test System (MCTS), developed by Applus IDIADA, is a flexible and programmable electric vehicle supply equipment (EVSE) emulator designed for laboratory testing of both AC and DC charging scenarios. It allows for realistic interactions with a real electric vehicle, enabling a wide range of charging profiles and control logic to be tested in a safe and controlled environment.

Within Task 6.2 of the FLOW project, the MCTS has played a central role in the validation of system integration and demand response services. Its technical capabilities include AC charging up to 30 kW and DC charging up to 36 kW with a real vehicle. The system supports industry protocols such as OCPP 1.6J for backend integration and Modbus TCP for local device control.

MCTS has been used in both the Rome and Menorca demo laboratories. In Rome, it was directly controlled via Modbus commands from a DSO interface device, enabling test scenarios that simulate local congestion mitigation through EV load modulation. In Menorca, it was integrated into Enel X Way's backend (CPO) to emulate the complete DR chain from aggregator to EVSE. Through these setups, MCTS enabled the emulation of V1G flexibility services, allowing to validate the responsiveness of charging infrastructure to demand response signals.

Due to its versatility, the MCTS proved to be a valuable asset for reproducing realistic use cases and evaluating the technical feasibility of DR flexibility services in different operational contexts.


**Figure 2. Modular Charging Test System (MCTS) Racks**



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# 4. Use Cases Description

## 4.1. RTDS-Based Simulation of EV Flexibility Impact on the Grid

### 4.1.1. General Overview

As part of Task 6.2 of the FLOW project, a real-time simulation was developed using RTDS (Real-Time Digital Simulator) to investigate the grid-level impact of flexible electric vehicle (EV) charging modulation. The main goal of these simulations is to validate how EV charging infrastructure can support the distribution grid in mitigating local congestion, voltage instability, and frequency deviations by responding to simulated flexibility signals such as Demand Response (DR) commands.

The simulation replicates a complete electrical network from the high-voltage transmission system down to the low-voltage level, where EVs are connected to charging points. Within this simulation, it is possible to control key variables such as local voltage and system frequency, enabling the simulation of both static and dynamic disturbances.

This activity contributes to the deliverable by demonstrating the use of advanced simulation tools to evaluate future flexibility services and understand system behaviour under stress scenarios before deploying use cases in the field.

The main goal of these simulations is to proof that EVs based flexibility could be potentially have a very good impact to solve grid issues only with a very large number of EVs that are available, and plug connected to the grid in order to be ready to respond to DR command.

Finally, although these scenarios are not widely applicable today due to the limited number of EVs and a low charging simultaneity factor, the studies demonstrate that, with the infrastructure ready to enable EV modulation, there will be significant potential for EVs as FSPs to provide grid services in the future.


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## 4.1.2. Description of the RTDS Simulation Architecture

The RTDS simulation environment is designed to model a realistic multi-level electrical system. The key layers and components are described as follows:

### 4.1.2.1. High Voltage Transmission Grid Model

The High Voltage (HV) grid of the system is represented using an ideal Thevenin generator model. This generator acts as the equivalent source of the transmission grid and allows dynamic adjustment of output voltage and frequency.

The RTDS model corresponding to the generator simulating the HV grid has the representation in Figure 3. As can be seen from the figure, the generator operates at impressed voltage (GE_mag=132 kV) and at set frequency (f=50 Hz). The frequency of the grid could be modified to generate disturbances on the simulated grid. The HV network parameter, specifically the short-circuit reactance (Xcc) and resistance (Rcc), have been selected based on typical values for Substation and Transmission-level nodes.

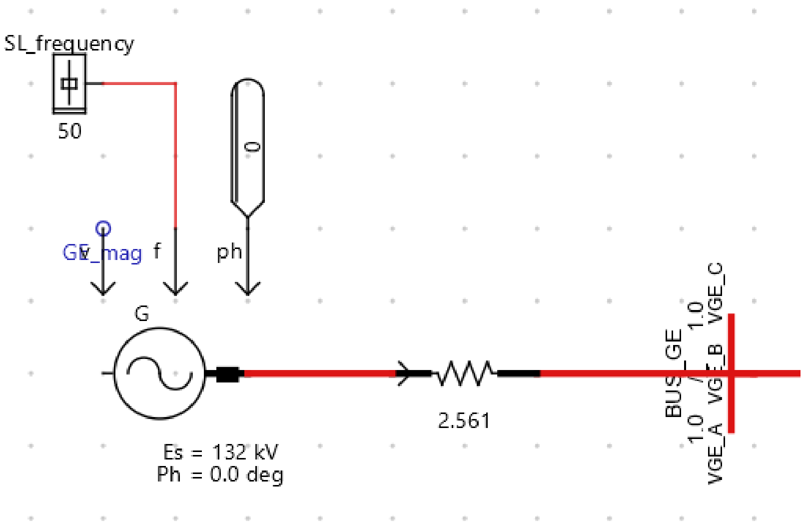


**Figure 3. RTDS Model of HV Grid Equivalent Generator**

### 4.1.2.2. HV/MV Substation Model and MV feeder

The HV/MV transformer was modelled with the values shown below in Table 1, based on typical values of HV/MV Transformer nameplate. An on-load tap changer (OLTC) was also included in the model to bring the MV busbar voltage close to the grid's nominal operating value (20 kV). The variator was modelled with 21 sockets.

| Parameter | Value | Measure Unit |
|---|---|---|
| V1n (Primary Nominal Voltage) | 127 | kV |



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| | | |
|---|---|---|
| V20 (No Load Secondary Voltage) | 21,6 | kV |
| An (Nominal Power) | 25 | MVA |
| Vcc (short circuit voltage) | 13 | % |
| Pcu (copper losses) | 0,0045 | pu |
| P0 (no load losses) | 0,001 | |
| Im (magnetizing current) | 1 | % |
| N° Tap | 21 | |
| ΔV Tap | 1,5 | % |

**Table 1. HV/MV Transformer Parameters**

In the RTDS model the transformer and the relative MV busbar have the following representation, see Figure 4.

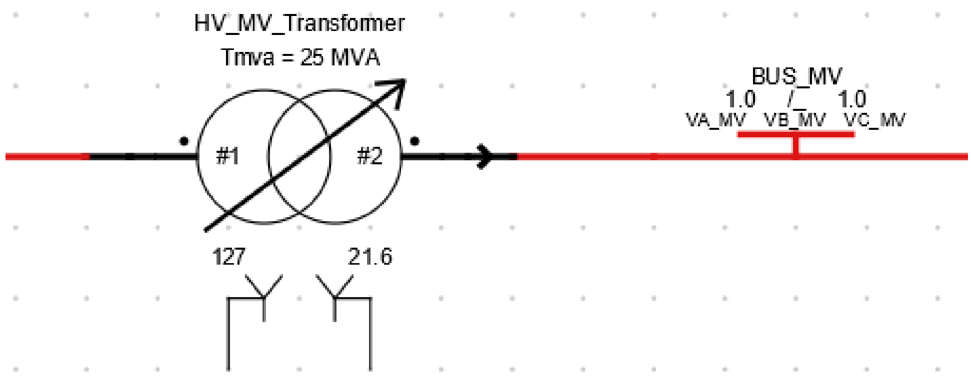


**Figure 4. RTDS Model of HV/MV Substation**

The MV feeder was inserted using the model of concentrated parameter "pi sections". The used parameters are typical of a MV line feeder of a distribution grid. In the following table the list of the used parameters.

| Rd [Ω] | Xd [Ω] | Xcd [MΩ] | Cd [µF] | R0 [Ω] | X0 [Ω] | Xc0 [MΩ] | C0 [µF] |
|---|---|---|---|---|---|---|---|
| 0,025 | 0,022 | 0,0388 | 0,082 | 0,2136 | 0,1526 | 0,0388 | 0,082 |

**Table 2. RTDS MV feeder parameters**


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The RTDS model of the MV feeder is represented in the following Figure 5.

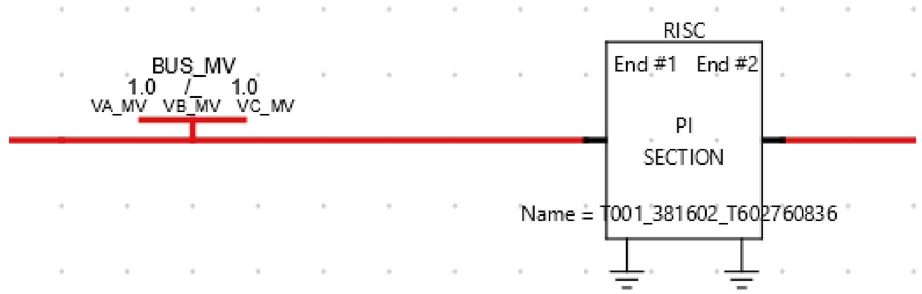


**Figure 5. RTDS Model of MV feeder**

#### 4.1.2.3. MV/LV Substation Model and related loads

The MV/LV transformer was modelled with the values shown below in Table 3, based on typical values of MV/LV Transformer nameplate.

| Parameter | Value | Measure Unit |
|---|---|---|
| V1n (Primary Nominal Voltage) | 20 | kV |
| V20 (No Load Secondary Voltage) | 0,66 | kV |
| An (Nominal Power) | 3 | MVA |
| Vcc (short circuit voltage) | 9,5 | % |
| Pcu (copper losses) | 0 | pu |
| P0 (no load losses) | 0 | |
| Im (magnetizing current) | 1 | % |

**Table 3. MV/LV Transformer Parameters**

Moreover, in the modelled MV/LV substation there are the following components:

- One ideal bidirectional generator (±3 MW), used to simulate a controllable load or a DER (Distributed Energy Resource).
- Four simulated EVSEs, each modelled to consider four different simulation scenarios with all EVs charging simultaneously. In detail:
    - Scenario A: 5 simulated EVs, each modelled to power in AC mode at 22 kW, for a total charging power impact of 110 kW.
    - Scenario B: 10 simulated EVs, each modelled to power in AC mode at 22 kW, for a total charging power impact of 220 kW.
    - Scenario C: 50 simulated EVs, each modelled to power in AC mode at 22 kW, for a total charging power impact of 1.1 MW.



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- Scenario D: 100 simulated EVs, each modelled to power in AC mode at 22 kW, for a total charging power impact of 2.2 MW.

- One real EVSE emulator (MCTS), operating in AC charging mode and connected via PHIL interface. The PHIL interface is possible thanks to electronic board of RTDS, called GTAO, sending node voltages (in ± 10 V RMS) to the grid emulator that can amplify them and to power the EVSE emulator; while the feedback signal of the current is sent from the EVSE emulator to the RTDS thanks to another electronic card called GTAI.

The PHIL EVSE Emulator is only used as real time feedback of the real EVSE emulator into the simulated grid but, due to the limited power of the EV and EVSE real power is not possible only with one EVSE emulator to adjust the congestions of the grid local generated. So, it is not considered for the real time simulations use cases.

The use case scenarios related to the RTDS simulated grid are used to consider the effect of several simulated EVSE that are connected to the same LV voltage bus. Two different use case scenarios will be discussed in the next section.

The RTDS model of the MV/LV substation and of the related components are shown in the following Figure 6.

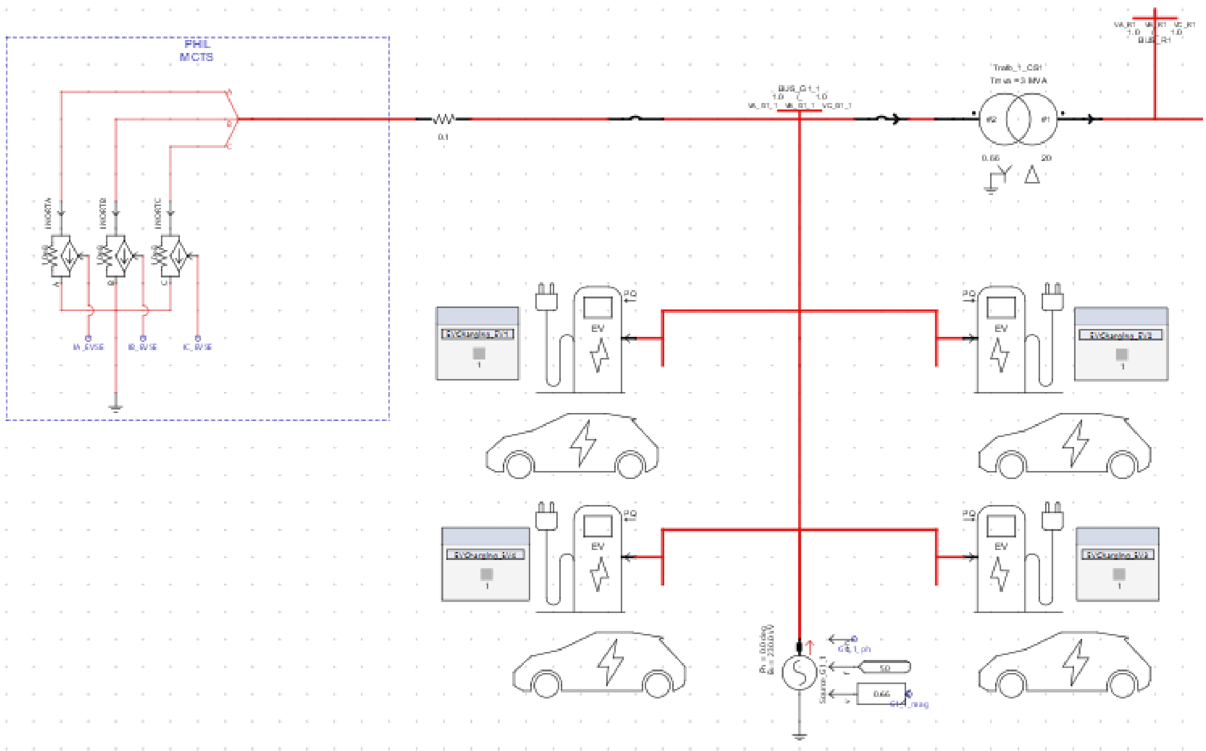


**Figure 6. RTDS Model MV/LV Substation and related load/EV's**



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### 4.1.3. Simulated Use Cases and Scenarios

#### 4.1.3.1. Use Case 1: Congestion Mitigation via V1G Load Reduction

This use-case investigates the ability of a fleet of EVs to mitigate local voltage drops and network congestion through coordinated charging modulation, simulating a Demand Response (DR) event initiated by the Distribution System Operator (DSO). The simulation is implemented in RTDS and replicates a realistic low-voltage (LV) grid scenario centered around a secondary substation supplied by a 20 kV/0.66 kV transformer. The substation feeds both a constant background load, representing typical residential or commercial demand, and a fleet of AC EV chargers modeled as individual flexible loads. The topological elements and parameters of the network represents a typical MV and LV grid of Italian distribution grid.

Each EV charger is configured to simulate AC charging at 22 kW, a common value for three-phase charging stations. To evaluate scalability and assess how EV fleet size influences DR effectiveness, four different simulations are carried out with 5, 10, 50, and 100 EVs connected in parallel to the LV bus. This corresponds to an aggregated load of approximately 110 kW, 220 kW, 1.1 MW, and 2.2 MW respectively. This value will consider the effect of several EVs charging simultaneously for future scenarios in which the penetration of EVs could be very high.

The test begins with all EVs charging at full nominal power. After a stable initial state is reached, a step increase in background load is introduced pushing the LV voltage to critical levels (0.90 p.u.) or just below the admissible threshold for standard operation. This replicates a realistic network congestion scenario, such as one caused by a sudden increase in localized demand.

Upon reaching this congested condition, a simulated DR command is triggered to reduce the power drawn by each EV to a lower level (from 22 kW to 11 kW per EV), thus decreasing the total demand on the transformer and solving voltage problems at the LV busbar.

During each simulation, the following parameters are monitored:

- RMS voltage at the LV busbar;
- RMS current at the LV busbar;
- Total active (P) power absorbed at the LV busbar level;
- Time-to-response, inside RTDS, of the simulated EVs and voltage stabilization curve post DR activation.

Expected outcomes vary depending on the number of EVs involved:

- For 5 or 10 EVs, the total load reduction (55–110 kW) has only a marginal impact on voltage recovery and transformer current.
- With 50 EVs, the DR event produces a significant improvement, raising the LV to an acceptable operational level and so lowering current at the LV busbar.
- For 100 EVs, the load flexibility becomes substantial, enabling the system to restore the voltage to good levels (>0.95 p.u.) effectively.


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This use case demonstrates how EV fleet can act as a distributed, load modulation resource, fully integrated into DR programs aimed at preventing overloading conditions in secondary substations. In general, the study is focused on the effect, at LV level, of the steady state grid conditions after simulated DR V1G power modulation.

Moreover, the meaningful result is that EV based flexibility for grid services could not be provided with a small number of EVs but only with a large number of fleets of EVs.



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#### 4.1.3.2. Use Case 2: Frequency Support using V2G Simulation

This use case focuses on the evaluation of V2G (Vehicle-to-Grid) functionalities for supporting primary frequency regulation in the distribution network. This use case is of critical relevance in the context of increasing penetration of non-dispatchable renewable energy sources, which are progressively reducing the inertia of the electric grid. In this evolving scenario, EVs when enabled for bidirectional power exchange, could act as distributed energy resources capable of actively contributing to grid stabilization services.

The simulated network comprises a simplified but representative structure of a real power system: it includes a high-voltage node emulated by an ideal voltage generator, connected to a primary substation with a 20 kV/0.66 kV transformer. Downstream, a secondary substation (MV/LV) feeds a low voltage busbar to which multiple EVSE (Electric Vehicle Supply Equipment) are connected.

The objective of the simulation is to investigate whether the coordinated action of a group of EVs, each implementing local frequency control (droop control), can provide frequency regulation at the distribution level. To emulate a frequency disturbance, the grid frequency is perturbed within RTDS. A typical event simulated in this scenario is an underfrequency deviation from the nominal 50 Hz value, simulating an imbalance between generation and demand.

Each EV is assumed to be capable of injecting up to 10 kW (considered as a common value of V2G EVs for power injection), of active power into the grid when a frequency drop is detected. The droop control algorithm follows a linear behavior: as the frequency decreases below a set threshold, the EV begins injecting power proportionally, reaching its maximum capability when the frequency reaches a certain lower value (in this case 49.7 Hz). No centralized control is involved in this mechanism; all EVs respond independently based on their local frequency measurements.

Four different simulation configurations are explored to evaluate the effect of fleet size:

- Scenario A: 5 EVs
- Scenario B: 10 EVs
- Scenario C: 50 EVs
- Scenario D: 100 EVs

In each case, the system's behaviour in terms of frequency restoration, voltage stabilization, and current flow is observed. The frequency deviation is introduced in the same way for each configuration to enable comparative analysis. The EVs are connected to the grid in V2G-ready mode at the start of each test.

The main expectation of the test is that, while a small number of EVs may provide only limited support, the aggregated contribution of several EVs, charging simultaneously and ready to provide injection of power, will show a clear effect on network frequency stabilization. In general, the study is focused on the effect, at LV level, of the steady state grid conditions after simulated DR V2G power injection event.

As the previous use case, also in this simulation study, the main goal is to prove that the frequency stabilization based on V2G EVs could work only having certain conditions such as large fleet of EVs plugged and ready for response.


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## 4.2. Menorca Demo Laboratory Use Case

### 4.2.1. General Overview

The Menorca Demo Laboratory Use Case has been developed as a preparatory testing framework designed to emulate, in a controlled lab environment, the technical and operational conditions required for the deployment of Demand Response (DR) flexibility services involving Electric Vehicle Supply Equipment (EVSE) and Electric Vehicles (EVs). This use case aims to validate the communication and control pathways between the different actors in the flexibility ecosystem such as, the Aggregator (BSP, Balance Service Provider, Enel x), the Charge Point Operator (CPO, Enel x Way), and the EVSE device using standard protocols and replicating the architecture that will be used in the field deployment on the island of Menorca and in part also on the field demo of Rome.

This lab setup leverages a high-fidelity emulation of an EVSE, represented by the Modular Charging Test System (MCTS) and a real EV (Opel Corsa-e), connected in DC mode, to evaluate the performance, interoperability, and responsiveness of the backend platforms. The MCTS is configured with two charging plugs (Plug ID 1 for DC charging, Plug ID 2 for AC charging), each associated with distinct maximum power thresholds (36 kW and 30 kW respectively). For the laboratory phase, plug ID 1, in DC mode was used.

The purpose of the use case is to emulate a full DR activation chain, starting from the Aggregator's backend platform (Enel X), through the Charge Point Operator (Enel X Way), down to the EVSE emulator (MCTS) and, ultimately, the EV. The system was designed to test standard-based communication protocols: OpenADR for the Aggregator - CPO interface, and OCPP 1.6J for the CPO to the EVSE emulator interface. The core objective was to demonstrate that a flexibility signal, originating from the DSO or energy market platform (OMIE, not tested in this lab use case), could be processed and translated by the Aggregator (for Menorca on field DEMO they are sent with an email communication), dispatched to the CPO, and then delivered to the charging point to adjust the ongoing charging session.

The ultimate goal was to validate this process under real charging conditions in a lab setting and simulate the same logical behaviour expected in the field demonstration (WP7, Task 7.3, Menorca Demo). Furthermore, the lab-based emulation provides a means to verify the technical readiness of each system component and interface (hardware and software) before deploying them in the on-field scenario (Task 7.3, Menorca Demo).


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## 4.2.2. Description and Architecture

The architecture of the Menorca Demo Laboratory Use Case is based on a multi-layered interaction between physical test infrastructure and cloud-based control platforms, reflecting a real-world DR program deployment scenario. It consists of two main domains: GSP E-Mobility Lab Environment and the AGG-CPO Cloud Environment.

In the following Figure 7 there is the block diagram of the lab use case architecture.

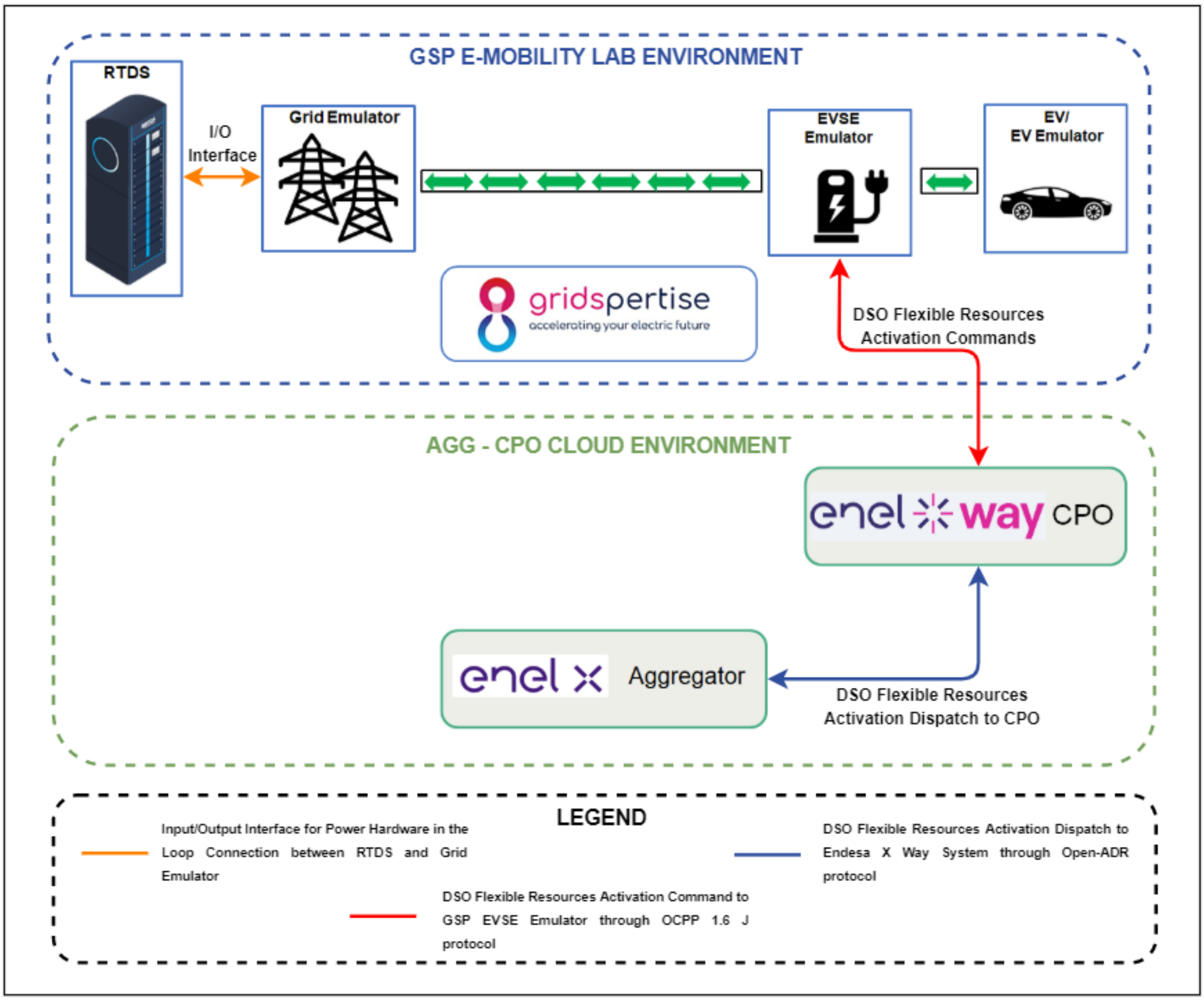


Figure 7. Block Diagram of Lab Architecture of Menorca Demo Use Case

### 4.2.2.1. GSP E-Mobility Lab Environment

This environment is physically located within the Gridspertise laboratory infrastructure and is responsible for the real-time emulation and testing of the EVSE and EV components:

- Modular Charging Test System (MCTS): It emulates a smart charging station (EVSE) and can manage both AC and DC charging modes. It supports Plug ID 1 (DC up to 36 kW) and Plug ID 2


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(AC up to 30 kW). For these tests, only Plug ID 1 was used. The MCTS can receive and respond to OCPP 1.6J commands.

- EV (Opel Corsa-e): Connected to MCTS via CCS2 plug, the vehicle represents the flexible load in this scenario. It is used to emulate a V1G demand modulation scenario. No V2G functionality is currently available for this configuration.
- EVSE Backend Integration: The MCTS was registered as a real charging station within the Enel X Way backend, with proper association of its two plug IDs, session authorization modes, and charging profiles. This included definition of maximum power limits, user tokens for remote start, and scheduling flexibility parameters.

#### 4.2.2.2. AGG-CPO Cloud Environment

This cloud-based control layer consists of two interconnected platforms, forming the heart of the DR communication chain:

- Enel X Aggregator Platform (BSP): This system is responsible for dispatching flexibility activation requests to the CPO using the OpenADR protocol. It includes a GUI for configuring demand requests, specifying activation timeframes, power modulation requirements, and asset groupings.
- Enel X Way CPO Backend (CPO, eVOS System and Energy Services System): Upon receiving DR signals via OpenADR, this backend is responsible for translating those requests into specific OCPP 1.6J messages and sending them to the enrolled charging stations (in this case, MCTS). It supports direct remote control of sessions, power setpoints, charging schedules, and availability toggling.

The communication flow is structured as follows:

- Demand Response Activation: The Aggregator platform issues a DR request to the Enel X Way CPO using OpenADR (event-based communication). The event contains all the relevant parameters.
- OCPP Command Dispatch: The CPO platform converts the DR event into an OCPP 1.6J command and sends it to the EVSE (MCTS), which reacts accordingly, modifying the ongoing charging session.
- Real-Time Charging Response: MCTS enforces the new command and reflects these changes in its interface and telemetry.


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### 4.2.2.3. Scenarios and Testing Procedures

In the context of this use case, the objective of the activities conducted under Task 6.2 was the validation of end-to-end of the demand response (DR) processes in a laboratory setting, prior to deployment in field. The testbed included the integration of a custom-built EVSE emulator, the EVSE Emulator (MCTS), with Enel X Way systems, the EVOS backend (backend platform of Enel X way) (see Figure 8 - Figure 9), the Energy Services platform (CPO interface, see Figure 10), and communication with the Enel X aggregator platform. The activities focused on ensuring the operability of all system components involved in the DR chain and validating the capability to execute DR events through real-time modulation of an EV charging session.

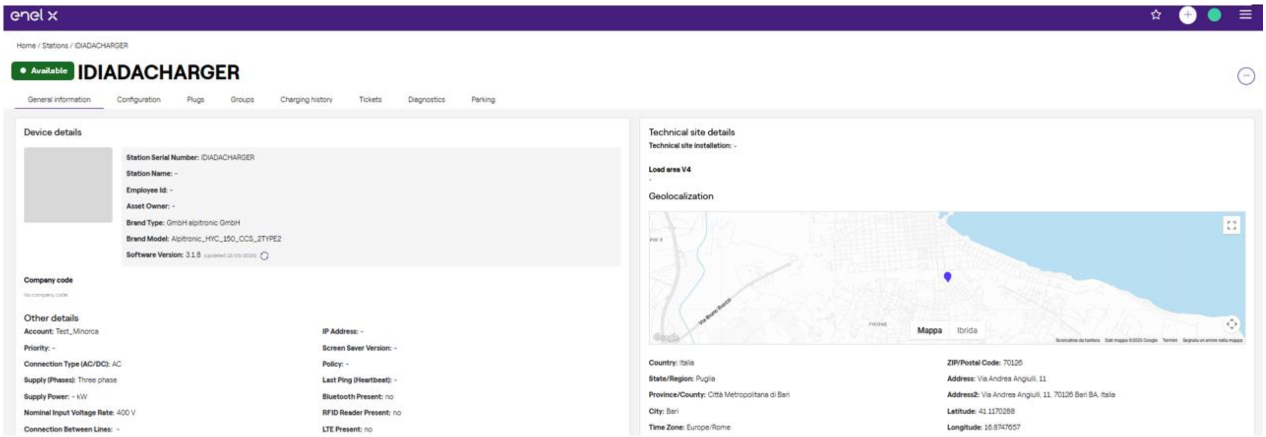


**Figure 8. Integration of EVSE Emulator (MCTS) with Enel X eVOS backend**

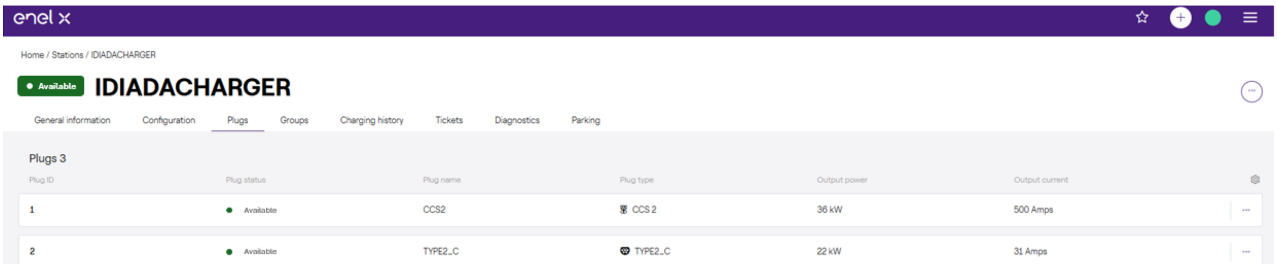


**Figure 9. Integration of EVSE Emulator (MCTS) with Enel X eVOS backend, details of plug ID configuration**


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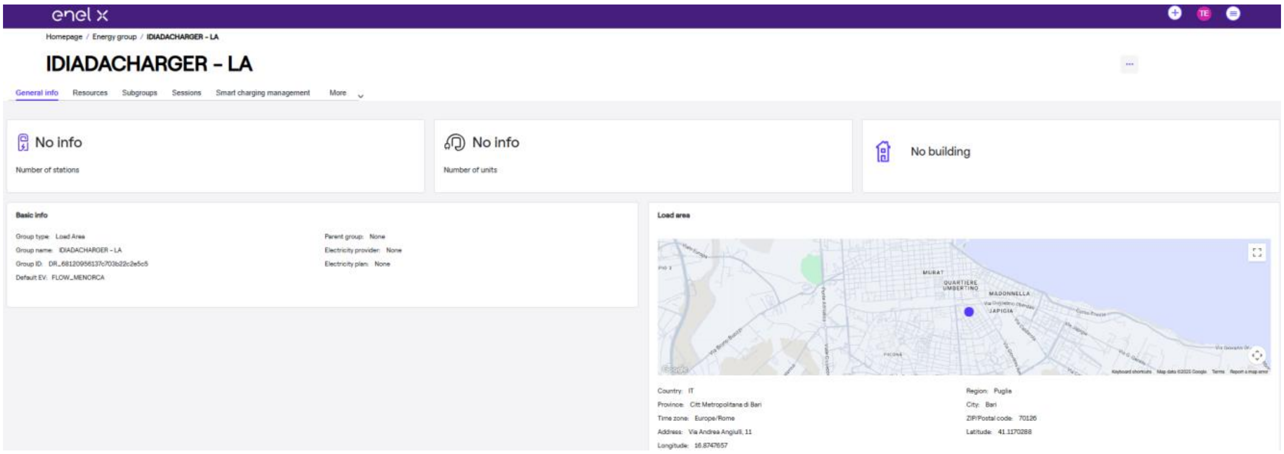


**Figure 10. Integration of EVSE Emulator (MCTS) with Enel X Energy System platform**

The first phase of activities consisted in the integration of the MCTS (Modular Charging Test System) simulator within the Enel X Way backend infrastructure, enabling it to be treated as a functional EVSE unit for the lab test, on the Energy Services platform (CPO platform for DR programs). A dedicated Load Area was instantiated to represent the MCTS, with a unique identification and OCPP connectivity.

Within this Load Area, an Aggregated Area named “MENORCATESTLAB” was configured. This area included the EVSE Emulator (MCTS) as a FSP (Flexible Service Provider) and provided the aggregated group (with only one emulated EVSE) necessary for testing DR aggregation logic. The configuration allowed the emulation of the interactions between Aggregator, CPO, and EVSE unit, enabling the flow of DR commands from BSP systems to the actual point of delivery.

Due to the custom nature of the MCTS system, the integration with the Enel X cloud backend required significant development efforts. The MCTS was adapted to communicate over the OCPP 1.6J protocol. This involved not only basic protocol implementation but also:

- Ensuring compliance with backend message format;
- Enabling support for key procedures of the OCPP 1.6J communication flow;
- Addressing timing and session synchronization issues that are especially critical when working with emulated environments.

This phase also involved close cooperation between the emulator development team and the Enel X Way integration team, with multiple iterations of debugging and firmware level adaptation to ensure full alignment with backend expectations.

Following successful integration, a structured multi-phase test campaign was executed to validate the platform behaviour and DR operability. The tests were designed to incrementally build confidence in the system and validate the capability to deliver DR modulation on real EV charging sessions. The tests included:


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- Test A - OCPP Communication Validation: The first set of tests validate the fundamental communication path between MCTS and the Energy Services platform (CPO Platform). This includes the Successful registration of the EVSE Emulator and the execution of remote commands such as "*RemoteStartTransaction*", Modulation commands and "*RemoteStopTransaction*", launched from the CPO platform and reflected on the MCTS.

- Test B - Charging Needs Configuration: A charging session is initiated in DC mode (25 kW using CCS2 plug) using a real electric vehicle (Opel Corsa-e). During the session, charging needs are defined within the Energy Services interface, including target energy, maximum time window for charging session, and DR enablement status. The platform, recognizing the long available charging window, issue a downward setpoint modulation (approx. 3 kW) to optimize grid interaction. MCTS must dispatch the command and adjusts the charging power, validating the modulation logic.

- Test C - Aggregator to CPO DR Program Transmission: DR events are created on the aggregator platform (Enel X) and routed through the system to the Energy Services backend. These events include time-based reduction profiles and flexibility constraints. The successful reception of these events by the CPO interface demonstrates the correct upstream-downstream interoperability in DR signalling.

- Test D - CPO to Emulated EVSE DR Execution: It includes the creation of DR programs directly within the Energy Services platform (bypassing the aggregator), to validate its capability to act independently and deliver modulation profiles directly to MCTS. This pathway allows a deep control over session behaviour and serves to isolate and test the DR logic internal to the CPO.

- Test E - End-to-End DR Test with V1G Modulation: It simulates a complete V1G-based DR modulation sequence, involving the following steps:
  - A DC charging session is initiated at 30 kW via the EVOS app;
  - Charging needs are configured with DR enabled;
  - A DR program is activated with a 3 modulation steps:
    - Step 1: reduce to 10 kW for 15 minutes;
    - Step 2: reduce to 5 kW for 15 minutes;
    - Step 3: restore to 15 kW, then stop.

  The MCTS has to receive all setpoints and adapt the charging current in near real time. This test serves as a validation of the control chain from user app → aggregator → CPO → EVSE, simulating a real-world DR flexibility delivery flow in laboratory conditions.


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### 4.2.2.4. Pictures of the experimental laboratory setup

Hereafter several photos of the experimental laboratory setup used for the validation of the related use case.

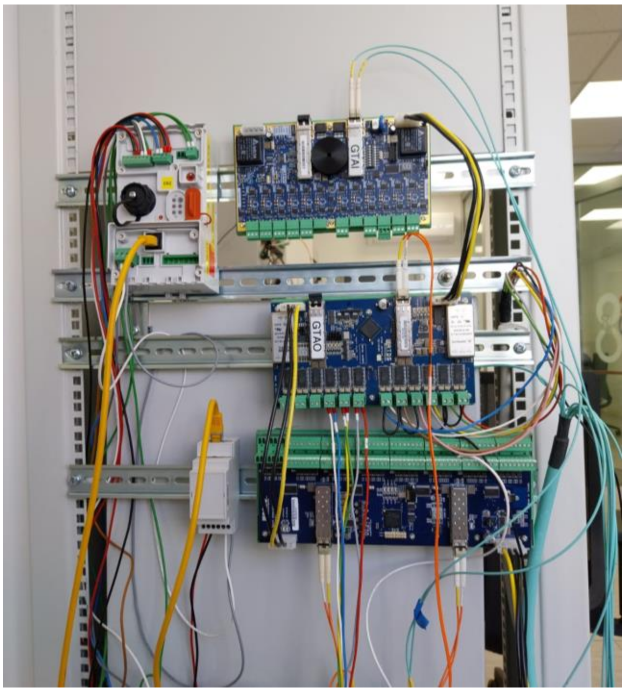


Figure 11. Electronic Card Interface of Analog Input and Output Signals of RTDS Simulator


Figure 12. Grid Emulator Rack of MCTS System



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**Figure 13. MCTS System and Battery Simulator Rack**

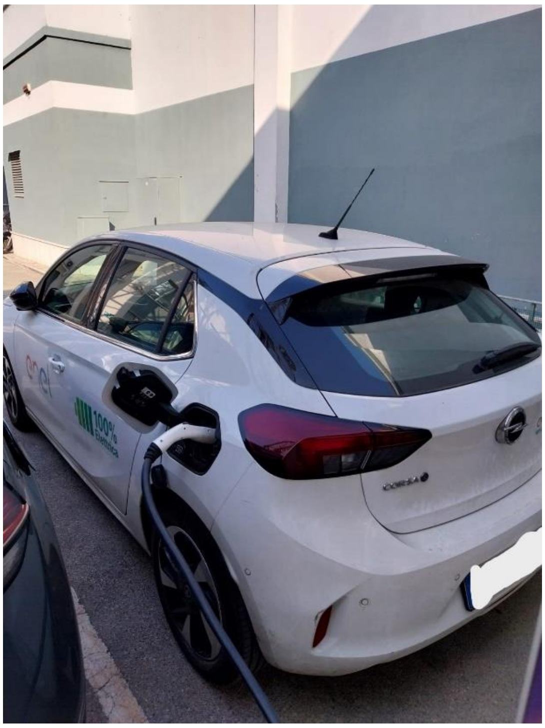

**Figure 14. EV Car (Opel Corsa Model) Charging Session**

**Figure 15. Entire MCTS System**



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### 4.2.3. Platform Used for Demand Response Flexibility Programs

The following diagram (Figure 16) describes the BSP and CPO platforms involved in the Lab tests.

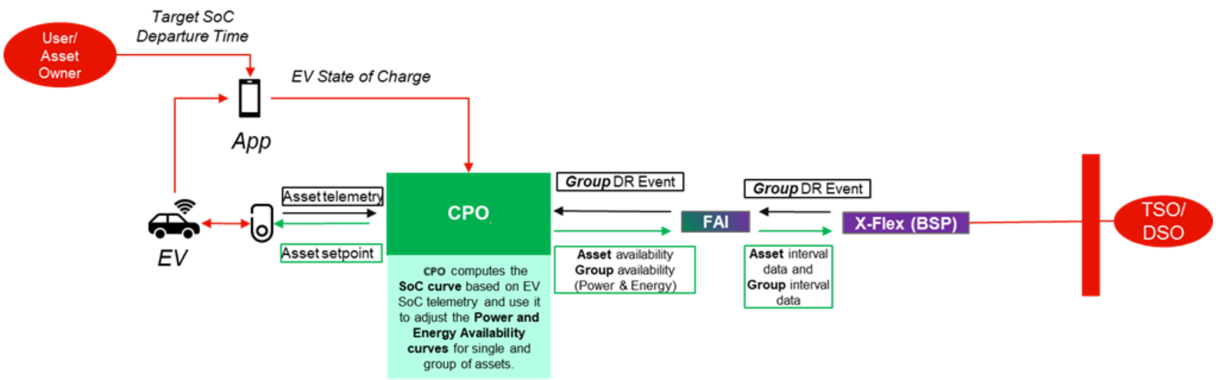


Figure 16. BSP and CPO platforms architecture


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### 4.2.4. Expected outcomes

The Menorca laboratory demonstration is intended to serve as a controlled environment to validate the operational integration of demand response (DR) services during a real EV charging session. The primary expected outcomes of this use case focus on the technical feasibility, interoperability, and replicability of flexibility programs activated through coordinated actions between the aggregator, CPO, and EVSE.

The main outcomes expected from this demo laboratory setup include:

- Validation of OCPP 1.6J protocol integration: The demonstration aims to confirm that a custom EVSE can be effectively integrated into backend system (Enel X Way, eVOS System and Energy Services System) using the OCPP 1.6J protocol.
- Demonstration of DR program activation workflows: The test scenarios are designed to showcase the ability to activate DR programs through the entire control chain:
  - From the aggregator platform (Enel X):
  - To the CPO backend (Energy Services);
  - Down to the EVSE emulator (MCTS) and the EV.

  A successful outcome includes the reception and the execution of DR events by the EVSE, aligned with the defined flexibility needs.
- Evaluation of charging needs management and user session control: By activating a real EV charging session, the system is expected to validate that user-defined charging needs can be used to calculate flexibility margins, which in turn enable DR modulation without compromising final user expectations.

In this use case, all DR signal activations are expected to occur in real time, adjusting the ongoing charging session. A detailed analysis of command activation latency is not performed; however, the DR activation flow is considered successful if the command is executed within a few seconds (less than 10) during the test session.

By documenting the procedures, challenges, and results of integrating a custom EVSE with commercial aggregator/CPO platforms, this test activity contributes to a broader understanding of the interoperability requirements for smart charging and DR services. In summary, the expected outcomes center around confirming that laboratory-based testing of DR services can meaningfully support the deployment of flexible EVSE control, with potential scalability and replicability. While technical constraints remain due to lab test environment, the test activities pre-validate the field-level implementation for the on field demo of Menorca Island (Task 7.3 of WP7).


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## 4.3. Rome Demo Laboratory Use Case

### 4.3.1. General Overview

The demonstration activities conducted within Task 6.2of Rome Demo Lab Use Case of the FLOW project focuses on the validation of direct, local flexibility control strategies for Electric Vehicle Supply Equipment (EVSE), with a specific emphasis on the operational interaction between a Distribution System Operator (DSO) and charging infrastructures located at the grid edge. In particular to support direct activation of demand response (DR) services initiated by the DSO through a local control architecture.

In contrast to more centralized cloud-based approaches, where flexibility commands are typically routed through backend aggregators and energy management systems, this use case adopts a distributed intelligence paradigm wherein the DSO is able to directly actuate charging behaviour at local sites via real-time control paths.

The central innovation of this use cases lies in its full local control loop, involving:

- A DSO System Platform (owned by Areti) that issues flexibility dispatch commands based on real-time and or forecasted grid needs.
- A Power Grid User Interface (PGUI) (owned by Areti) device, installed in the field, which receives commands from the DSO via MQTT over 4G communication and dispatch, through Modbus TCP/IP protocol, the demand response flexibility needs to the EV that acts as local flexible service provider.
- An MCTS (Modular Charging Test System) acting as a high-fidelity EVSE emulator capable of DC and AC operation, which executes the received commands via Modbus TCP/IP from PGUI device. The MCTS system emulates both AC and DC charging sessions and can operate in various configurations (up to 30 kW in AC and 36 kW in DC). This modular flexibility enables the testing of multiple DR strategies, including full charging session interruption, gradual power modulation (V1G), and parameter reconfiguration via register manipulation.

This architecture allows the DSO to bypass centralized aggregators and interact directly with EVSE devices deployed at critical nodes in the distribution network. It also provides a testbed to explore how EV charging stations, when equipped with appropriate interfaces, can participate in near-real-time flexibility services, including controlled load shedding, charging session interruption, and dynamic modulation of active power (V1G).

All tests were performed using MCTS. For this use case, the system was configured in V1G mode (unidirectional), both in DC (up to 36 kW) and AC (up to 11 kW, due to constraints imposed by the EV used during tests) charging configurations.

These tests are an essential demonstration of how EVSEs, especially those deployed in urban low-voltage networks, can become active, controllable elements of the electrical grid, offering flexibility and contributing to the grid's operational stability.


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The overall goal is to validate the interoperability and functional response of the EVSE in alignment with the constraints and priorities defined by the DSO. All tests are executed within the GSP e-Mobility Lab and rely on DR activation commands from DSO devices.



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### 4.3.2. Description and Architecture

The architecture of the Lab Use case for Rome demonstration integrates three principal environments: the GSP E-Mobility Lab Environment, the DSO Cloud Environment, and the Interface Device Layer, (PGUI), each playing a specific role in enabling the near real-time delivery and execution of flexibility commands.

In the following Figure 17 there is the block diagram of the lab use case architecture.

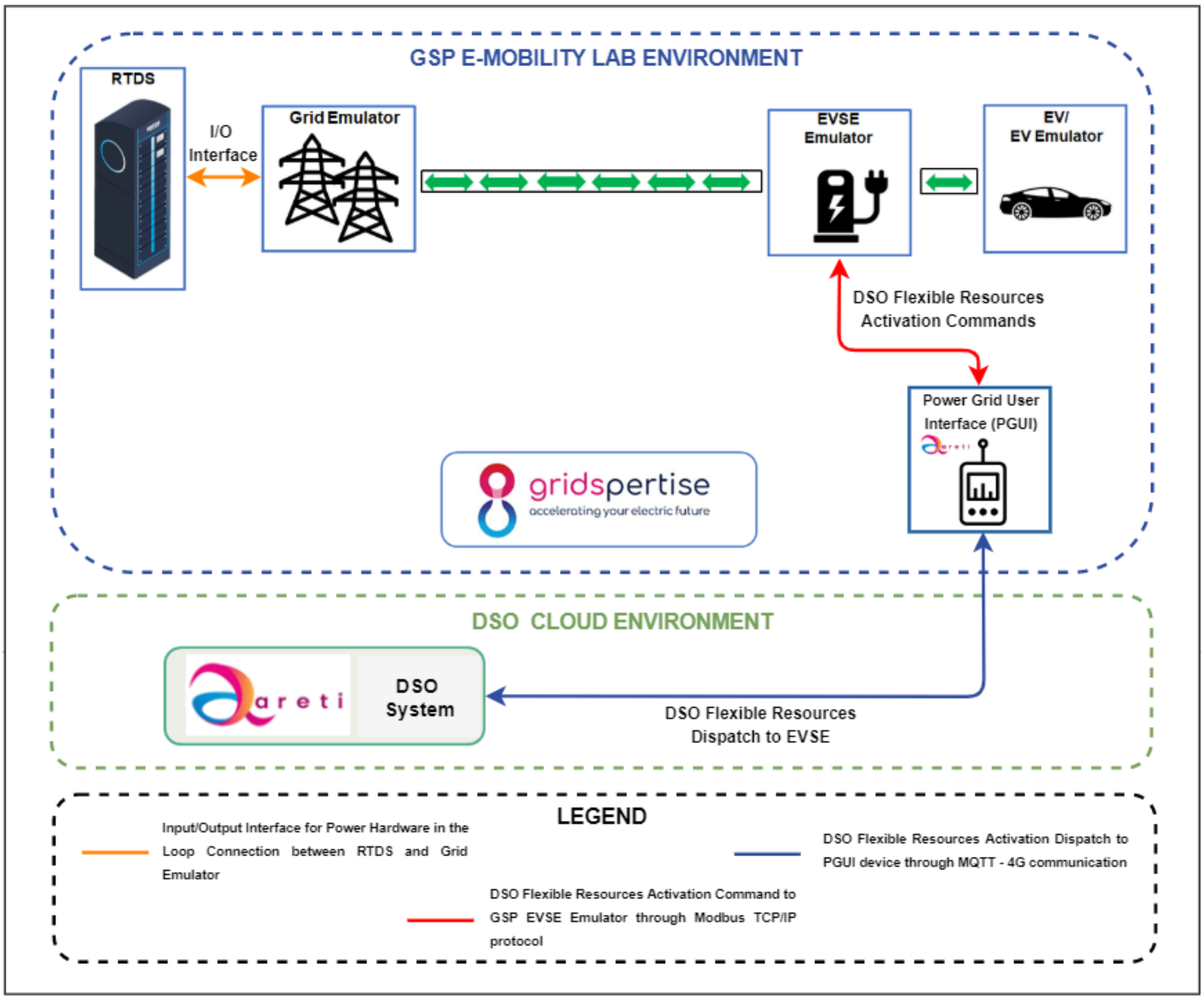


Figure 17. Block Diagram of Lab Architecture of Rome Demo Use Case

#### 4.3.2.1. GSP E-Mobility Lab Environment

This environment hosts the MCTS system, which acts as an EVSE emulator, supporting both DC and AC charging sessions. The MCTS is connected directly via Ethernet to the PGUI (Power Grid User Interface) device. The PGUI is configured to interpret and dispatch flexibility commands received from the Areti


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DSO system via 4G-MQTT communication. It acts as a field gateway, translating digital grid requests into Modbus TCP/IP messages.

A real-time simulated grid, operated through RTDS, is optionally connected to the EVSE emulator via a PHIL (Power Hardware-in-the-Loop) interface, but in this use case the control path remains local, handled independently from the simulation. This enables focused validation of protocol execution and response behaviour under different Modbus sequences.

The EV used for this test in an Opel Corsa, capable of charging with these different modes:

| Type of Charging | Plug | Max Charging Power |
|---|---|---|
| One Phase AC | AC Type 2 | 7,4 kW |
| Three Phase AC | AC Type 2 | 11 kW |
| DC | CCS Combo 2 | 100 kW |

**Table 4. EV charging modes**

For the test only the three phase AC at 11 kW and the DC up to 36 kW of charging power were used.

### 4.3.2.2. Scenarios and Testing Procedures

The use case comprises four well-defined test scenarios, each addressing a different operational modality. Each testing scenario is detailed in the following tables.

| **Scenario 1: DC CCS2 Charging Stop Command** | | | | | | |
|---|---|---|---|---|---|---|
| **Description** | Once the DC charging procedure has started at P=36 kW on MCTS, the PGUI executes a stop charging command. This scenario simulates the case of direct control of the charging station by the DSO and proceeds with a remote stop charging to limit congestion on the network node to which the charging station is connected. | | | | | |
| **Objective** | Test the ability to remotely terminate an ongoing DC charging session (36 kW) via a Modbus Stop command from PGUI device. | | | | | |
| **Modbus Command Procedure** | | | | | | |
| **Test Procedure** | **Modbus Function** | **Address** | **Description** | **Parameter** | **Value** | **Unit** |
| **Test Setting** | Coil | 4 | Simulator Mode | EVSE | 1 | NA |
| | Coil | 5 | ConfigPower | Power On | 1 | NA |
| | Coil | 6 | Reset Default Parameters | Reset | 0 | NA |
| | Coil | 7 | Test Case Mode | OFF | 0 | NA |
| **Test Procedure** | Coil | 2 | Stop Test | Stop | 1 | NA |



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| | |
|---|---|
| **Expected result** | Charging stops immediately; the MCTS confirms session termination without faults. Validate DSO's capability to halt EV DC charging session in response to possible grid needs. |

**Table 5. Scenario 1 Test Description**

| **Scenario 2: AC Type 2 Charging Stop Command** | | | | | | |
|---|---|---|---|---|---|---|
| **Description** | Once the DC charging procedure has started at P=11 kW on MCTS, the PGUI executes a stop charging command. This scenario simulates the case of direct control of the charging station by the DSO and proceeds with a remote stop charging to limit congestion on the network node to which the charging station is connected. | | | | | |
| **Objective** | Test the ability to remotely terminate an ongoing AC charging session (11 kW) via a Modbus Stop command from PGUI device. | | | | | |
| **Modbus Command Procedure** | | | | | | |
| **Test Procedure** | **Modbus Function** | **Address** | **Description** | **Parameter** | **Value** | **Unit** |
| **Test Setting** | Coil | 4 | Simulator Mode | EVSE | 1 | NA |
| | Coil | 5 | ConfigPower | Power On | 1 | NA |
| | Coil | 6 | Reset Default Parameters | Reset | 0 | NA |
| | Coil | 7 | Test Case Mode | OFF | 0 | NA |
| **Test Procedure** | Coil | 2 | Stop Test | Stop | 1 | NA |
| **Expected result** | Charging stops immediately; the MCTS confirms session termination without faults. Validate DSO's capability to halt EV AC charging session in response to possible grid needs. | | | | | |

**Table 6. Scenario 2 Test Description**

| **Scenario 3: V1G Power Modulation of DC CCS2 Chargin Mode** | |
|---|---|
| **Description** | Once the DC charging procedure is started at P=36 kW on MCTS, the PGUI performs a V1G modulation of the charging by executing Demand Response commands from the DSO platform. This scenario simulates the case of direct control of the charging station by the DSO by implementing Demand Response flexibility sessions to limit congestion on the network node to which the charging station is connected. The test proceeds as follows:<br><br>1. Charging session starts at P=36 kW;<br>2. After 30 seconds (time in test environment) a modulation command is sent at P=20 kW;<br>3. After a further 30 seconds a modulation command is sent at P=10 kW;<br>4. After a further 30 seconds a modulation command is sent at P=5 kW;<br>5. After a further 30 seconds a remote stop charging command is sent. |



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| | | | | | | |
|---|---|---|---|---|---|---|
| | The modulation times of the charging session are purely demonstrative, occurring in a laboratory context. | | | | | |
| **Objective** | Implement a dynamic load shedding strategy by gradually reducing power via register commands. Perform and actuate a V1G Modulation of a DC charging session from DSO device. | | | | | |
| **Modbus Command Procedure** | | | | | | |
| **Test Procedure** | **Modbus Function** | **Address** | **Description** | **Parameter** | **Value** | **Unit** |
| **Test Setting 1** | Coil | 4 | Simulator Mode | EVSE | 1 | NA |
| | Coil | 5 | ConfigPower | Power On | 1 | NA |
| | Coil | 6 | Reset Default Parameters | Reset | 0 | NA |
| | Coil | 7 | Test Case Mode | OFF | 0 | NA |
| **Test Setting 2** | Holding Registers | 40001 | Set Charge type | Charge Type | 0 | NA |
| | Holding Registers | 40002 | Set Charge Type Interface | Charge Type Interface | 1 | NA |
| | Holding Registers | 40003 | Set Charge Protocol | Charge Protocol | 0 | NA |
| | Holding Registers | 40008 | Set Value | Max Voltage | 500 | V |
| | Holding Registers | 40010 | Set Value | Max Charge Power | 36 | kW |
| | Holding Registers | 40011 | Set Value | Max Charge Current | 72 | A |
| | Holding Registers | 40015 | Set Value | Min Charge Current | 0 | A |
| | Holding Registers | 40018 | Set Value | Min Charge Power | 0 | kW |
| | Holding Registers | 40019 | Set Value | Min Voltage | 0 | V |
| **Test Setting 3** | Coil | 8 | Set Protocol | ON | 1 | NA |
| | Coil | 9 | Set Protocol | ON | 1 | NA |
| **Test Modulation 1** | Holding Registers | 40010 | Set Value | Max Charge Power | 20 | kW |
| | Holding Registers | 40011 | Set Value | Max Charge Current | 40 | A |
| | Coil | 10 | Set Modulation | Set Modulation | 1 | NA |
| **Test Modulation 2** | Holding Registers | 40010 | Set Value | Max Charge Power | 10 | kW |
| | Holding Registers | 40011 | Set Value | Max Charge Current | 20 | A |
| | Coil | 10 | Set Modulation | Set Modulation | 1 | NA |
| | Holding Registers | 40010 | Set Value | Max Charge Power | 5 | kW |


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| | | | | | | |
|---|---|---|---|---|---|---|
| **Test Modulation 3** | Holding Registers | 40011 | Set Value | Max Charge Current | 10 | A |
| | Coil | 10 | Set Modulation | Set Modulation | 1 | NA |
| **Stop Test** | Coil | 2 | Stop Test | Stop | 1 | NA |
| **Expected Result** | Demonstrate multi-step DR response in DC. The EVSE follows all steps smoothly. The current follows the expected power setting, validating proper Modbus control logic. | | | | | |

**Table 7. Scenario 3 Test Description**

| **Scenario 4: V1G Power Modulation of AC Type 2 Chargin Mode** | | | | | | |
|---|---|---|---|---|---|---|
| **Description** | Once the DC charging procedure is started at P=11 kW on MCTS, the PGUI performs a V1G modulation of the charging by executing Demand Response commands from the DSO platform. This scenario simulates the case of direct control of the charging station by the DSO by implementing Demand Response flexibility sessions to limit congestion on the network node to which the charging station is connected. The test proceeds as follows:<br><br>1. Charging session starts at P=11 kW;<br>2. After 30 seconds (time in test environment) a modulation command is sent at P=7 kW;<br>3. After a further 30 seconds a modulation command is sent at P=4 kW;<br>4. After a further 30 seconds a remote stop charging command is sent.<br><br>The modulation times of the charging session are purely demonstrative, occurring in a laboratory context. | | | | | |
| **Objective** | Implement a dynamic load shedding strategy by gradually reducing power via register commands. Perform and actuate a V1G Modulation of a AC charging session from DSO device. | | | | | |
| **Modbus Command Procedure** | | | | | | |
| **Test Procedure** | **Modbus Function** | **Address** | **Description** | **Parameter** | **Value** | **Unit** |
| **Test Setting 1** | Coil | 4 | Simulator Mode | EVSE | 1 | NA |
| | Coil | 5 | ConfigPower | Power On | 1 | NA |
| | Coil | 6 | Reset Default Parameters | Reset | 0 | NA |
| | Coil | 7 | Test Case Mode | OFF | 0 | NA |
| **Test Setting 2** | Holding Registers | 40001 | Set Charge type | Charge Type | 1 | NA |
| | Holding Registers | 40002 | Set Charge Type Interface | Charge Type Interface | 1 | NA |
| | Holding Registers | 40003 | Set Charge Protocol | Charge Protocol | 0 | NA |
| | Holding Registers | 40008 | Set Value | Max Voltage | 230 | V |


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| | | | | | | |
|---|---|---|---|---|---|---|
| | Holding Registers | 40010 | Set Value | Max Charge Power | 11 | kW |
| | Holding Registers | 40011 | Set Value | Max Charge Current | 16 | A |
| | Holding Registers | 40015 | Set Value | Min Charge Current | 0 | A |
| | Holding Registers | 40018 | Set Value | Min Charge Power | 0 | kW |
| | Holding Registers | 40019 | Set Value | Min Voltage | 0 | V |
| **Test Setting 3** | Coil | 8 | Set Protocol | ON | 1 | NA |
| | Coil | 9 | Set Protocol | ON | 1 | NA |
| **Test Modulation 1** | Holding Registers | 40010 | Set Value | Max Charge Power | 7 | kW |
| | Holding Registers | 40011 | Set Value | Max Charge Current | 10 | A |
| | Coil | 10 | Set Modulation | Set Modulation | 1 | NA |
| **Test Modulation 2** | Holding Registers | 40010 | Set Value | Max Charge Power | 4 | kW |
| | Holding Registers | 40011 | Set Value | Max Charge Current | 5 | A |
| | Coil | 10 | Set Modulation | Set Modulation | 1 | NA |
| **Stop Test** | Coil | 2 | Stop Test | Stop | 1 | NA |
| **Expected Result** | Demonstrate multi-step DR response in AC. The EVSE follows all steps smoothly. The current follows the expected power setting, validating proper Modbus control logic. | | | | | |

**Table 8. Scenario 4 Test Description**

All the aforementioned scenarios, which demonstrate the controllability of the emulated EVSE through the PGUI device, were monitored in real time using Modbus Input Registers (see Table 9). This setup enables the reproduction of a complete Demand Response (DR) activation scenario on flexible assets such as the EVSE, as all relevant charging parameters are continuously monitored and the signals are made available to the DSO system platform.

| EVSE Observability | | | |
|---|---|---|---|
| **Modbus Function** | **Address** | **Description** | **Unit** |
| Input Register | 30005 | EV Charging Voltage | V |
| Input Register | 30007 | EV Charging Current | A |
| Input Register | 30008 | EV Charging Power | kW |
| Input Register | 30009 | EV Current SoC | % |
| Input Register | 30011 | EV charging time | s |

**Table 9. MCTS Monitoring Parameters**



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### 4.3.2.3. Pictures of the experimental laboratory setup

Hereafter several photos of the experimental laboratory setup used for the validation of the related use case.

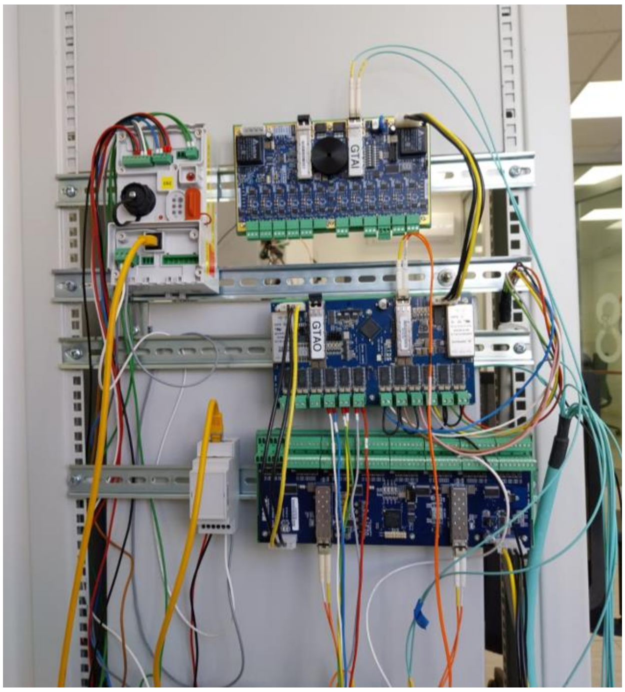


Figure 18. Electronic Card Interface of Analog Input and Output Signals of RTDS Simulator


Figure 19. Grid Emulator Rack of MCTS System



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Figure 20. MCTS System and Battery Simulator Rack

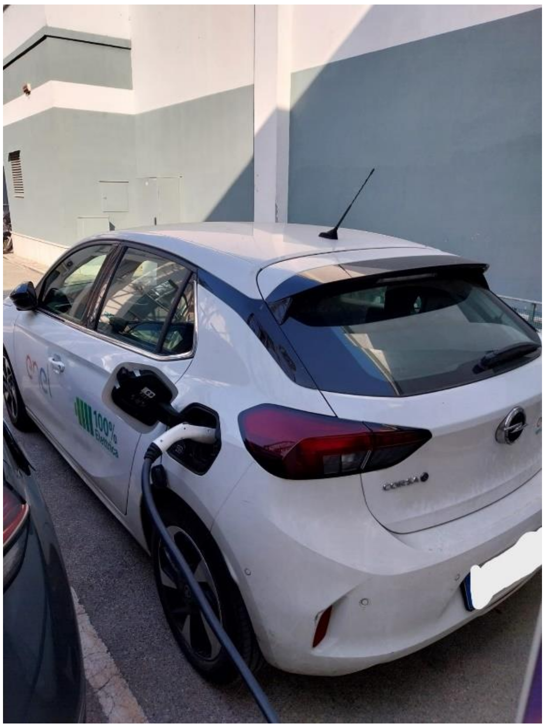

Figure 21. EV Car (Opel Corsa Model) Charging Session

Figure 22. Entire MCTS System



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## 4.3.3. Platform Used for Demand Response Flexibility Programs

### 4.3.3.1. PGUI

The Power Grid User Interface (PGUI) is an edge device installed in the test facility, to enable the gathering of measurement data from the EVSE. Moreover, it’s the gateway to interact with the DSO, indeed it can receive the activation signal and forward it to the charging point. Subsequent sections outline the architecture of the PGUI.

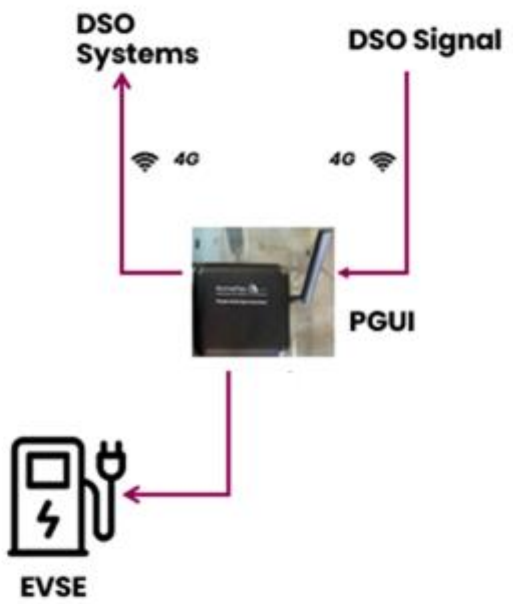


Figure 6: PGUI interactions

The PGUI acquires the data from the asset (including power, energy, voltage, currents, etc.), providing this information to the DSO systems. Additionally, it receives signals from the DSO and forwards them to the EVSE.

The main functionalities are:

- Acquisition of command sent by the DSO;
- Blockchain Certification of data;
- Data exchange with EVSE.


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The following figure depicts the device architecture:

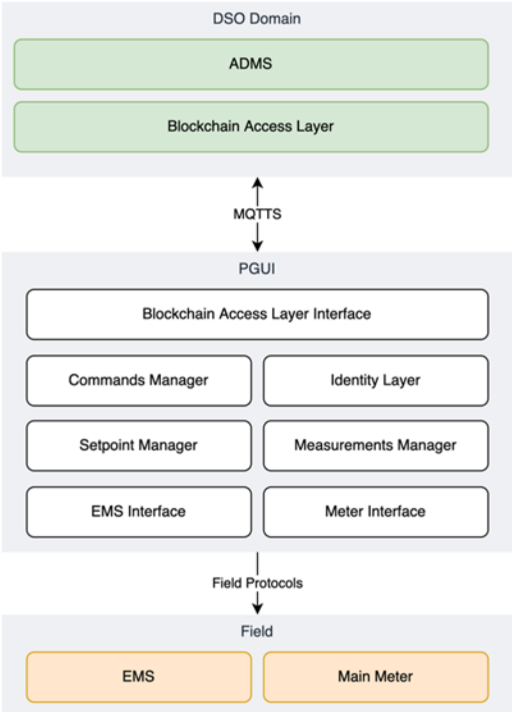


**Figure 6: PGUI architecture**

The PGUI operates with dedicated firmware, which integrates multiple functional blocks, each responsible for specific aspects of role in facilitating secure and reliable communication between field devices, the Blockchain Access Layer (BAL), and the DSO. The components of the firmware are:

1. Blockchain Access Layer Interface: this module manages a two-way communication channel with the BAL using the MQTTS protocol. It serves as the bridge enabling PGUI to interact securely with the DSO. Its key functionalities include message caching to ensure critical data is not lost during network disconnections, and secure message handling for the exchange of uplink and downlink messages with the BAL.

2. Identity Layer: the Identity Layer is responsible for managing cryptographic operations and ensuring the secure identification of the PGUI within the system. Its core features include key rotation to maintain security standards, message signing to guarantee data authenticity and integrity, and credential management for secure storage and updates of authentication credentials.

3. Commands Manager: this module processes incoming commands received from the BAL, which are encapsulated as downlink messages. Its responsibilities include command parsing


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to decode and validate commands, and command execution to forward them to relevant modules based on their type and purpose.

4. Setpoints Manager: the Setpoints Manager is designed to handle setpoints issued by the DSO (via specific commands). It processes setpoint-related commands received through the BAL, and exposes the setpoints to on-field devices, such as Energy Management Systems (EMS), through Modbus TCP/RTU protocols.

5. Measurements Manager: this block processes measurements collected from the meter and prepares them for transmission through the BAL. It gathers measurements from the Modbus TCP, signs the received measurements using the Identity Layer, and forwards them to the BAL Interface for further processing.

6. Meter Interface: the Meter Interface handles communication with physical meters using specific protocols, such as Modbus TCP/RTU, enabling real-time bidirectional communication with the metering devices.

7. EVSE Interface: the EVSE Interface sends the activation command to the charging point. The communication protocol used depends on the EMS installed at customer's side:
   - Industrial application: In this environment, the communication protocol is Modbus RTU or Modbus TCP;
   - Energy Community application: In this environment, the communication protocol is REST API or MQTT;
   - Electric Vehicle Charger application: The communication protocol is REST API or Modbus RTU or Modbus TCP.

The EMS Interface sends the Activation Dataset to the Blockchain Access Layer signed by the Identity Layer.
The PGUI communicates with the Meter in different ways explained below, that can be activated in the configuration phase of the device.

The EVSEs involved in the demo will be equipped with a PGUI to perform the flexibility service defined in the project.


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#### 4.3.3.2. DSO System

Recognizing a local flexibility request is crucial for grid management, particularly where the integration of renewable energy sources and distributed energy resources (DERs) is high. The DSO identifies a potential constraint or need within a specific part of their network. This could be due to grid congestion, where the demand for power in a particular area exceeds the capacity of the local infrastructure, perhaps during peak hours or due to unexpected outages. Another common trigger is a voltage deviation, where the voltage levels fall outside acceptable operational limits, either too high or too low. This often happens with significant renewable generation or heavy loads connecting to a local feeder. The DSO's advanced monitoring systems, including SCADA (Supervisory Control and Data Acquisition) and AMI (Advanced Metering Infrastructure), play a vital role here, collecting real-time data on power flows, voltage, and consumption at various points in the network.

Predictive analytics are used to anticipate future flexibility needs, considering weather patterns, historical demand, and planned maintenance. Once a potential issue is detected, algorithms assess the severity, and the specific location impacted. This leads to the formalization of a flexibility request, specifying the amount of power (e.g., in kW or MW) and the duration (e.g., 30 minutes, 2 hours) needed, as well as the desired action, such as increasing local generation, reducing demand, or shifting load. This request is then communicated to market participants or flexibility providers who can offer solutions.

All these phases are simulated in the testbed and the activation setpoint (amount of power, duration and direction), is sent to the PGUI that forwards it to the EVSE.


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### 4.3.4. Expected Outcomes

The execution of the Rome Demo Lab use cases should produce concrete and measurable results that support the technical and functional validation of the DSO's ability to manage flexible assets such as EVSE. Specifically, the four test scenarios focused on remote stop and stepwise modulation of AC and DC charging are designed to confirm the responsiveness, interoperability, and observability of the EVSE Emulator (MCTS) when interfaced with the PGUI control device via Modbus TCP/IP protocol.

From a technical standpoint, the tests are expected to demonstrate that remote commands (e.g., stop, power setpoint changes) issued by the DSO can be effectively executed by the EVSE with low latency and high reliability.

Moreover, the ability of the PGUI device to continuously monitor charging parameters via Input Registers is crucial. The expected outcome is that the DSO can maintain full real-time visibility of each charging session, including actual power levels, voltage, current, session status, and other diagnostic information (like time of charging and SoC). This end-to-end monitoring capability is key for enabling secure Demand Response (DR) services, where the DSO must both issue control actions and verify their proper execution and effect.

All DR signal activations are expected to occur in real time, adjusting the ongoing charging session. A detailed analysis of command activation latency is not performed; however, the DR activation flow is considered successful if the command is executed within a few seconds (less than 10) during the test session.

The successful execution of modulation commands will demonstrate the feasibility of using such assets for grid flexibility programs, such as congestion management, overload prevention, or load balancing. Furthermore, the EV charging recordings across three layers such as MCTS GUI, CAN data logs, and DSO platform measurements are expected to confirm full coherence and alignment of the executed tests.

These outcomes will ultimately validate the readiness of the control chain from DSO platform to EVSE, laying the foundation for future deployments of direct flexibility services within DSO ecosystems.


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# 5. Results

## 5.1. RTDS-Based Simulation of EV Flexibility Impact on the Grid Results

### 5.1.1. Use Case 1: Congestion Mitigation via V1G Load Reduction Results

This simulation aimed to assess the effectiveness of coordinated charging power reduction, emulating a Demand Response (DR) event, in mitigating the impact of an unexpected overload condition in a low-voltage (LV) distribution grid. The scenario was modelled on a secondary substation (MV/LV transformer) in the RTDS environment, with EVs modelled as flexible, controllable AC loads (22 kW each) connected at the LV grid. The networks parameters are typical of a MV and LV distribution grid in Italy.

Voltage Drop Event: Load Perturbation

As shown in Figure 23 the grid scenario begins with all EVs charging at nominal power and a stable load condition on the grid. A sudden increase of 500 kW in background load is applied to simulate local overload (e.g., activation of industrial equipment or peak demand). This causes a rapid increase in the RMS current at the LV bus (top graph) and a corresponding drop in the RMS voltage (middle graph), which falls below 0.90 p.u. within approximately 60 ms.

Simultaneously, the active power drawn at the LV level increases sharply by the same magnitude (500 kW), as shown in the bottom graph of Figure 23. This event accurately reflects a local congestion event that risks pushing the distribution transformer and network elements toward operational limits.

This phase establishes a critical test condition where intervention through flexible asset control is necessary to avoid under-voltage violations or thermal overloading.



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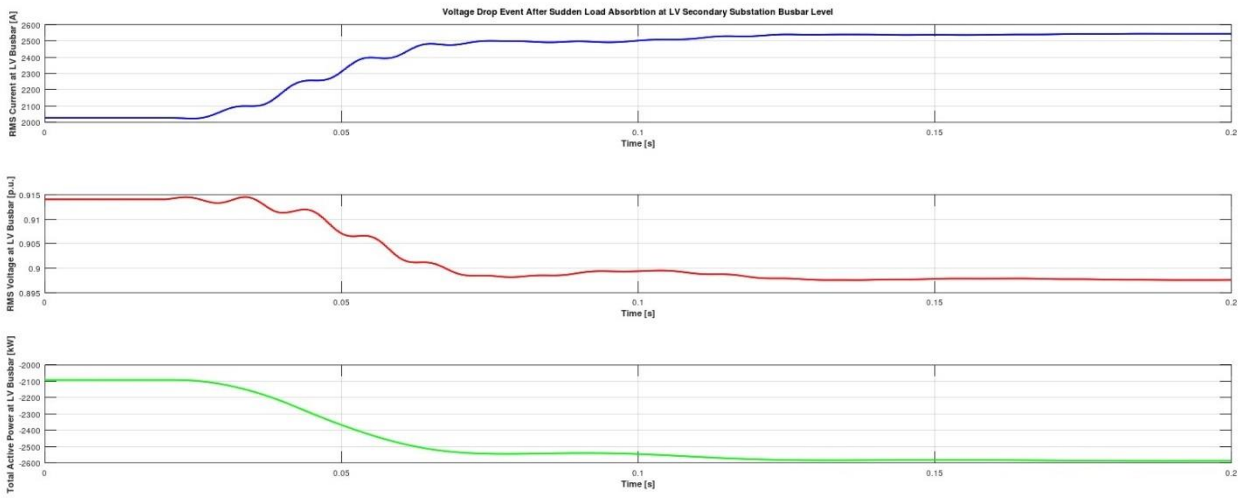


**Figure 23. RTDS Simulation Use Case 1: Voltage Drop Event After Sudden Load Absorption**

The response of the flexible EV fleet is illustrated in Figure 24, which compares the grid behaviour after a DR-triggered reduction in EV charging power for four different fleet sizes: 5, 10, 50, and 100 EVs.

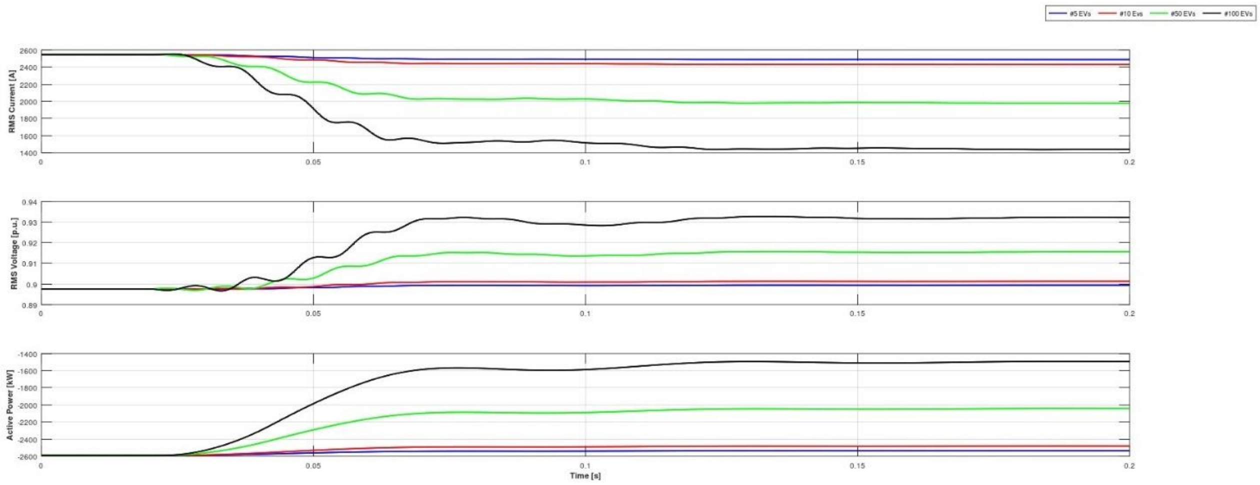


**Figure 24. RTDS Simulation Use Case 1: Demand Response Effect to Solve Load Congestion at LV Busbar Level**

Each curve represents the monitored quantities during the activation of the DR event. Such as:

- RMS current at the LV bus
- RMS voltage on the LV bus
- Total active power absorbed by the grid

After the perturbation, DR commands are sent to all EVs to reduce their power from 22 kW to a lower value (11 kW), simulating a grid-supporting charging modulation. The effect of this load shedding is evident and scales with the number of participating EVs.



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It can be observed that:

- The scenario with 100 EVs shows the most significant drop in LV bus current post-DR event, confirming a substantial release of loading on the transformer.
- The current with 50 EVs also decreases meaningfully, while 5 and 10 EVs offer only marginal relief.
- In the 100 EVs case (black line), voltage rapidly recovers from 0.89 p.u. to above 0.93 p.u., stabilizing well above the critical threshold.
- With 50 EVs (green), voltage also improves, reaching 0.92 p.u.
- 10 and 5 EVs (red and blue) show minimal recovery, insufficient to ensure safe voltage margins.
- The DR command clearly reduces the total active power absorbed at the LV node.
- The curve for 100 EVs shows a sharp drop in power consumption (2.6 MW to 1.6 MW), confirming 1 MW load flexibility.
- The 50 EVs case shows 500 kW response.
- For 5 – 10 EVs, the total flexibility is too limited to yield measurable grid benefit.

These simulations confirm that EV charging flexibility can be used effectively for congestion mitigation, but the impact is strongly dependent on fleet size and coordination. In detail:

- A small number of EVs (5–10) offer limited support and cannot significantly restore network parameters.
- With larger fleets (≥50 EVs), the DR event results in tangible improvements in voltage profile and transformer load reduction.
- The 100 EV case demonstrates the full potential of aggregated load flexibility as a controllable grid support mechanism.

The study is mainly focused on the effect, at LV level, of the steady state grid conditions after simulated DR V1G power modulation.

This use case validates the strategic role of EVs as active grid participants in future DSO-managed DR programs, particularly in urban or industrial areas with dense EV penetration.

The RTDS simulation provides a valuable pre-field testbed to calibrate and assess the sizing requirements and dynamic benefits of such interventions.

It is worth highlighting that the load congestion scenario was simulated under ideal and controlled network conditions using the RTDS platform. The modelled network does not incorporate the full complexity of real-world distribution systems, such as varying topology, unbalanced loads, stochastic behaviours of non-EV consumers and simultaneous charging of EVs and other charging parameters ( SoC, etc.). The load increase event and the DR response from EVs are tested in a deterministic context, without considering disturbances such as voltage flicker, grid faults, or communication delays that may impact the actual effectiveness of flexibility actions in real settings. Therefore, the results provide a technical validation of the mechanism's effectiveness in mitigating voltage drops through DR activation but do not cover operational risks or system-wide interactions that would need to be evaluated in field deployments or with more detailed co-simulation frameworks. These simulations should be seen as a functional benchmark to inform further developments in flexibility services testing.


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## 5.1.2. Use Case 2: Frequency Support using V2G Simulation Results

The analysis of the frequency regulation simulation begins with the observation of the system's reaction to an induced frequency drop. The artificial frequency deviation is introduced by setting the RTDS frequency to 49.7 Hz, which is slightly below the droop control activation threshold. As expected, this triggers a response from the V2G-enabled EVs, which begin injecting active power into the network according to their configured droop curve.

In the following Figure 25 the simulation plots results are shown.

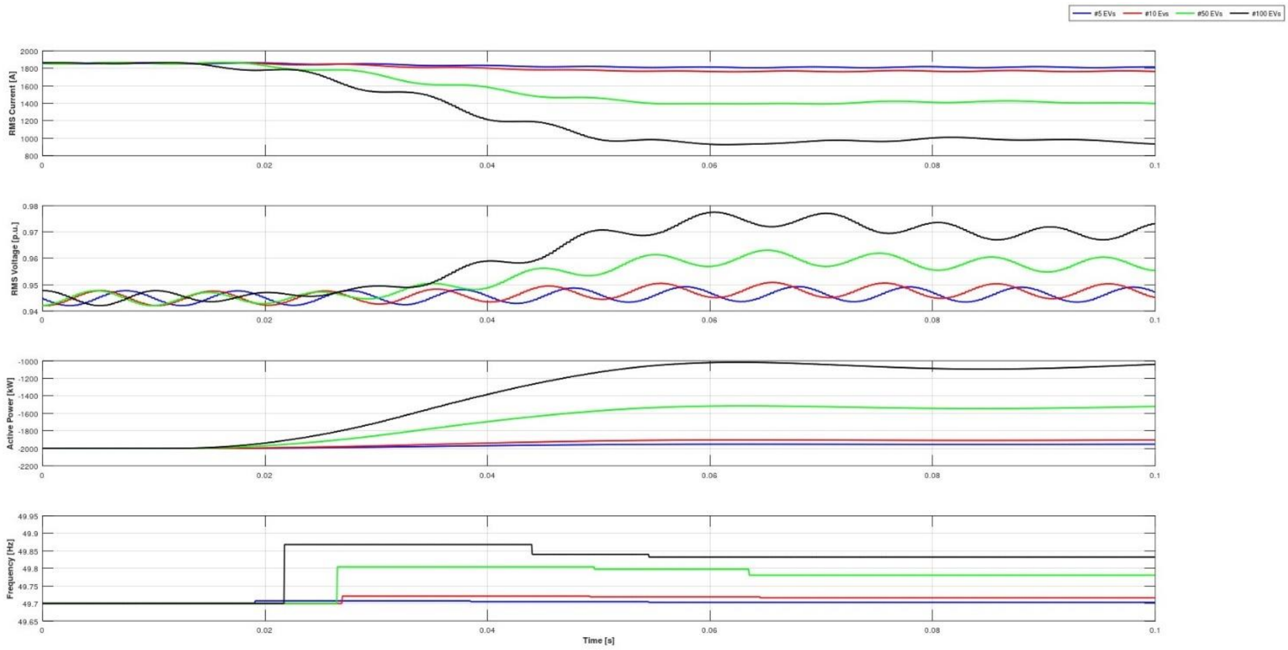

**Figure 25. RTDS Simulation Use Case 2: Effect of V2G simulated EVSE to Solve Frequency Grid Unbalance**

- In scenario A (5 EVs), the aggregated injection reaches a maximum of 50 kW. The effect on grid frequency is marginal: the frequency stabilizes around 49.73 Hz, with minimal impact on the LV busbar voltage. RMS current remains low and stable, and while some compensation is observed, the overall influence is limited. This confirms that very small fleets offer minimal benefit in primary frequency support.
- In Scenario B (10 EVs), the total power injection doubles to 100 kW. The frequency stabilizes around 49.75 Hz, showing a modest improvement compared to Scenario A. The current measured at the LV busbar rises slightly, and voltage RMS improves marginally, approaching nominal conditions. Still, the benefit is insufficient to fully counteract the disturbance.
- In Scenario C (50 EVs), a significant turning point is reached. The aggregated power injected by the fleet reaches 500 kW, which produces a clear restorative effect on grid frequency. The system responds by gradually returning to 49.82 Hz. RMS current increases in line with expectations, yet no overcurrent conditions are recorded. Voltage at the LV busbar shows


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enhanced stability and reduced fluctuations, suggesting that larger fleets can effectively contribute to grid balancing while maintaining network reliability.

- In Scenario D (100 EVs), the maximum simulated capacity is reached with 1 MW of power injected during the frequency event. The frequency recovers more substantially, reaching 49.88 Hz, close to nominal values. Voltage and current RMS values at the LV busbar remain within operational bounds. This scenario confirms that frequency regulation through decentralized EV support could be feasible to restore system stability during disturbances.

The study is mainly focused on the effect, at LV level, of the steady state grid conditions after simulated DR V2G power injection.

The main takeaway from the results is the direct correlation between the scale of EV participation and the effectiveness of frequency restoration. While a few EVs provide negligible impact, larger fleets (even in an aggregated number of more than the one showed in this use case) show strong, measurable results in both frequency stabilization and voltage support.

These findings reinforce the potential role of V2G technology in delivering grid services traditionally reserved for centralized generation assets, particularly in distribution grids with increasing penetration of electric vehicles.

It is important to note that this test scenario represents an idealized simulation of frequency support in a controlled environment. The RTDS-based setup emulates the dynamics of a simplified power system, assuming stable grid conditions. As such, the system's response reflects a best-case estimation of frequency stabilization potential from V2G-enabled EVs. While the outcomes clearly demonstrate the ability of aggregated electric vehicles to contribute to grid stability, real-world constraints—such as communication delays, grid condition variability, and unpredictable load behaviours are not considered. Therefore, the results should be interpreted as a proof-of-concept validation under nominal conditions, requiring further testing in more complex or field conditions to fully assess performance and robustness.



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## 5.2. Menorca Demo Laboratory Use Case Results

Hereafter all the testing scenarios results are presented.

### 5.2.1. Test A - OCPP Communication Validation

This test focused on verifying the ability of the emulated EVSE (MCTS) to correctly respond to a sequence of remote modulation commands sent through the Enel X Way eVOS platform using OCPP 1.6J protocol. Initially, a remote charging session was triggered at a power level of approximately 25 kW. Subsequently, three modulation commands were sent during the active session: a first reduction to 15 kW, followed by a deeper curtailment to 5 kW, and finally a return to 15 kW before the session was terminated.

The results from the power profile clearly show the effectiveness of each modulation command, with stable transitions in the setpoint and corresponding changes in the current profile. The voltage remains largely constant throughout the session.

In the following Figure 26 Figure 27 - Figure 28 the plots of the obtained results.

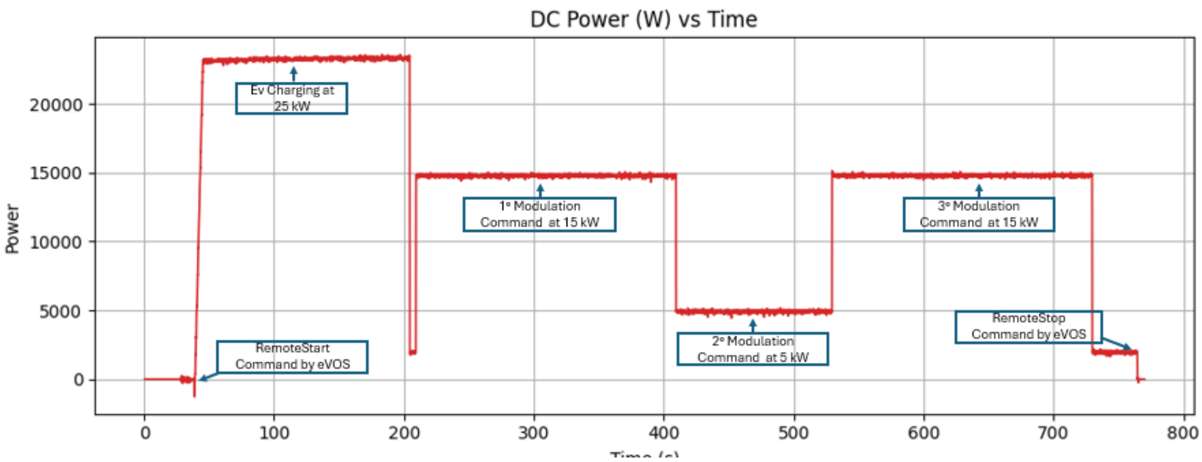


**Figure 26. Test A – Plot of charging power, log CAN of EVSE (MCTS) Emulator**


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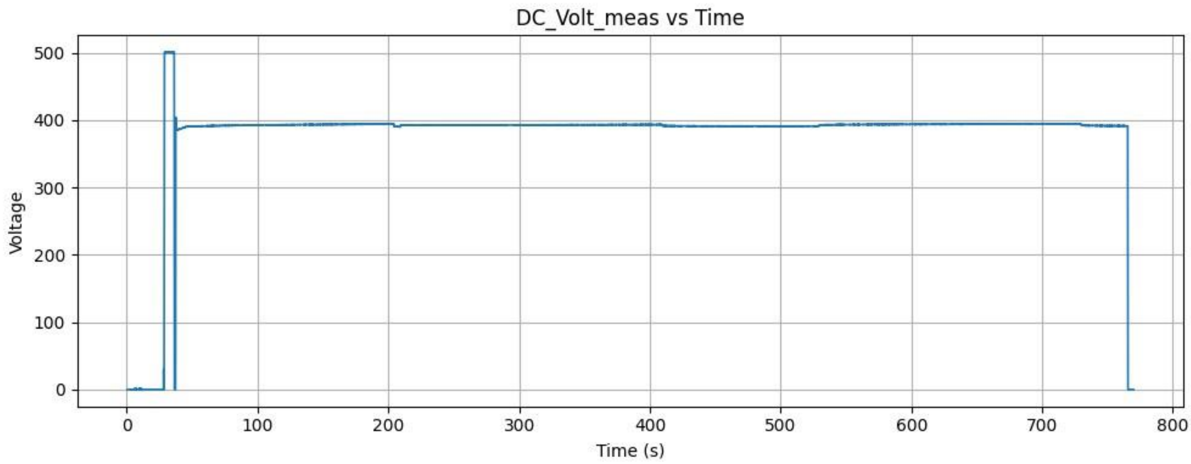


**Figure 27. Test A – Plot of charging voltage, log CAN of EVSE (MCTS) Emulator**

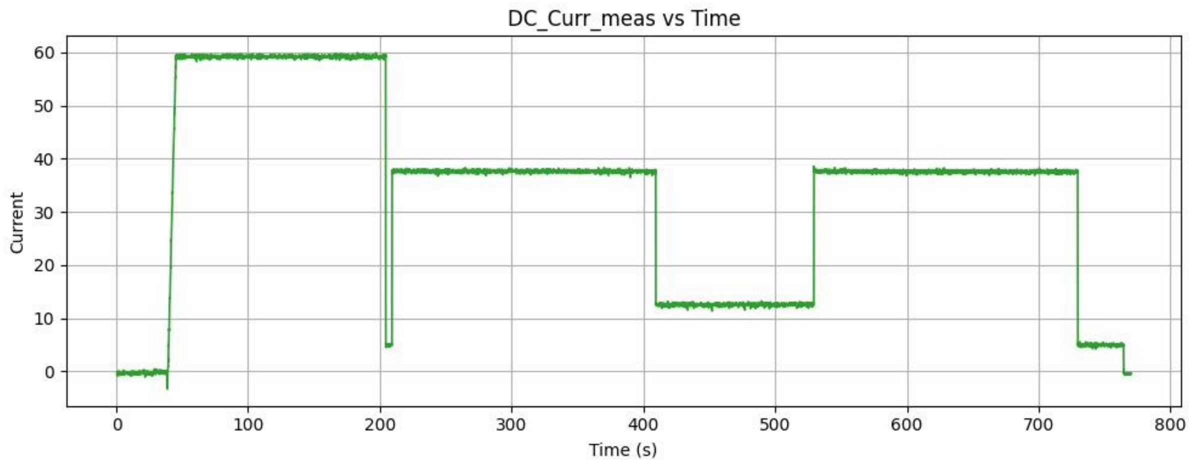


**Figure 28. Test A – Plot of charging current, log CAN of EVSE (MCTS) Emulator**

## 5.2.2. Test B - Charging Needs Configuration

Test B confirms the correct implementation of the DR logic based on configured charging needs. Initially, the EV charges at around 25 kW, but as the backend recognizes a long-time window charging (defined by the charging needs), it issues a modulation command reducing power to approximately 3 kW. The current profile reflects this reduction, while voltage remains stable throughout. The results show that the platform successfully adjusts charging based on flexibility constraints, validating the demand response mechanism.


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In the following Figure 29 - Figure 30 - Figure 31 the plots of the obtained results.

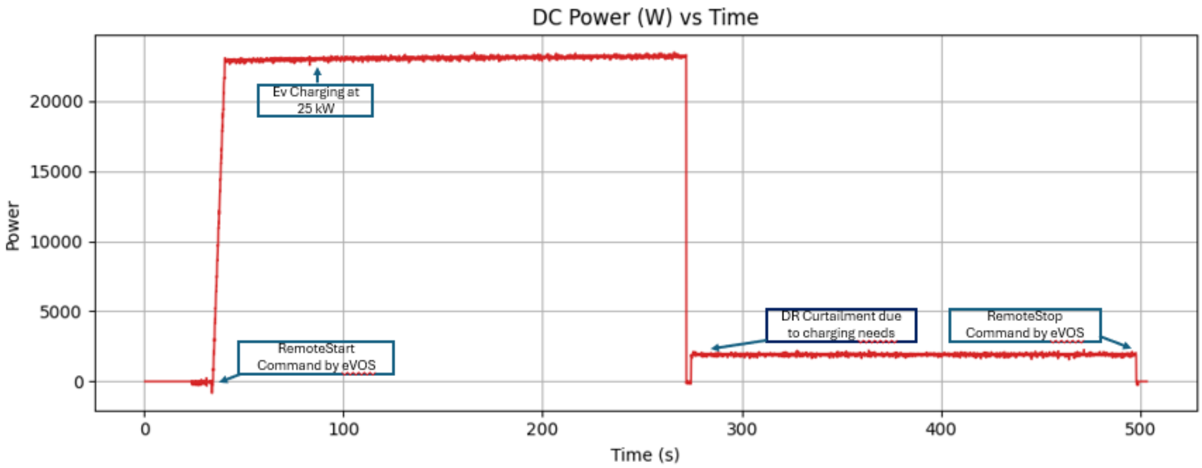


**Figure 29. Test B – Plot of charging power, log CAN of EVSE (MCTS) Emulator**

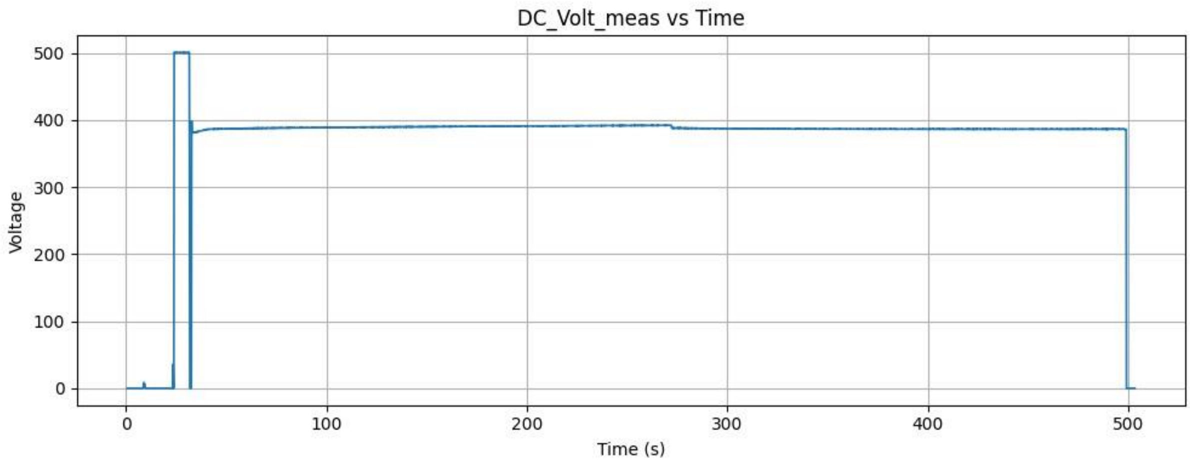


**Figure 30. Test B – Plot of charging voltage, log CAN of EVSE (MCTS) Emulator**



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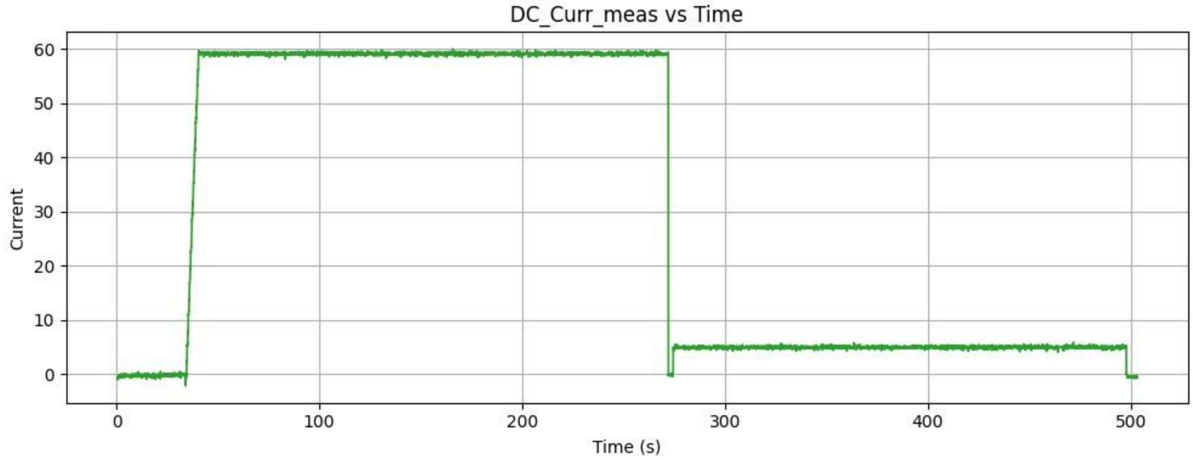


**Figure 31. Test B – Plot of charging current, log CAN of EVSE (MCTS) Emulator**

### 5.2.3. Test C - Aggregator to CPO DR Program Transmission

The results of Test C confirm the successful creation and transfer of DR events from the aggregator platform to the Enel X Way "Energy Services" platform. As shown in the screenshots (Figure 32 - Figure 33), multiple DR events were defined on the aggregator side, each with specific start and end times and DR setpoints ranging from 0 to 10 kW. These events were correctly received and registered on the Energy Services interface, associated with the MENORCATESTLAB resource, confirming that the interoperability via the OpenADR protocol is working as intended.

| Operator | Program | Product | Event Type | Portfolio | Obligation | Performance | Availability | Start Time | End Time | # of Registrations | Created By | Created Time | Status |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| e-distribución | FLOW Menorca demo | FLOW Menorca demo LAB | Official | FLOW Menorca demo LAB portfolio | 5000 kW | 0.0 % | 0 kW | 2025/05/22, 15:30 CEST | 2025/05/22, 15:45 CEST | Active: 1 Pending: 0 Opt-Out: 0 Cancelled: 0 | stefano.rosolia@enel.com | 2025/05/20, 17:21 CEST | Active |
| e-distribución | FLOW Menorca demo | FLOW Menorca demo LAB | Official | FLOW Menorca demo LAB portfolio | 10000 kW | 0.0 % | 0 kW | 2025/05/22, 16:00 CEST | 2025/05/22, 16:15 CEST | Active: 1 Pending: 0 Opt-Out: 0 Cancelled: 0 | stefano.rosolia@enel.com | 2025/05/20, 17:22 CEST | Active |
| e-distribución | FLOW Menorca demo | FLOW Menorca demo LAB | Official | FLOW Menorca demo LAB portfolio | 0 kW | 0.0 % | 0 kW | 2025/05/22, 16:30 CEST | 2025/05/22, 16:45 CEST | Active: 1 Pending: 0 Opt-Out: 0 Cancelled: 0 | stefano.rosolia@enel.com | 2025/05/20, 17:23 CEST | Active |
| e-distribución | FLOW Menorca demo | FLOW Menorca demo LAB | Official | FLOW Menorca demo LAB portfolio | 5000 kW | 0.0 % | 0 kW | 2025/05/23, 10:30 CEST | 2025/05/23, 10:45 CEST | Active: 1 Pending: 0 Opt-Out: 0 Cancelled: 0 | stefano.rosolia@enel.com | 2025/05/20, 17:25 CEST | Active |
| e-distribución | FLOW Menorca demo | FLOW Menorca demo LAB | Official | FLOW Menorca demo LAB portfolio | 10000 kW | 0.0 % | 0 kW | 2025/05/23, 11:00 CEST | 2025/05/23, 11:15 CEST | Active: 1 Pending: 0 Opt-Out: 0 Cancelled: 0 | stefano.rosolia@enel.com | 2025/05/20, 17:26 CEST | Active |
| e-distribución | FLOW Menorca demo | FLOW Menorca demo LAB | Official | FLOW Menorca demo LAB portfolio | 0 kW | 0.0 % | 0 kW | 2025/05/23, 11:30 CEST | 2025/05/23, 11:45 CEST | Active: 1 Pending: 0 Opt-Out: 0 Cancelled: 0 | stefano.rosolia@enel.com | 2025/05/20, 17:26 CEST | Active |

**Figure 32. Test C – DR Creation Event Screen from Enel X Aggregator (BSP) Platform**


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| Contract program | Reject reason | DR Event ID | Creation date | Start date | End date | Resource name | Event type | DR value (kW) |
|---|---|---|---|---|---|---|---|---|
| CP_ENELX | None | 1da97b80-358e-11f0-9c00-4fa... | 20/05/2025 - 17:22:05 | 22/05/2025 - 15:30:00 | 22/05/2025 - 15:45:00 | MENORCATESTLAB | Non zero | 5 |
| CP_ENELX | None | 48c6ed70-358e-11f0-92c2-c3... | 20/05/2025 - 17:23:31 | 22/05/2025 - 16:00:00 | 22/05/2025 - 16:15:00 | MENORCATESTLAB | Non zero | 10 |
| CP_ENELX | None | 65416ca0-358e-11f0-92c2-c30... | 20/05/2025 - 17:24:02 | 22/05/2025 - 16:30:00 | 22/05/2025 - 16:45:00 | MENORCATESTLAB | Zero | 0 |
| CP_ENELX | None | a6393300-358e-11f0-92c2-c3... | 20/05/2025 - 17:26:01 | 23/05/2025 - 10:30:00 | 23/05/2025 - 10:45:00 | MENORCATESTLAB | Non zero | 5 |
| CP_ENELX | None | c030b0d0-358e-11f0-92c2-c3... | 20/05/2025 - 17:27:01 | 23/05/2025 - 11:00:00 | 23/05/2025 - 11:15:00 | MENORCATESTLAB | Non zero | 10 |
| CP_ENELX | None | de4b9990-358e-11f0-9739-63... | 20/05/2025 - 17:27:32 | 23/05/2025 - 11:30:00 | 23/05/2025 - 11:45:00 | MENORCATESTLAB | Zero | 0 |

**Figure 33. Test C – DR Event Receiving Screen from Energy Services (CPO) Platform**

### 5.2.4. Test D - CPO to Emulated EVSE DR Execution

This test demonstrates the successful application of a demand response event initiated by the CPO platform to modulate the charging power of a DC-connected electric vehicle (an Opel Corsa Electric) through the MCTS EVSE simulator. The goal was to test a V1G modulation scenario with dynamic setpoint control, triggered remotely by the app of eVOS backend system.

The following Figure 34 - Figure 35 - Figure 36 show that:

- The charging session is remotely triggered via the Enel X Way mobile app. Shortly after, the EVSE begins supplying a constant power of approximately 16 kW, marking the steady-state pre-modulation charging regime.
- After the system stabilizes, a demand response signal is sent from the CPO's Energy Services platform, reducing the charging power to 10 kW for a period of 15 minutes. This decrease is clearly visible as a sustained lower plateau in the power curve.
- After the DR event concludes, the EV resumes charging at the original power level of 16 kW. This return to baseline validates the correct implementation of the charging needs logic and the flexible asset's ability to resume its standard operating state.
- At the end of the charging session, a remote stop command is sent from the app, which causes an immediate drop in power to 0, cleanly ending the session.
- The voltage remains nearly constant at 400 V throughout the test, confirming the stability of the supply voltage and validating that the modulation was purely current driven, as expected in constant voltage DC charging.
- The current mirrors the power behaviour: initially high at 40 A during full charging, reduced to 25 A during the DR modulation, and then returning to the higher value before the final drop-off at the session's end. This confirms that the modulation signal from the CPO correctly translated into a new current setpoint for the charging session.


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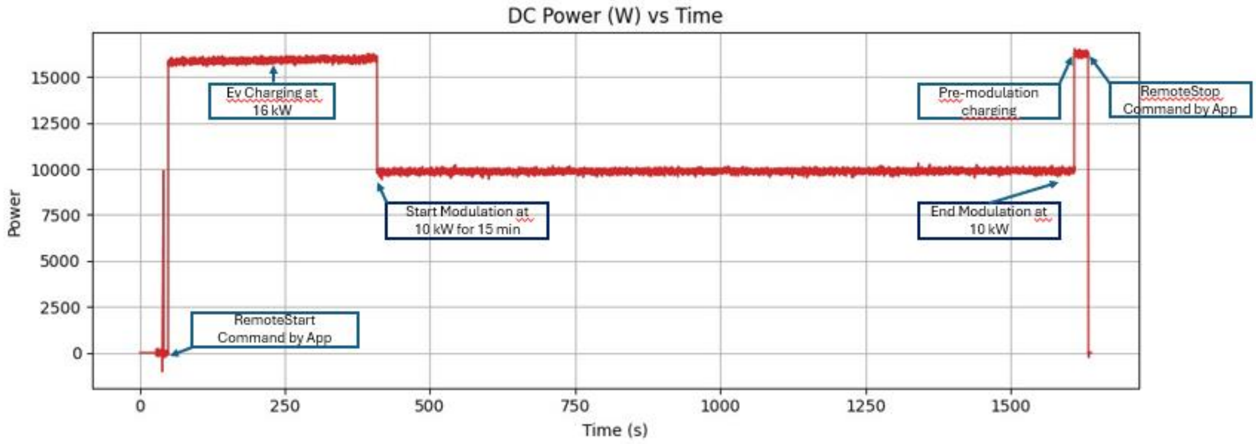


**Figure 34. Test D – Plot of charging power, log CAN of EVSE (MCTS) Emulator**

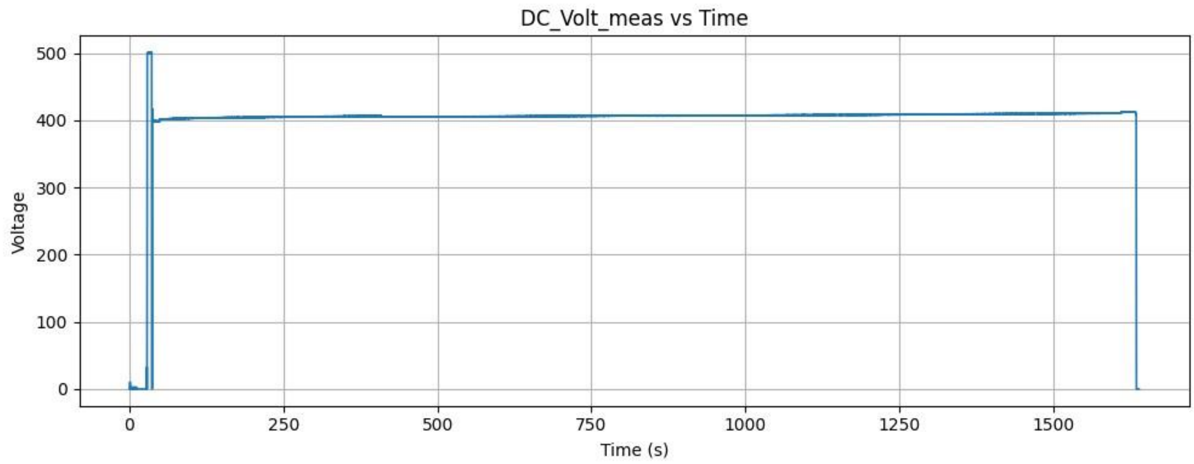


**Figure 35. Test D – Plot of charging voltage, log CAN of EVSE (MCTS) Emulator**

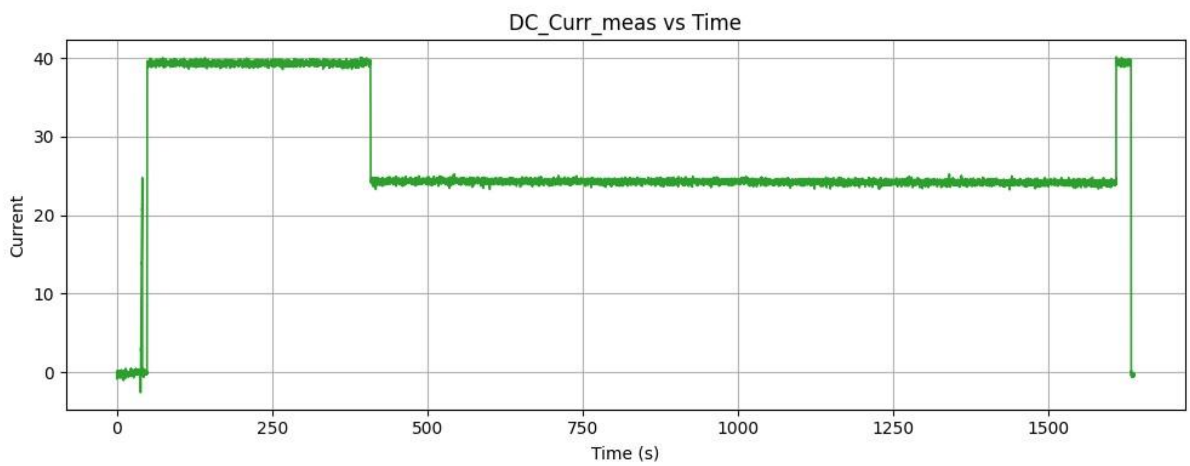


**Figure 36. Test D – Plot of charging current, log CAN of EVSE (MCTS) Emulator**



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Test D successfully validates the execution of a V1G modulation scenario triggered by the CPO platform and applied to a simulated DC EVSE. The real-time transition of charging current and power in response to the DR command demonstrates effective integration of OCPP 1.6J control logic and the enforcement of charging needs through the Energy Services platform.

### 5.2.5. Test E - End-to-End DR Test with V1G Modulation

Test E aimed to validate an end-to-end DR workflow involving: the Aggregator (Enel X), the CPO platform (Enel X Way – Energy Services), and the flexible resource (EVSE simulator - MCTS) connected to a real EV (Opel Corsa-e). The charging session was initiated via the mobile app, starting at approximately 30 kW.

Two DR events were scheduled:

- Event 1: 10 kW from 12:15 to 12:30 of 26/06/25
- Event 2: 5 kW from 12:30 to 12:45 of 26/06/25

The following Figure 37 - Figure 38 - Figure 39 - Figure 40 - Figure 41 show that:

- The session began as expected, with the EV charging steadily at 30 kW.
- At 12:15, instead of adjusting to 10 kW, the charging dropped to 0 kW. This over-modulation was caused by the internal logic of the Energy Services platform, which, taking into account a high SoC (73%) and a long departure time (next day at 10:00), opted to temporarily stop charging.
- The second DR event was correctly executed, modulating charging to 5 kW.
- After modulation, the power ramped back up and the session was ended via a RemoteStop command.
- The current and voltage trends confirmed the expected charging behaviour: current mirrored power, while voltage remained stable at 420 V.

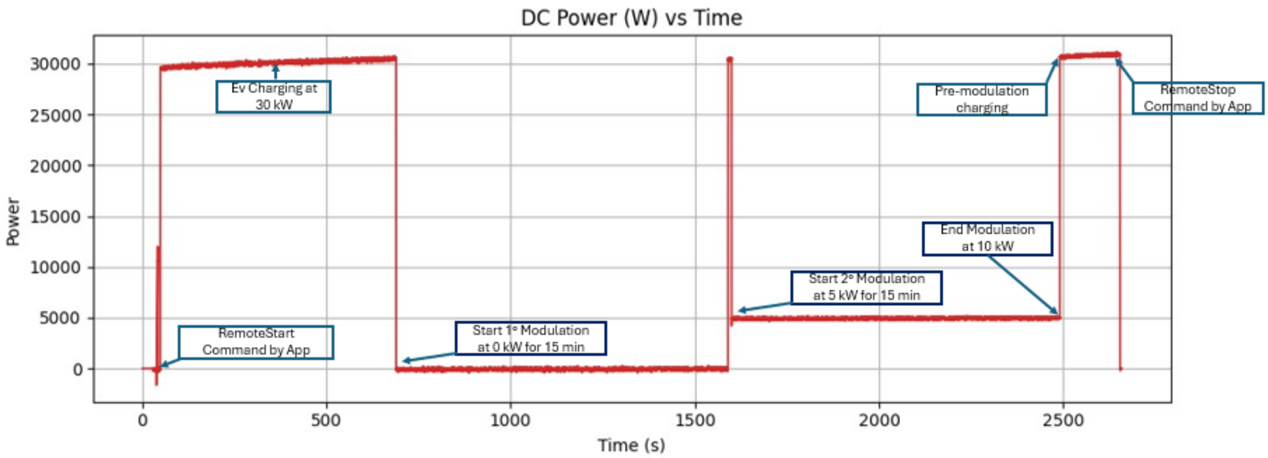


Figure 37. Test E – Plot of charging power, log CAN of EVSE (MCTS) Emulator


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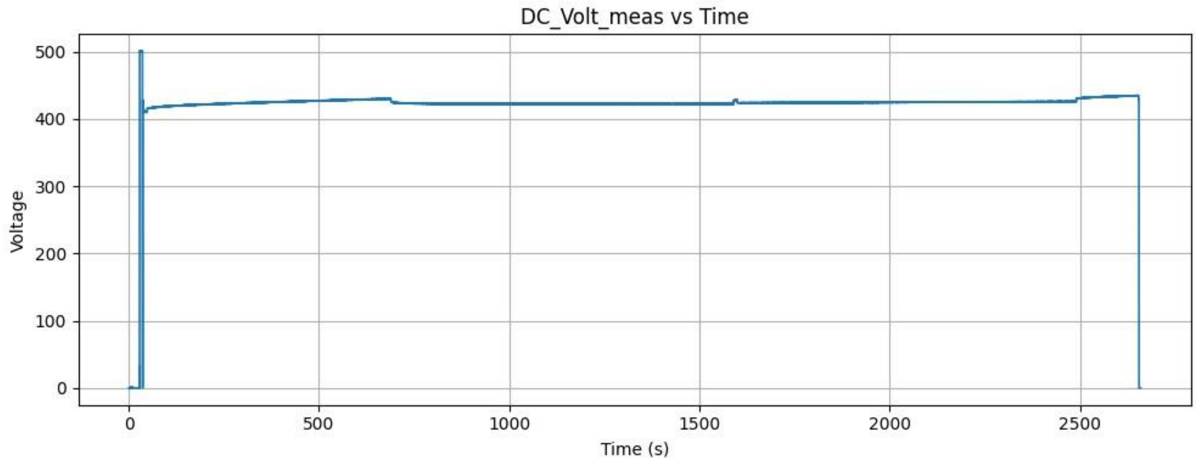


Figure 38. Test E – Plot of charging voltage, log CAN of EVSE (MCTS) Emulator

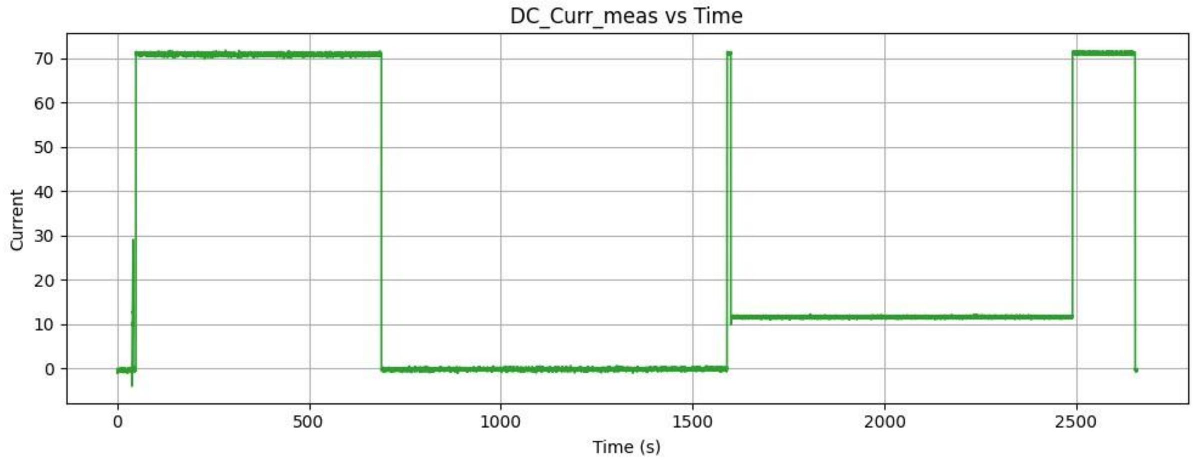


Figure 39. Test E – Plot of charging current, log CAN of EVSE (MCTS) Emulator

| Operator | Program | Product | Event Type | Portfolio | Obligation | Performance | Availability | Start Time | End Time | # of Registrations |
|---|---|---|---|---|---|---|---|---|---|---|
| e-distribución | FLOW Menorca demo | FLOW Menorca demo LAB | Official | FLOW Menorca demo LAB portfolio | 10 kW | 0.0 % | 0 kW | 2025/06/26, 12:15 CEST | 2025/06/26, 12:30 CEST | Active: 1<br>Pending: 0<br>Opt-Out: 0<br>Cancelled: 0 |
| e-distribución | FLOW Menorca demo | FLOW Menorca demo LAB | Official | FLOW Menorca demo LAB portfolio | 5 kW | 0.0 % | 0 kW | 2025/06/26, 12:30 CEST | 2025/06/26, 12:45 CEST | Active: 1<br>Pending: 0<br>Opt-Out: 0<br>Cancelled: 0 |

Figure 40. Test E – DR Event Screen from Enel X Aggregator (BSP) Platform



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Events 230

26/06/25 - 02:42:34 PM

| | Output power | Phase 1 Current | Phase 2 Current | Phase 3 Current | Phase 1 Voltage | Phase 2 Voltage | Phase 3 Voltage | Phase 1 Energy | EV battery SoC |
|---|---|---|---|---|---|---|---|---|---|
| 26/06/25 - 02:42:... | - | - | - | - | - | - | - | 6563.00 Wh | 77 % |
| 26/06/25 - 02:42:... | - | - | - | - | - | - | - | 6549.00 Wh | 77 % |
| 26/06/25 - 02:42:... | - | - | - | - | - | - | - | 6535.00 Wh | 77 % |
| 26/06/25 - 02:42:... | - | - | - | - | - | - | - | 6521.00 Wh | 77 % |
| 26/06/25 - 02:41:... | - | - | - | - | - | - | - | 6508.00 Wh | 77 % |
| 26/06/25 - 02:41:... | - | - | - | - | - | - | - | 6494.00 Wh | 77 % |

**Figure 41. Test E – Telemetry from Energy Services (Enel X Way, CPO) Platform**

The test demonstrated the ability of the platform to perform DR actions effectively, with some optimization logic taking a conservative approach when favourable charging conditions are detected.

In all of the aforementioned use cases, all DR signal activations are expected to occur in real time, adjusting the ongoing charging session. A detailed analysis of command activation latency is not performed; however, the DR activation flow is considered successful if the command is executed within a few seconds (less than 10) during the test session.

All test scenarios demonstrated robust communication and interoperability between the Aggregator (Enel X), the CPO platform (Enel X Way/Energy Services), and the MCTS EVSE simulator.



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## 5.3. Rome Demo Laboratory Use Case Results

Hereafter all the four scenarios' results are presented.

### 5.3.1. Scenario 1: DC CCS2 Charging Stop Command

This test aimed to simulate a direct interruption of a DC charging session, triggered by the DSO for network congestion management purposes.

The PGUI device was configured to read live charging session parameters via Input Registers:

- Actual EV charging power
- Voltage and current charging levels
- State of Charge (SoC)
- Time charging duration in seconds

This confirms that the DSO, via its field device (PGUI), has complete real-time visibility and control of the asset during operation.

The charging process started with the EVSE Emulator (MCTS) delivering 32,5 kW to a real EV. Upon sending a remote stop command via Modbus (through the PGUI and DSO System), the system successfully terminated the charging session.

The following figures (Figure 42 - Figure 43 - Figure 44 - Figure 45 - Figure 46) shows a clear and immediate drop in both DC voltage and current, confirming the correct interpretation of the Modbus coil signal and proper execution by the EVSE Emulator (MCTS). In particular:

- the MCTS GUI interface confirms a "Stop Charging" event, showing a transition from "Charging" to "stop session" state in real time;

- In the CAN-based plots, a sharp drop in current and active power is observed immediately after the stop command;

- The same transition is mirrored in the DSO-side monitoring, with a clear fall of RMS voltage, current and power to zero, confirming full observability of the asset's state.


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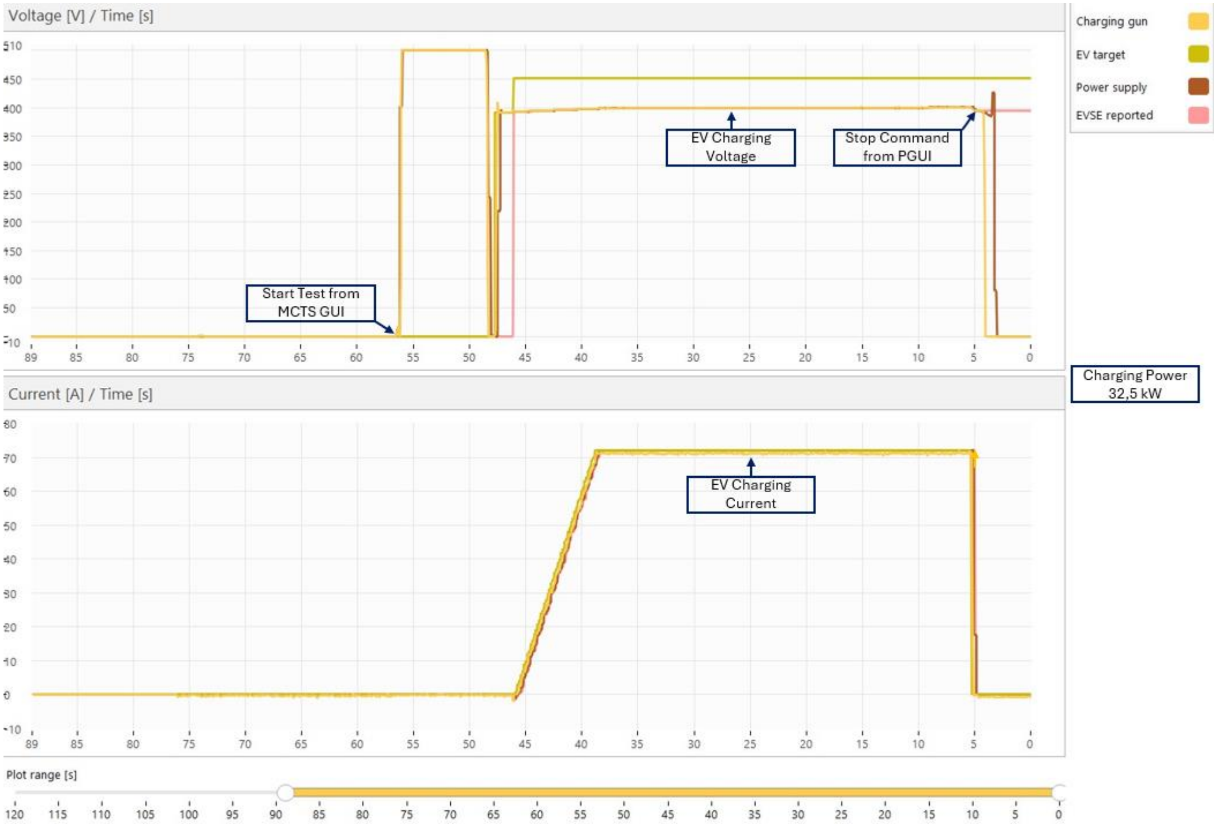


Figure 42. MCTS GUI Screen of Scenario 1 Test

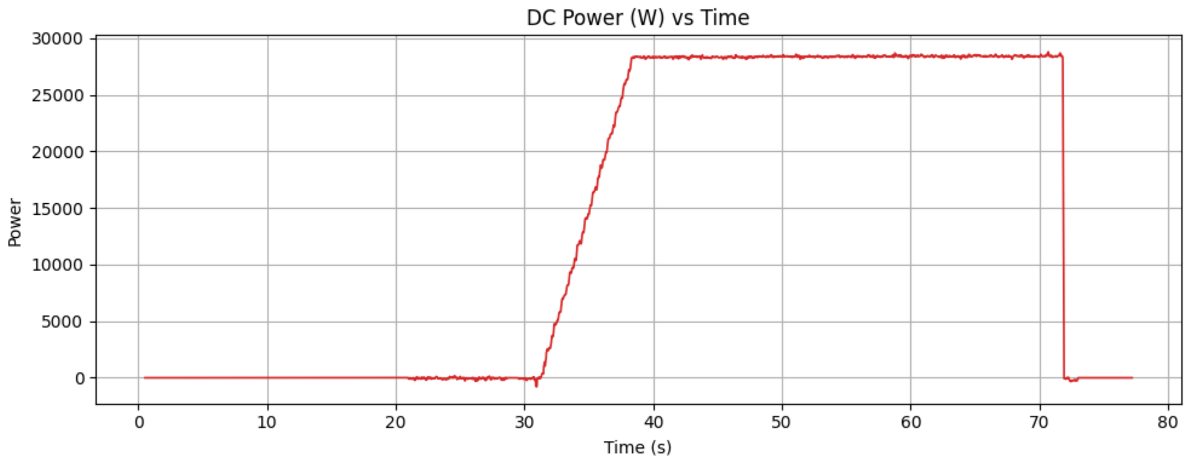


Figure 43. Scenario 1 Test – Power plot, log can of EVSE emulator (MCTS)



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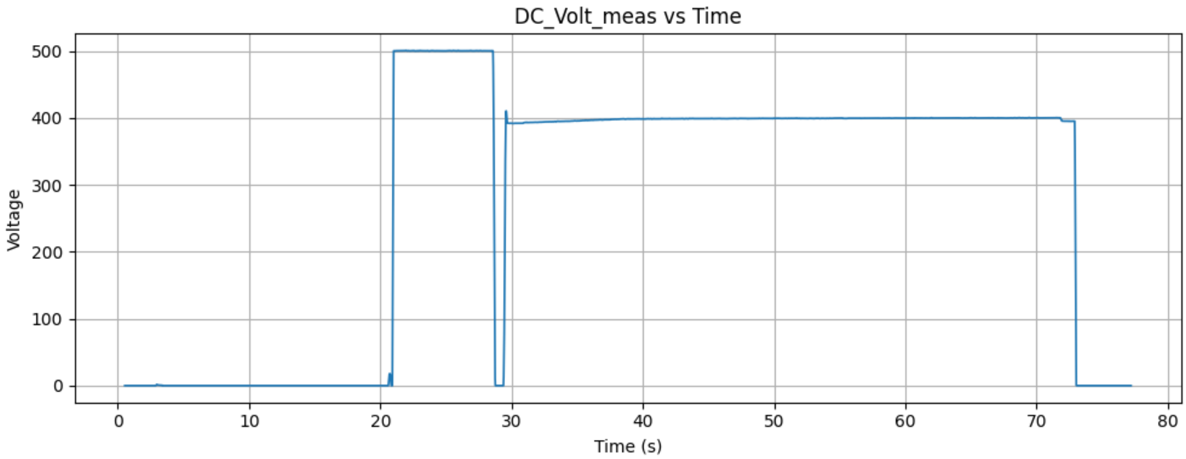


**Figure 44. Scenario 1 Test – Voltage plot, log can of EVSE emulator (MCTS)**

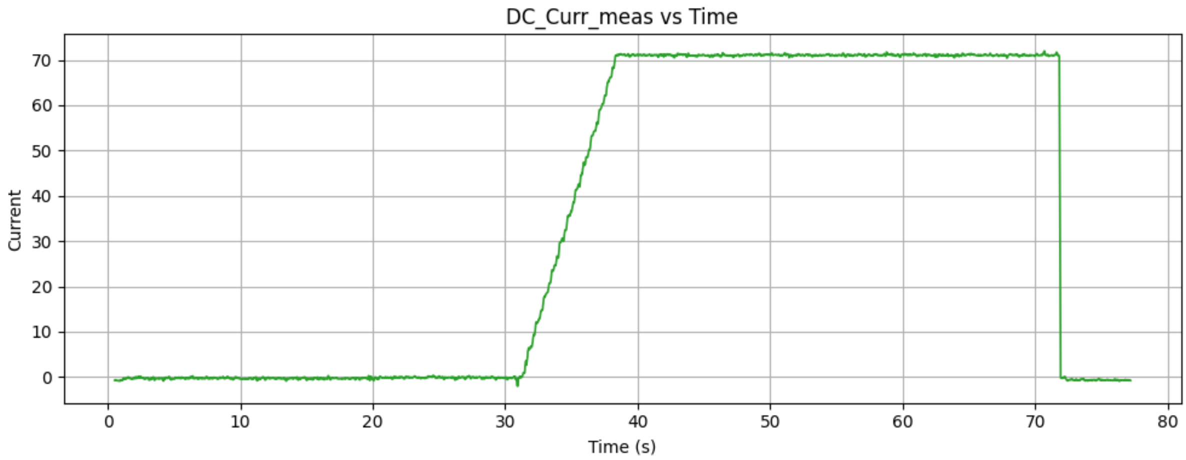


**Figure 45. Scenario 1 Test – Current plot, log can of EVSE emulator (MCTS)**

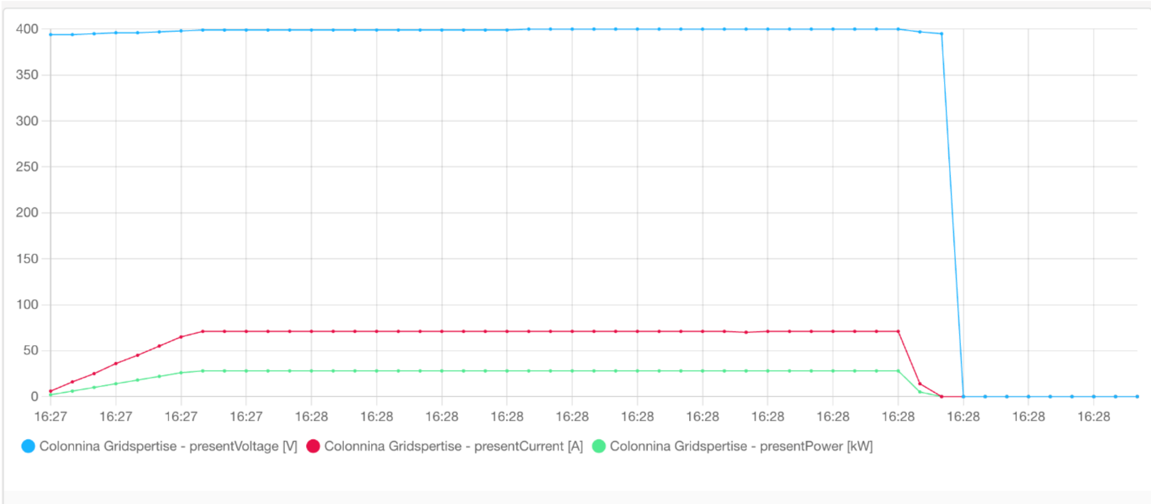


**Figure 46. Scenario 1 Test – Screen from Interface of DSO System**



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The results demonstrate the effectiveness of the EVSE emulation environment using MCTS; while real chargers may respond differently due to hardware or firmware constraints, the use case highlights the potential of direct EVSE control by DSO edge devices for implementing grid flexibility strategies.

The remote stop was completed successfully within one control cycle. The coordinated view from the MCTS GUI, the CAN analysis, and the DSO telemetry illustrates a full end-to-end alignment in asset state.

This test validates the DSO's direct control loop over EVSEs in DC mode for flexibility actions such as emergency disconnection and/or overload management.



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### 5.3.2. Scenario 2: AC Type 2 Charging Stop Command

This test reproduces the same scenario as Use Case 1 but under AC charging conditions. The EVSE Emulator (MCTS) was configured to operate at 11 kW on an AC interface with a real EV because of its maximum absorbing power capability with AC Type 2 plug.

The PGUI device was configured to read live charging session parameters via Input Registers:

- Actual EV charging power
- Voltage and current charging levels
- Time charging duration in seconds

This confirms that the DSO, via its field device (PGUI), has complete real-time visibility and control of the asset during operation.

The charging process started with the EVSE Emulator (MCTS) delivering 11 kW to a real EV. Upon sending a remote stop command via Modbus (through the PGUI and DSO System), the system executed a controlled shutdown of the charging session.

The following figures (Figure 47 - Figure 48 - Figure 49- Figure 50 - Figure 51) show a symmetric power down across the three phases, with the RMS current smoothly decreasing to zero within one second. This behaviour highlights the controlled power management logic implemented in the MCTS firmware. The absence of phase imbalance and overshoot confirms the system's suitability for DSO-commanded session management in low-voltage distribution networks. In particular:

- the MCTS GUI interface confirms a "Stop Charging" event, showing a transition from "Charging" to "stop session" state in real time;

- In the CAN-based plots, a sharp drop in current and active power is observed immediately after the stop command;

- The same transition is mirrored in the DSO-side monitoring, with a clear fall of RMS voltage, current and power to zero, confirming full observability of the asset's state.



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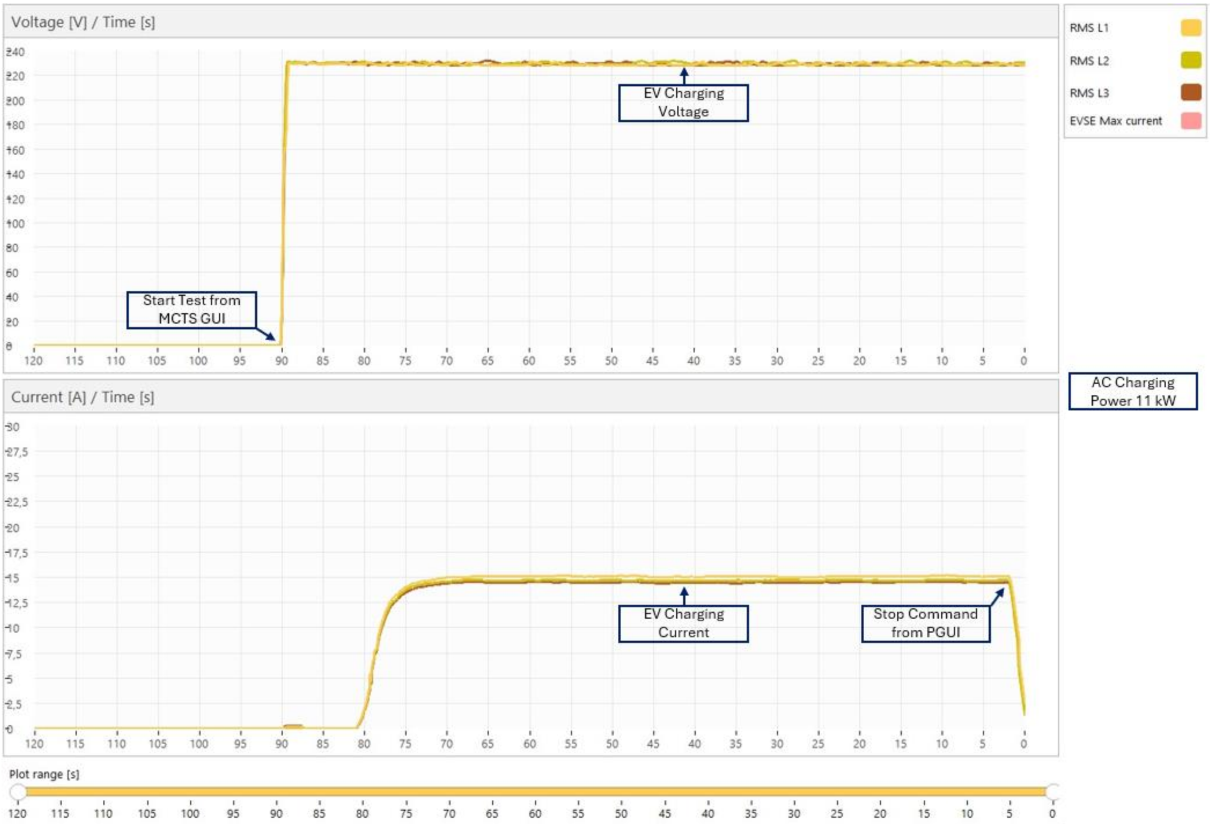


Figure 47. MCTS GUI Screen of Scenario 2 Test

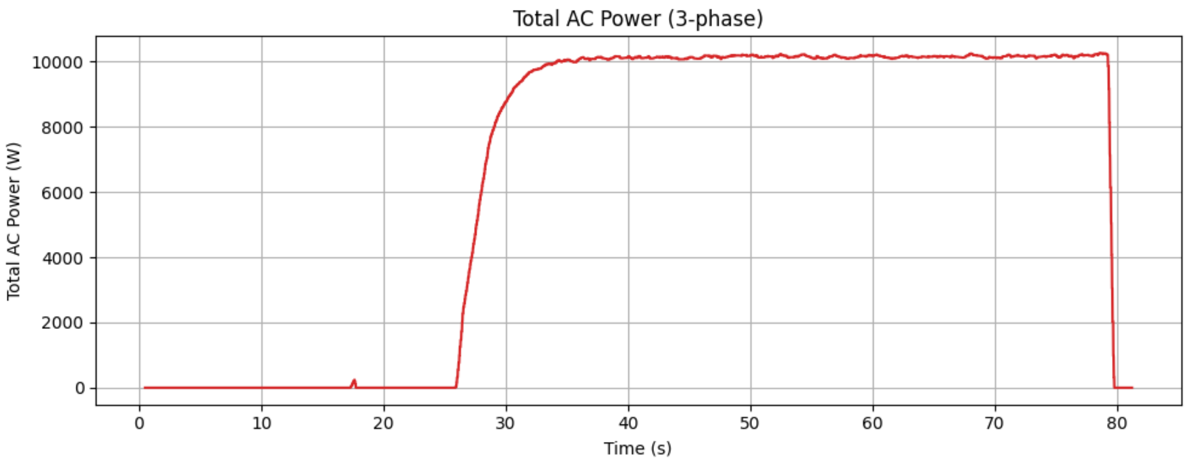


Figure 48. Scenario 2 Test – Power plot, log can of EVSE emulator (MCTS)



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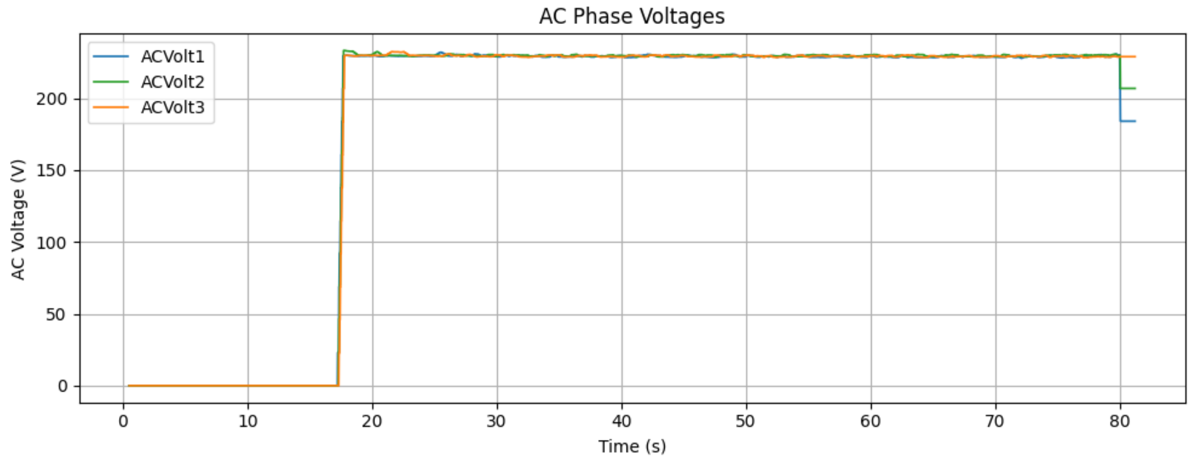


**Figure 49. Scenario 2 Test – Voltage plot, log can of EVSE emulator (MCTS)**

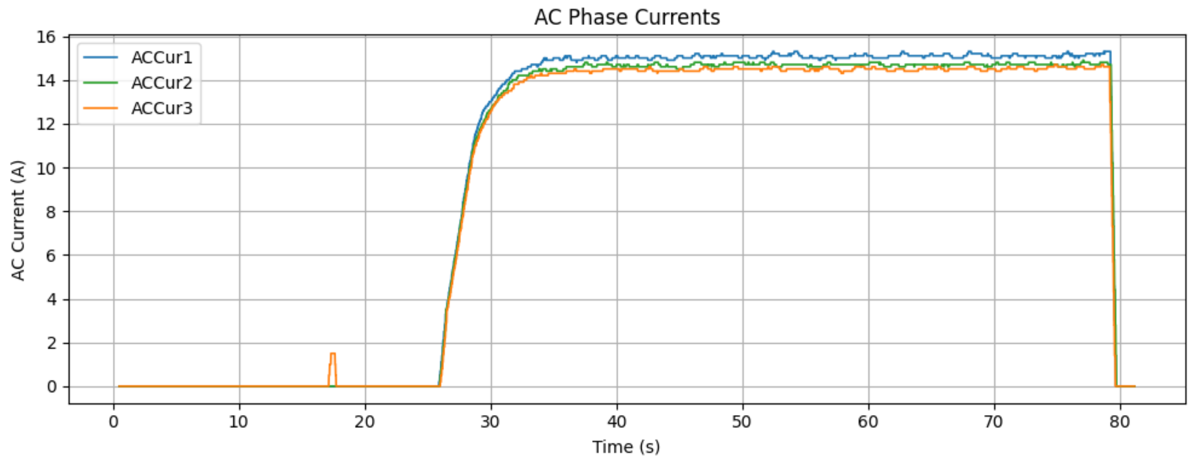


**Figure 50. Scenario 2 Test – Current plot, log can of EVSE emulator (MCTS)**

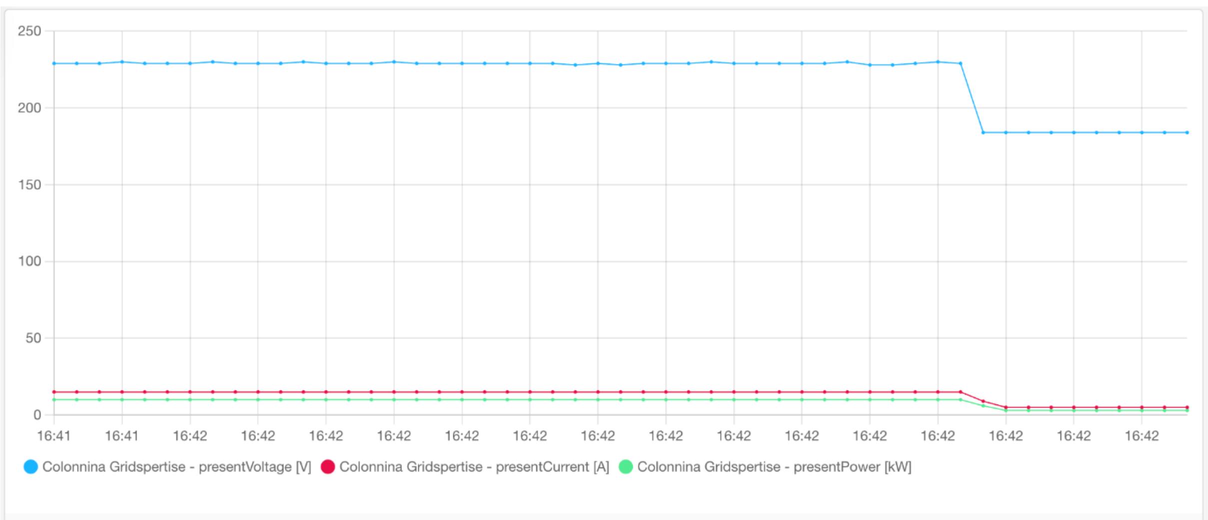


**Figure 51. Scenario 2 Test – Screen from Interface of DSO System**



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The results demonstrate the effectiveness of the EVSE emulation environment using MCTS; while real chargers may respond differently due to hardware or firmware constraints, the use case highlights the potential of direct EVSE control by DSO edge devices for implementing grid flexibility strategies.

This use case confirms the feasibility of DSO-driven remote shutdown of AC chargers, with low latency and full observability. The coherence across EVSE Emulator (MCTS) interface, CAN data, and DSO monitoring plots confirm successful execution and synchronization.

This test validates the DSO's direct control loop over EVSEs in AC mode for flexibility actions such as emergency disconnection and/or overload management.



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### 5.3.3. Scenario 3: V1G Power Modulation of DC CCS2 Charging Mode

This test validated the EVSE's ability to modulate DC charging power in steps, simulating a DSO-initiated DR program sent via Modbus commands.

The PGUI device was configured to read live charging session parameters via Input Registers:

- Actual EV charging power;
- Voltage and current charging levels;
- State of Charge (SoC);
- Time charging duration in seconds.

This confirms that the DSO, via its field device (PGUI), has complete real-time visibility and control of the asset during operation.

The charging process started with the EVSE Emulator (MCTS) delivering 30 kW to a real EV. After that, the PGUI issued power modulation commands to reduce the charging power in 3 steps. In particular, each 30 seconds a command of power modulation was sent reducing it at a level of 20 kW, then 10 kW, then 5 kW followed by a remote stop charging command.

The modulation times of the charging session are purely demonstrative, occurring in a laboratory context.

The following figures (Figure 52 - Figure 53 - Figure 54 - Figure 55 - Figure 56 - Figure 57) reflect each modulation command, with current and power signals showing sharp transitions and stable values between steps. Each new setpoint is accurately followed in less than one second, without oscillations or instability. In particular:

- The MCTS GUI displays each power setpoint in real time, showing stable target tracking at each step;

- The CAN-derived plots show clear, sharp transitions in current and power levels, with no overshoots or oscillations.

- On the DSO side, the power and current readings mirror those seen in the CAN logs, confirming external observability of the modulation path.


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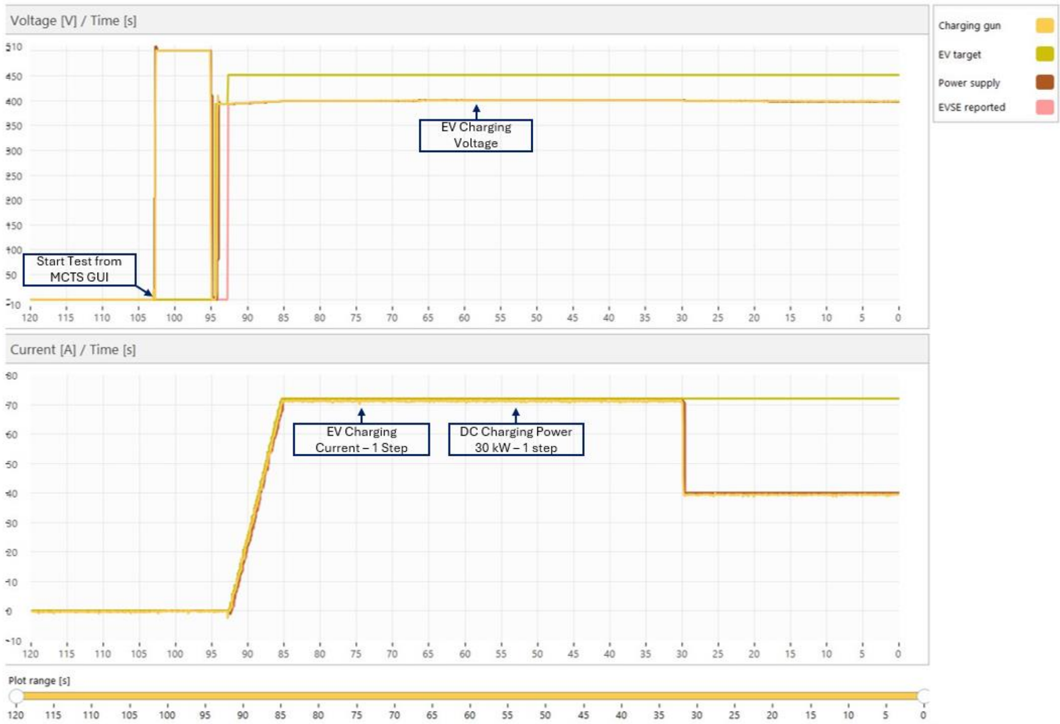


**Figure 52. MCTS GUI Screen of Scenario 3 Test – part 1**

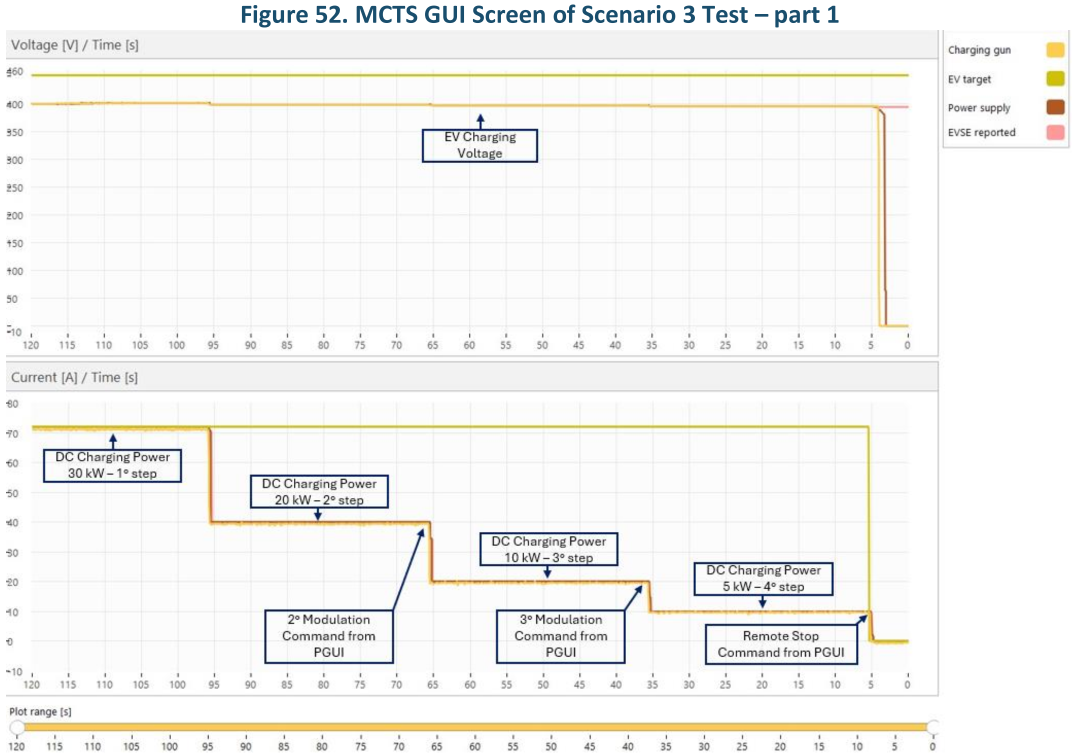


**Figure 53. MCTS GUI Screen of Scenario 3 Test – part 2**



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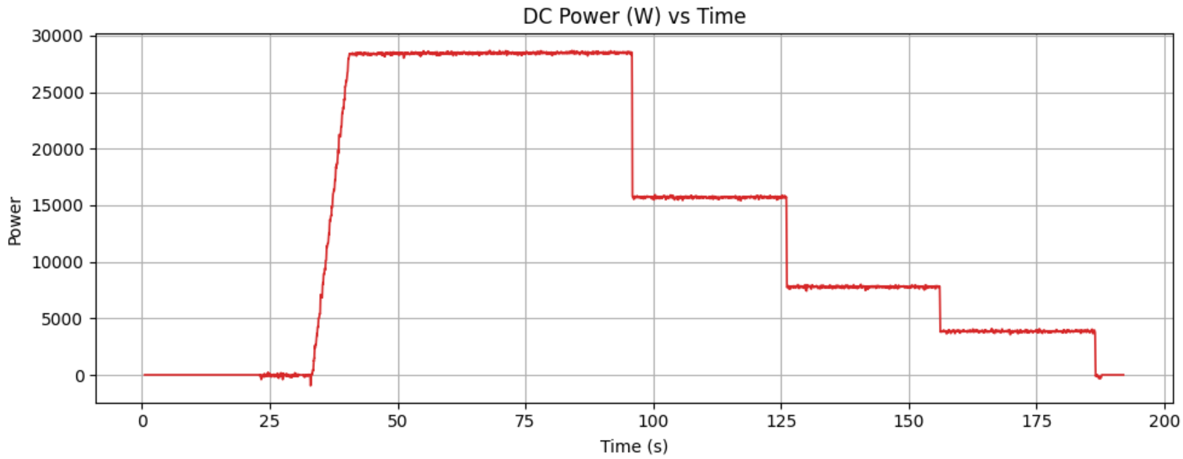


**Figure 54. Scenario 3 Test – Power plot, log can of EVSE emulator (MCTS)**

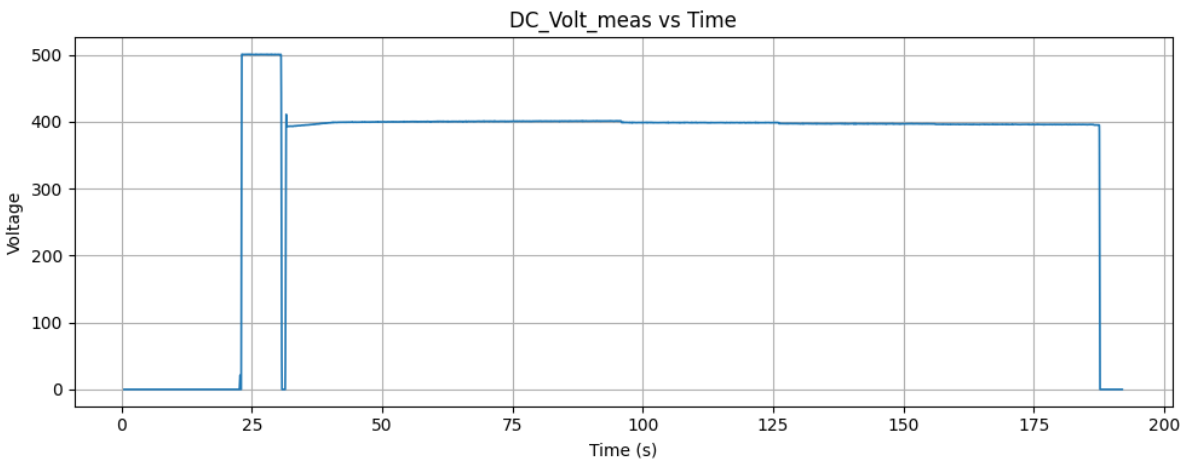


**Figure 55. Scenario 3 Test – Voltage plot, log can of EVSE emulator (MCTS)**

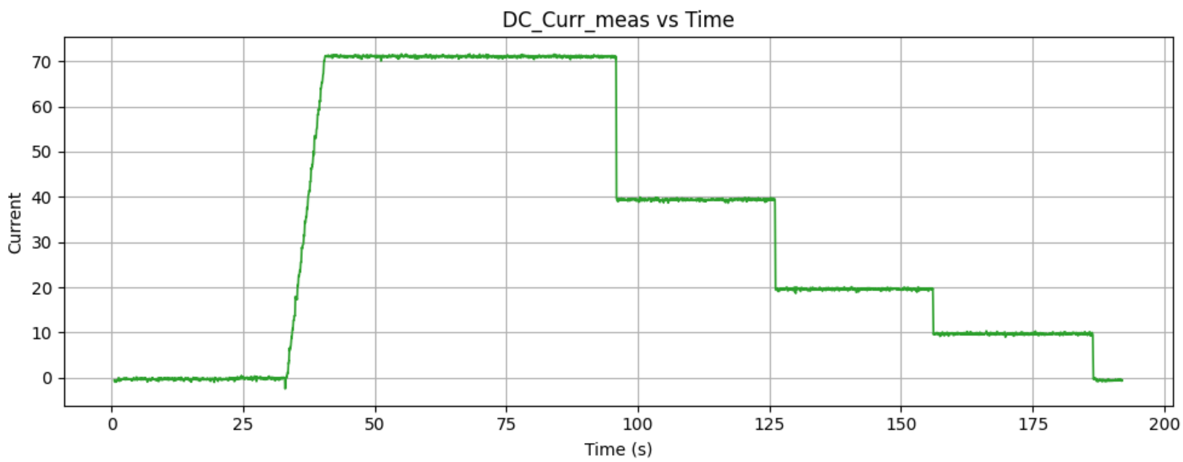


**Figure 56. Scenario 3 Test – Current plot, log can of EVSE emulator (MCTS)**


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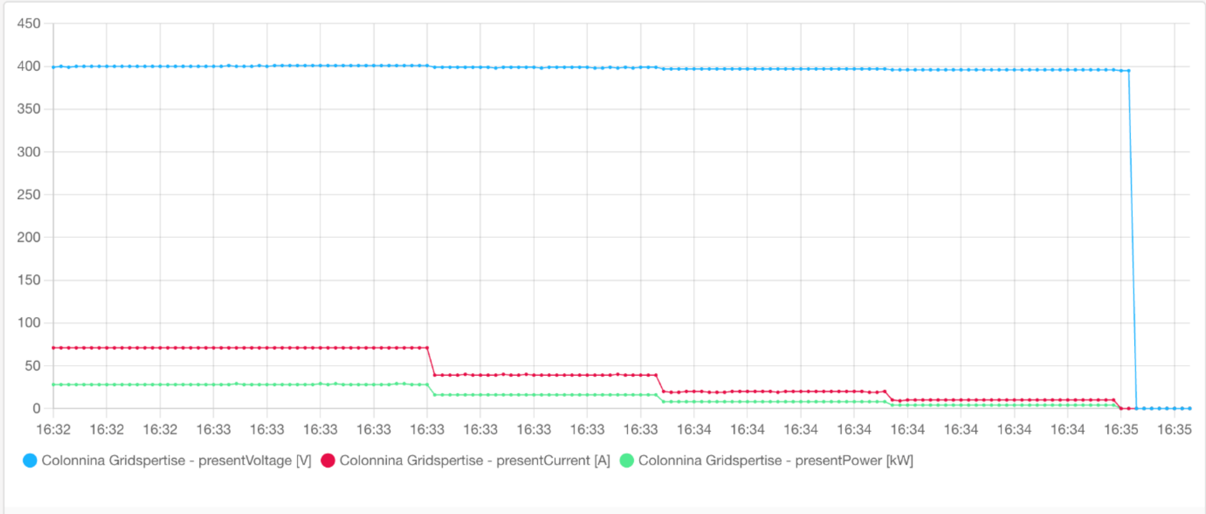


**Figure 57. Scenario 3 Test – Screen from Interface of DSO System**

The EVSE responded promptly and predictably to each setpoint change, illustrating its suitability for DR programs (V1G) requiring active load modulation. The test confirms the viability of real-time flexible asset control, especially in DC fast-charging scenarios where power impact is significant.

The results demonstrate the effectiveness of the EVSE emulation environment using MCTS; while real chargers may respond differently due to hardware or firmware constraints, the use case highlights the potential of direct EVSE control by DSO edge devices for implementing grid flexibility strategies.

This use case confirms that the system can be used to simulate flexible load control strategies, and that the EVSE Emulator (MCTS) hardware and software reliably follow Modbus commands in real time.

The test also demonstrates the potential of MCTS as a platform for pre-validating grid services like congestion mitigation or peak shaving.


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### 5.3.4. Scenario 4: V1G Power Modulation of AC Type 2 Charging Mode

The final test focused on the V1G modulation of AC charging power, in particular the test validated the EVSE's ability to modulate AC charging power in steps, simulating a DSO-initiated DR program sent via Modbus commands.

The PGUI device was configured to read live charging session parameters via Input Registers:

- Actual EV charging power;
- Voltage and current charging levels;
- Time charging duration in seconds.

This confirms that the DSO, via its field device (PGUI), has complete real-time visibility and control of the asset during operation.

The charging process started with the EVSE Emulator (MCTS) delivering 11 kW to a real EV. After that, the PGUI issued power modulation commands to reduce the charging power in 2 steps. Each 30 seconds a command of power modulation was sent reducing it at a level of 7 kW, then 4 kW, followed by a remote stop charging command.

The modulation times of the charging session are purely demonstrative, occurring in a laboratory context.

In the following figures (Figure 58 - Figure 59 - Figure 60 - Figure 61 - Figure 62 - Figure 63) the three-phase RMS current and total active power plots show a clean, linear reduction of charging power, consistent with the predefined Modbus setpoints. Each step in the control signal corresponds precisely to a reduction in load. Each new setpoint is accurately followed in less than one second, no undesired current transients or power quality issues are observed, which indicates the system’s capability to perform grid-friendly load adjustments even on AC connections. Moreover:

- The MCTS GUI displays each power setpoint in real time, showing stable target tracking at each step;

- The CAN-derived plots show clear, sharp transitions in current and power levels, with no overshoots or oscillations;

- On the DSO side, the power and current readings mirror those seen in the CAN logs, confirming external observability of the modulation path.


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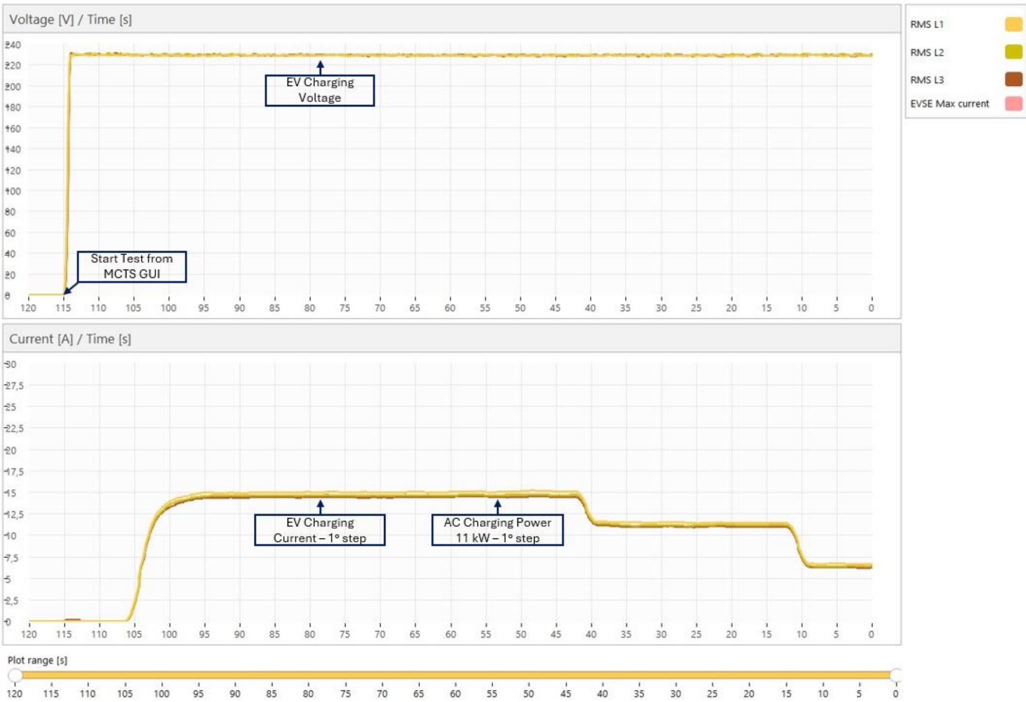


Figure 58. MCTS GUI Screen of Scenario 4 Test – part 1

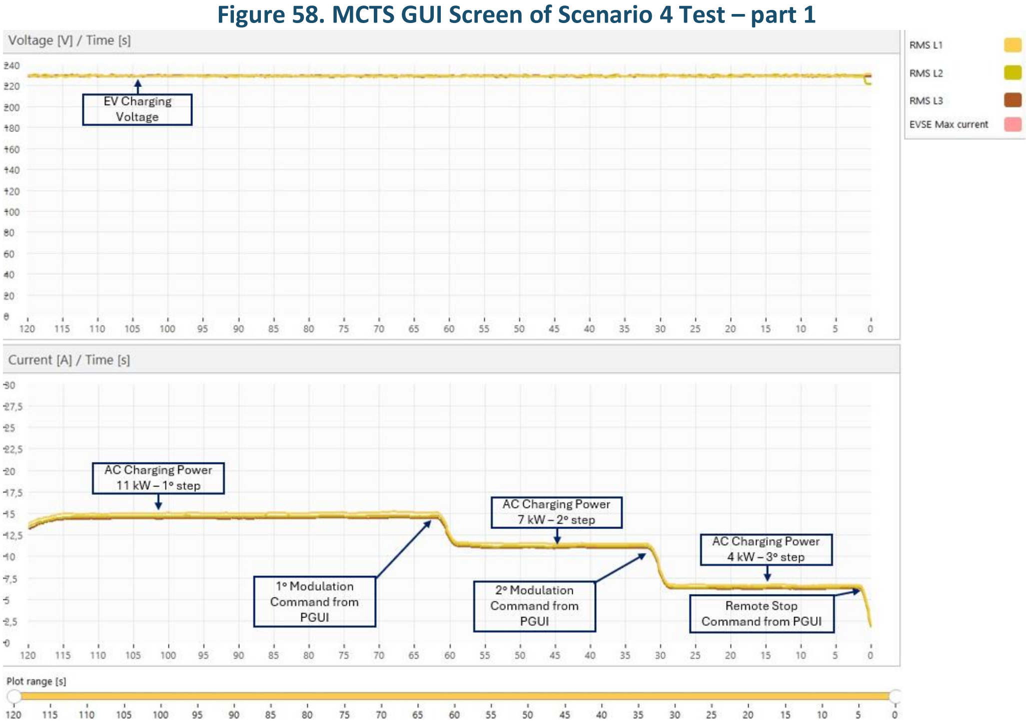


Figure 59. MCTS GUI Screen of Scenario 4 Test – part 2



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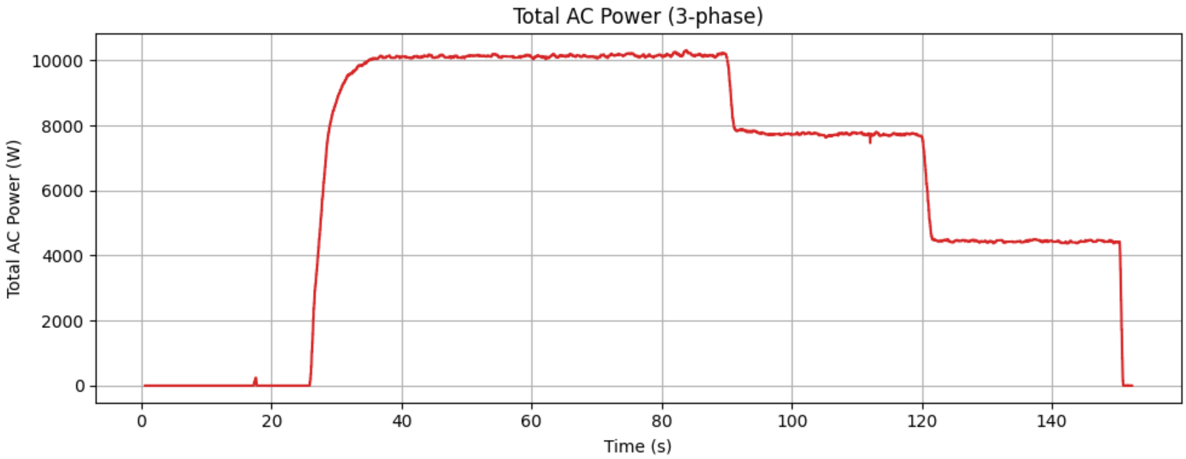


**Figure 60. Scenario 4 Test – Power plot, log can of EVSE emulator (MCTS)**

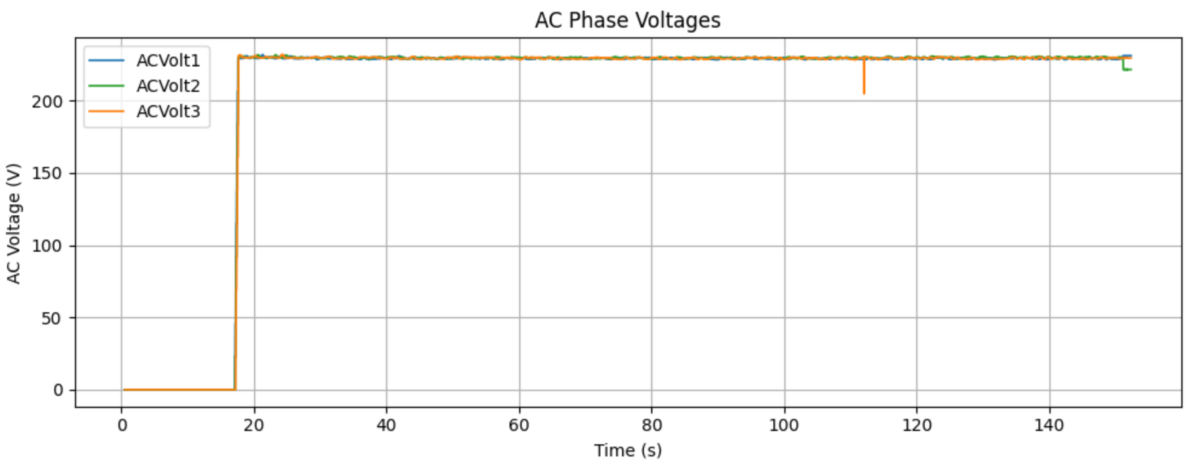


**Figure 61. Scenario 4 Test – Voltage plot, log can of EVSE emulator (MCTS)**

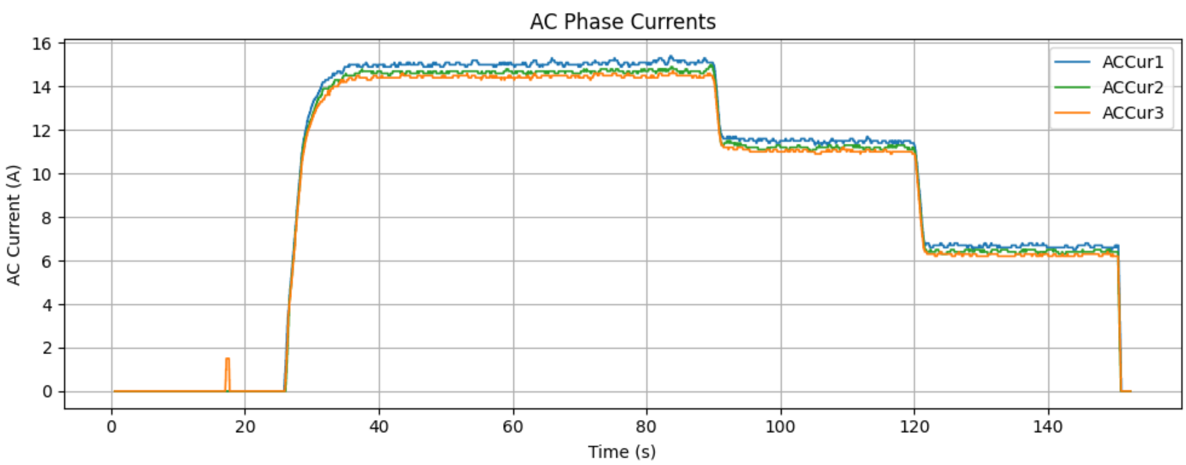


**Figure 62. Scenario 4 Test – Current plot, log can of EVSE emulator (MCTS)**



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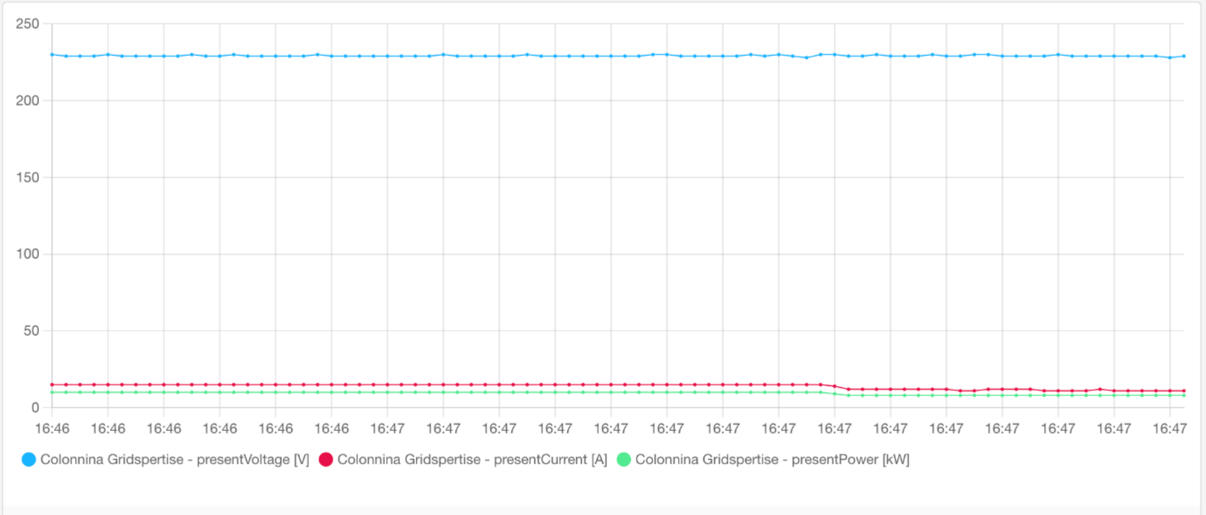


**Figure 63. Scenario 4 Test – Screen from Interface of DSO System**

The results demonstrate the effectiveness of the EVSE emulation environment using MCTS; while real chargers may respond differently due to hardware or firmware constraints, the use case highlights the potential of direct EVSE control by DSO edge devices for implementing grid flexibility strategies.

The test proves that real-time modulation of AC charging can be effectively managed by a DSO via Modbus control. It also confirms that flexible asset visibility and traceability are ensured through the PGUI input register polling.

Finally, this use case underlines the effectiveness of the MCTS in validating DR programs from the DSO side, and its suitability for smart charging scenarios involving real-time power modulation in response to network needs.



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In all of the aforementioned use cases, all DR signal activations are expected to occur in real time, adjusting the ongoing charging session. A detailed analysis of command activation latency is not performed; however, the DR activation flow is considered successful if the command is executed within a few seconds (less than 10) during the test session.

Moreover, they confirm that the EVSE as Flexible Service Providers (FSPs), when managed by a DSO-side control platform, behaves as a fully observable and controllable flexible assets. The combination of:

- Controllability;
- System observability;
- Real-time performance validation

provides a complete and replicable setup for local DR programs, congestion mitigation, and pre-field validation of flexibility mechanisms in distribution networks.


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# 6. Conclusions

The activities conducted under Task 6.2 have demonstrated the technical feasibility and relevance of integrating flexible EV charging infrastructures within broader Demand Response (DR) frameworks. The laboratory tests carried out in both the Rome and Menorca demo labs provided meaningful insights into how electric vehicle charging infrastructure can be effectively controlled and monitored for flexibility purposes.

In the Rome Demo Lab, the integration between the EVSE simulator (MCTS) and the DSO interface (PGUI) allowed to validate various use cases of direct controllability. Through standard Modbus communication, the DSO was able to perform real-time monitoring and modulation of the charging process in both AC and DC modes with the MCTS emulator. These scenarios showed that EV charging stations can be actively managed as flexible grid assets, supporting operational needs such as congestion management and load modulation.

In the Menorca Demo Lab, the focus shifted to the communication chain between the aggregator and the EVSE, mediated by the CPO backend platform. Here, tests verified the configuration of charging assets, the definition of charging needs, and the flow of DR events using standard protocols such as OpenADR and OCPP 1.6J. Several DR use cases were executed, including load modulation in response to predefined flexibility programs, and the system responded as expected, showing that the full chain of backend infrastructure and control logic can reliably deliver flexibility services through connected EV charging stations.

In parallel, the simulated grid scenarios provided insights into the systemic impact of coordinated DR actions. Using a modelled low-voltage grid supplied by a medium-voltage transformer, various scenarios were tested to assess how aggregated EV charging behaviour influences grid stability. In the load congestion use case, demand-side modulation from a growing number of EVs was shown to mitigate local voltage drops. In the frequency support use case, coordinated V2G discharging provided frequency stabilization capabilities. Although simplified assumptions were adopted in the simulation environment, the outcomes demonstrate the technical potential of EV-based flexibility services at large scale.

Looking ahead, future developments may focus on extending the tested system architectures to real-world environments, assessing their robustness under operational variability and broader user participation. There is also potential to explore integration with market-based mechanisms for flexibility, enabling scalable deployment of DR programs across larger fleets of electric vehicles. Further efforts could aim to enhance interoperability, optimize control algorithms, and evaluate user acceptance, ultimately supporting the transition toward a more flexible and intelligent energy ecosystem.


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