Implementation of solution V1.0

Deliverable D6.2

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EXECUTIVE SUMMARY

This report (deliverable) named D6.2 Implementation of solution is deliverable of WP6 within InterFlex H2020 (project co-founded by the European Commission). CEZ Distribuce as WP6 leader performing demonstration of innovative smart grid solutions in order to increase DER hosting capacity, integrate EV charging stations and home energy storage systems more effectively and thus cover important challenges of European DSOs.

The use cases demonstration is performed under the coordination and management of CEZ Distribuce. Partners involved in the WP6 are Austrian Institute of Technology (AIT), CEZ Solarni, Fronius, Schneider Electric and Siemens.

As it is stated in GA in Description of Work (DoW), D6.2 Implementation of solution contains information about implementation process of all technical solutions of all use cases (UC1, UC2, UC3, UC4) which are described in deliverable D6.1 Design of solutions and also additional lab test results.

This report describes the implementation of solutions for WP6 that were implemented within the project and which are a prerequisite for the demonstration of all use cases. The implementation phase of the Czech Demo (WP6) is now finishing which allows successful demonstration of tested solutions.

After the demonstration and evaluation phase of the project, WP6 results will be reported in D6.3 Demonstration activities results (due date 12/2019). This final deliverable of WP6 will also contain KPIs evaluation and CBA and SRA of demonstrated solutions together with the regulatory framework update recommendations.

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1. INTRODUCTION

1.1. Scope of the document

This document named D6_2_Implementation of solution contains detail description of the implementation of SW and installation of equipment for all WP6 use cases (WP6_1, WP6_2, WP6_3, WP6_4) including lab test reports which are included in separate annexes.

1.2. Notations, abbreviations and acronyms

The table below provides an overview of the notations, abbreviations and acronyms used in the document.

CBA	Cost Benefit Analysis
DoW	Description of Work
DMS	Distribution Management System
DSO	Distribution System Operator
DER	Distributed Energy Resources
EC	European Commission
EU	European Union
EV	Electric Vehicle
GA	Grant Agreement
HV	High Voltage
KPI	Key Performance Indicator
LV	Low Voltage
MV	Medium Voltage
OLTC	On Load Tap Changer
P	Active power
PCC	Point of Common Coupling
PV	Photovoltaic
Q	Reactive power
RTU	Remote Terminal Unit
S	Apparent power
SGAM	Smart Grid Reference Architecture
SRA	Scalability and Replicability Analysis
SW	SoftWare
U	Voltage
WP	Work Package

Figure 1 – List of acronyms

2. IMPLEMENTATION OF SOLUTIONS

The Czech demonstration project WP6 is implemented in several areas in the Czech Republic where CEZ Distribuce operates its distribution networks. The demonstration is not concentrated in one region in order to prove replicability and interoperability of designed solutions. The detail description of use cases is written in previous deliverable D6.1 Design of solutions.

WP6 is implementing 4 use cases:

WP6_1 - Increase DER hosting capacity of LV distribution networks by smart PV inverters
WP6_2 - Increase DER hosting capacity in MV networks by volt-var control
WP6_3 - Smart EV charging
WP6_4 - Smart energy storage

Implementation of solutions and installation of equipment (including SW solutions) took place in below pointed areas:

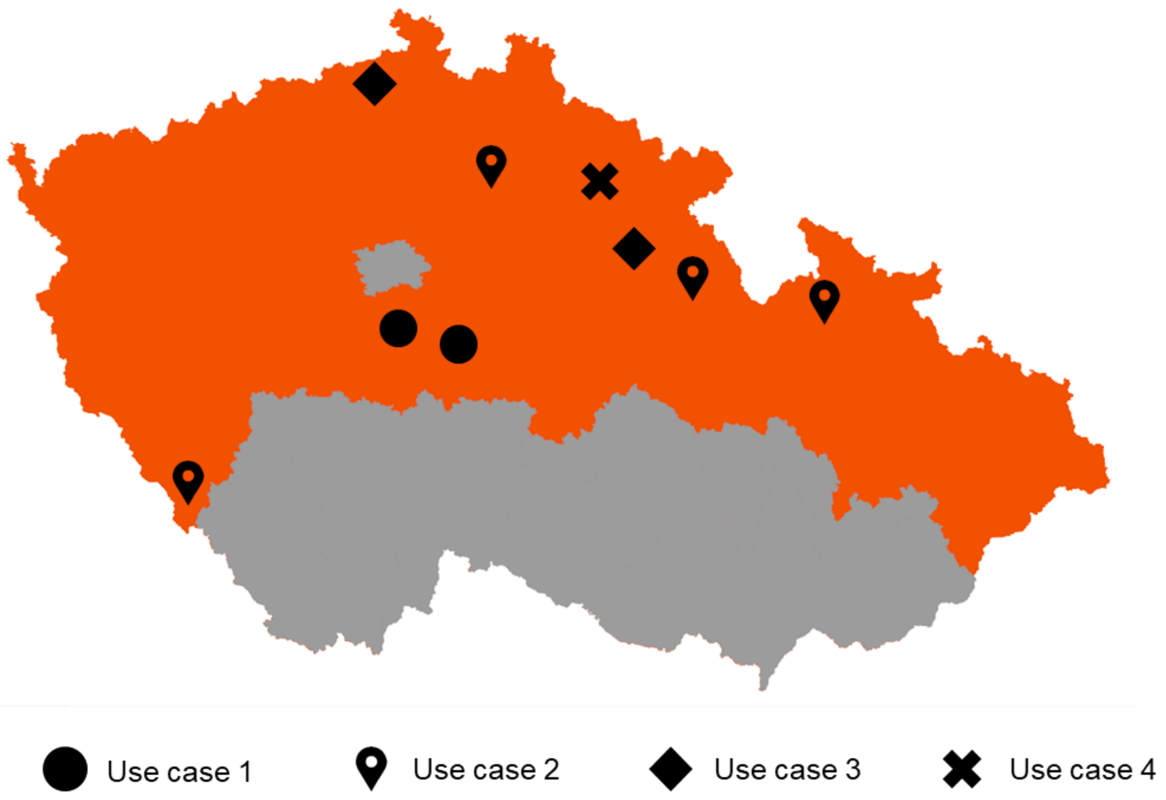

Figure 2 – WP6 demonstration areas in the Czech Republic (CEZ Distribuce regions are coloured in orange)

2.1. Use case WP6_1 - Increase DER hosting capacity of LV distribution networks by smart PV inverters

CEZ Distribuce and its partners aim at demonstrating how the combination of new smart PV inverter autonomous functions Q(U) and P(U), under real operation conditions within LV distribution networks, can increase the DER hosting capacity. A successful demonstration requires appropriate conditions for testing residential PV systems using smart PV inverters (fulfilling the EN 50438 ed.2 standard) installed under preselected MV/LV secondary sub-stations. Areas with different LV network topologies with high penetration of PV systems compared with baseline scenario were needed. In order to obtain high penetration of PV systems in selected different LV networks, CEZ Solarni secured customer recruitment and later installation of rooftop PV systems with smart PV inverters.

Q(U) function – CEZ Distribuce requirements:

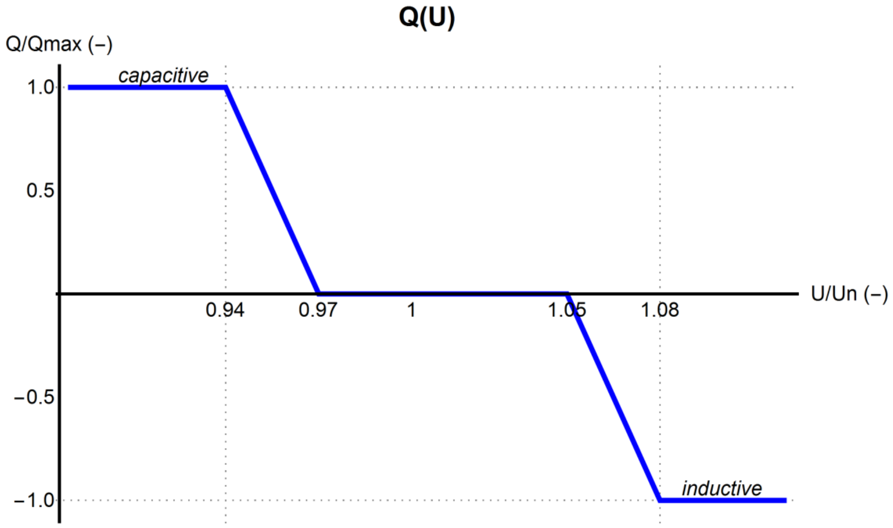

Figure 3 - Autonomous Q(U) function with set points used in WP6

P(U) function – CEZ Distribuce requirements:

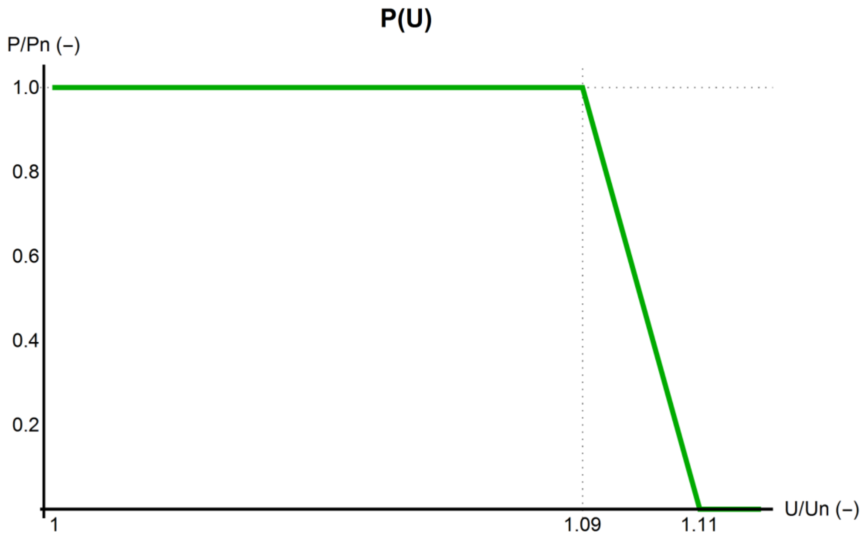

Figure 4 - Autonomous P(U) function with set points used in WP6

For use case WP6_1, CEZ Solarni recruited customers in both selected areas – Divisov and Teptin. The installation of rooftop PV systems with smart PV inverters started in November 2017 and was was finished in June 2018.

Rooftop PV installations included in the project:

Below listed selected customers (please see figure 6) provide sufficient installed capacity of PV systems which is needed for demonstration of WP6 solution and KPIs fulfilment in both areas (Divisov and Teptin). The reason is that existing DER hosting capacity in selected areas is very low due to very long LV feeders with very thin cross sections of cables/overhead lines. Divisov area has app. 600 m long LV feeder with 50AYKY50 cable at the end of the feeder. Teptin has app. 530 m long LV feeder with 25AYKY25 at the end of the feeder. Methodology for hosting capacity calculation is defined by Czech grid code ("Pravidla Provozovani Distribucni Soustavy" or "PPDS"). For LV networks the main constraint is usually the voltage increase caused by generators and the maximum limit based on voltage value before and after connection in PCC is set to 3% according to the grid code. CEZ Distribuce within InterFlex project allowed connection of more PV installed capacity compared with existing grid code as it is shown in the table below.

	Hosting capacity calculated according to the Czech grid code [kWp]	Installed capacity of PVs within InterFlex project [kWp]	Voltage increase caused by PVs within InterFlex project (calculated with power factor = 1) [%]
Divisov	38.4	51.4	3.83
Teptin	14.6	25.7	5.03

Figure 5 - Comparison of hosting capacity calculated according to the grid code and real installed capacity in selected areas (for dedicated LV feeders with PV systems)

DER hosting capacity was evaluated in SW DNCalc (reference CEZ Distribuce load flow tool) based on the load flow analysis of selected LV networks. Load flow analysis takes into account all DER installed under selected MV/LV transformer and the topology and all needed parameters of the distribution network.

New PV installations in Divisov area participating in the InterFlex project:

Divisov a)	4.94 kWp (D12)
Divisov b)	4.94 kWp (D14)
Divisov c)	4.94 kWp (D15)
Divisov d)	4.94 kWp (D16)

Figure 6 – New PV systems installed in Divisov area by CEZ Solarni (with ID which corresponds with red arrows in figure 8)

It's also important to mention that in Divisov area (at the selected LV feeder) there is 31.64kWp of installed capacity in old rooftop PV systems which were installed before the InterFlex project and which are not equipped with autonomous Q(U) and P(U) functions, but included in load flow calculations.

Figure 7 – New rooftop PV installations in Divisov area (all in operation)

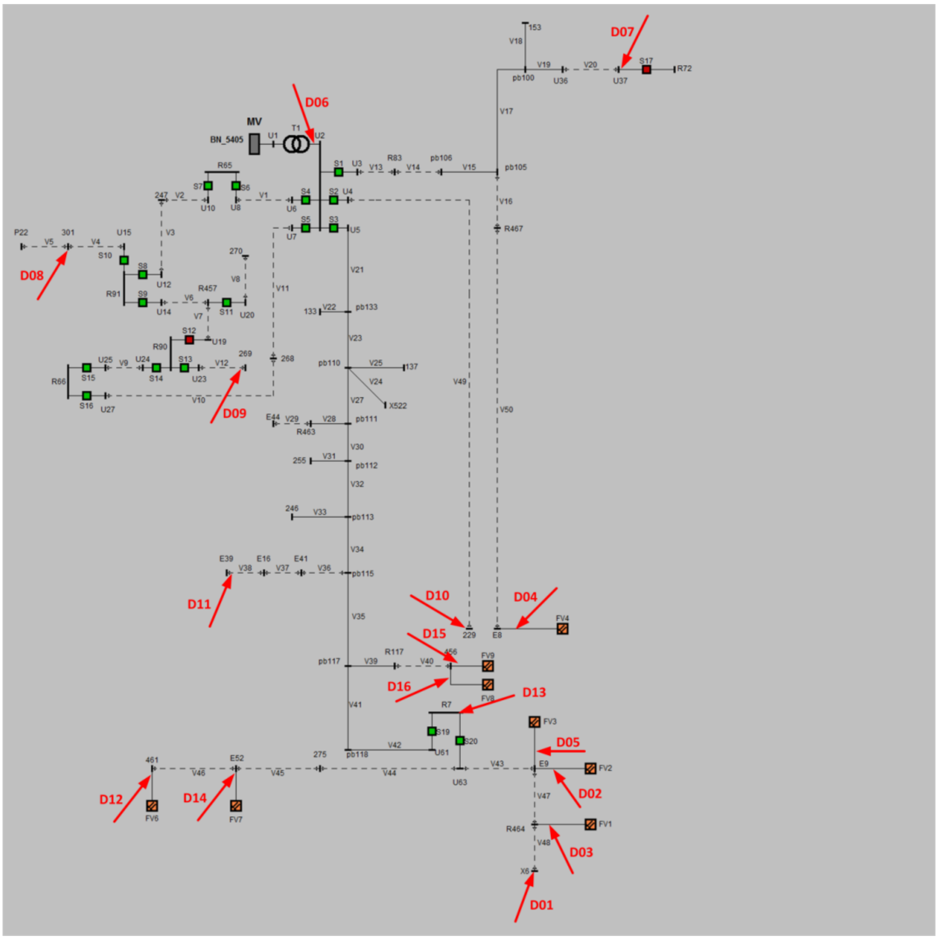

Figure 8 – Use case WP6_1 – LV grid topology in Divisov area (DNCalc model) with marked places for installation power quality measurement devices (red arrows)

Figure 9 – Two of the rooftop PV installations in Divisov area

New PV installations in Teptin area participating in the InterFlex project:

Teptin a)	9.81 kWp (T13)
Teptin b)	9.81 kWp (T14)
Teptin c)	3.12 kWp (T15)
Teptin d)	3.12 kWp (T17)

Figure 10 - New PV systems installed in Teptin area by CEZ Solarni (with ID which corresponds with red arrows in figure 12)

Figure 11 – New rooftop PV installations in Teptin area (all in operation)

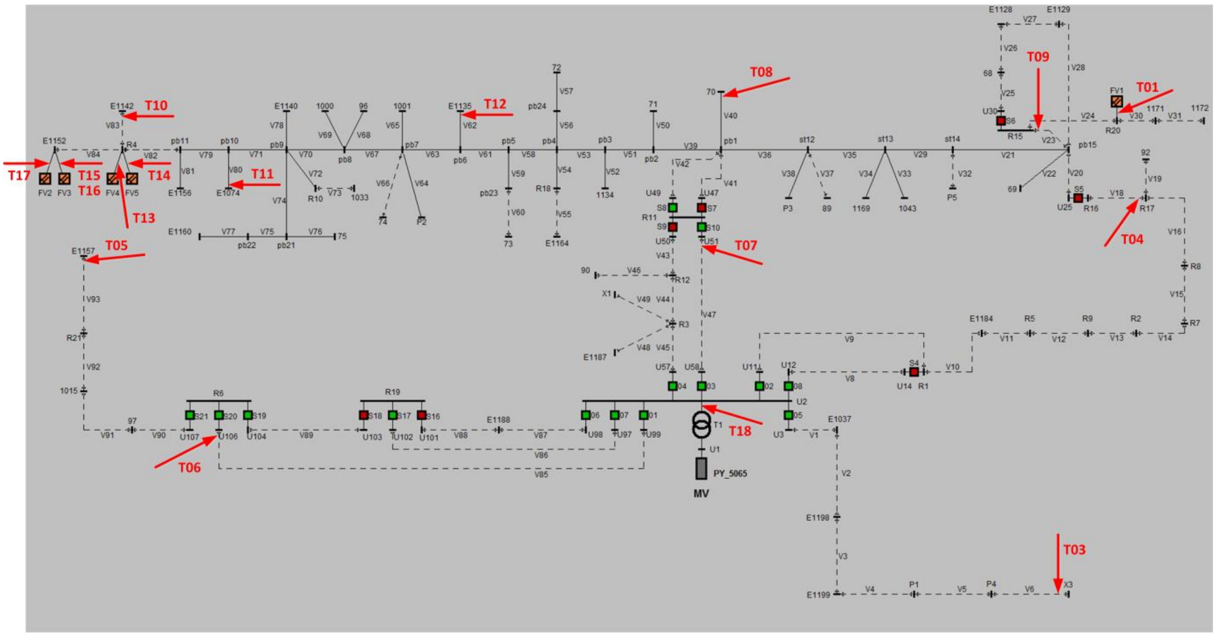

Figure 12 – Use case WP6_1 – LV grid topology in Teptin area (DNCalc model) with marked places for installation power quality measurement devices (red arrows)

Figure 13 – One of the rooftop PV installations in Teptin area

<u>Smart PV inverters used for the demonstration:</u>

Since Schneider Electric Conext RL 3000 inverters are not available on the market any more, all rooftop PV systems in both selected areas under use case WP6_1 were all equipped with Fronius Symo PV inverters. Parametrization of autonomous Q(U) and P(U) functions in all inverters according to the CEZ Distribuce requirements was done manually via display by CEZ Solarni installers during the commissioning of PV systems following the Fronius service manual. CEZ Distribuce supervises the parametrization of autonomous Q(U) and P(U) in order to ensure that there are no mistakes in the settings. Fronius PV inverters are (or will be soon) connected to the Fronius Solar.web portal via internet connection and this data monitoring will help to evaluate and validate the behaviour of autonomous Q(U) and P(U) functions in later stage of the project. Within the InterFlex project, Fronius also developed a new Czech country setup which includes all settings of advanced autonomous functions and electric protections for CEZ Distribuce areas thus significantly reducing the time needed for the commissioning of the devices for future PV installations. This country setup will also reduce the number of incorrect settings caused by the possible lack of experience on the installers' side.

Figure 14 – Fronius Symo smart PV inverter installed in Divisov area (the same type of PV inverters is used on all PV installation in Divisov and Teptin areas which are included in the InterFlex project)

Voltage regulated distribution transformers with OLTC:

In order to have also a consistent field data for evaluation that are not affected by voltage fluctuations on MV, CEZ Distribuce reconstructed the MV/LV secondary substations in both selected areas and equipped them with voltage regulated distribution transformers (OLTC) and advanced power quality measurement devices. Voltage regulated distribution transformer with OLTC could be used for simulating different voltage levels in LV grid in order to check behaviour of Q(U) and P(U) functions in greater detail.

Voltage regulated transformers with OLTC are manufactured and assembled by SGB company, the OLTC regulator and its control unit is manufactured by Maschinenfabrik Reinhausen company. For the remote control towards DSO SCADA, RTU with GPRS/LTE communication is used. Voltage regulated transformers with OLTC installed in Divisov and Teptin area are designed as 22/0.4kV with 400kVA of nominal power and ±4x2 % steps.

Figure 15 – Voltage regulated distribution transformer 22/0.4 kV with OLTC installed in Divisov area

Figure 16 – Voltage regulated distribution transformer 22/0.4 kV with OLTC installed in Teptin area

Three operation modes of OLTC are possible:

a) Remote control from DSO SCADA system by CEZ Distribuce's dispatchers (change of the tap possition)
b) Autonomous regulation based on local voltage measurement (change of the tap so that the voltage set point with the respect of the bandwidth on LV is achieved, voltage set point could be set in wide range, the exact value depends on the DSO requirements)
c) Manual control from the local control unit terminal (change of the tap possition)

CEZ Distribuce's dispatchers could also change the operation mode from remote to autonomous or local control.

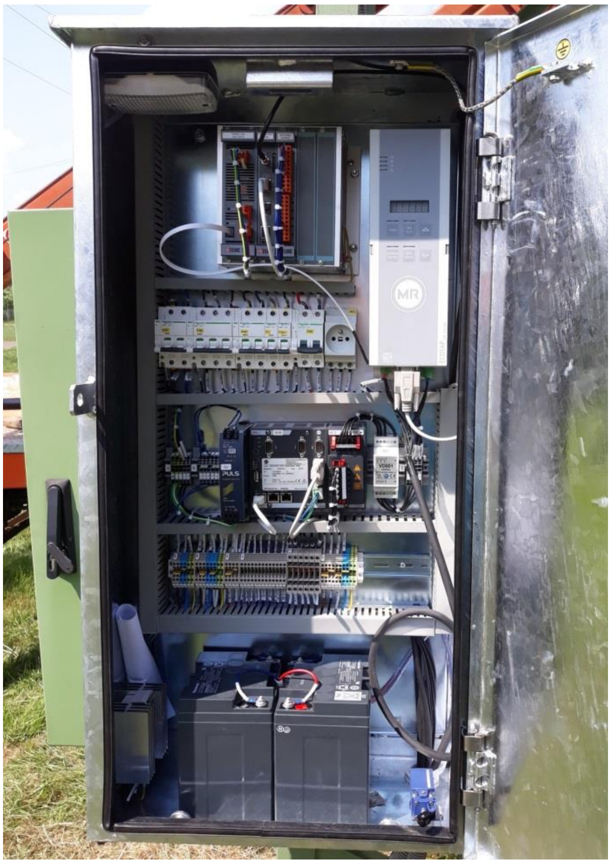

Figure 17 – LV cabinet with RTU and OLTC regulator installed in Divisov area

<u>Power quality measurement for use case evaluation:</u>

Power quality is monitored in the LV grids through DSO power quality measurement devices MEg38 (with online remote data download using GPRS/LTE). Locations where MEg38 power quality measurement devices are installed within use case WP6_1 are shown in figures 8 and 12. MEg38 power quality devices are standard equipment used by CEZ Distribuce for the remote monitoring of the LV distribution grids.

Figure 18 – Meg38 power quality measurement device with GPRS/LTE

2.2. Use case WP6_2 - Increase DER hosting capacity in MV networks by volt-var control

CEZ Distribuce integrates selected DER connected to MV networks into volt-var control system (PV: 1.1MW, biogas station: 1.25MW, wind: 4.6MW and small hydro 6.4 MW). The DSO can send required voltage set points from its SCADA to the DER unit, which then reacts and regulates at the required voltage set points (thanks to reactive power generation/consumption). Further information about UC2 and difference in control strategy compared with UC1 are included in D6.1 Design of solutions. For this volt-var control strategy, CEZ Distribuce leans on existing DER over 100kW with RTU and communication capabilities (usually GPRS/LTE) towards the DSO dispatching control system (SCADA).

Targeted regulation of reactive power by DER could stabilize voltage in MV grid and thus increasing of DER hosting capacity is possible.

In order to demonstrate volt-var control in the MV network, 4 different types of DERs were selected at the beginning of the InterFlex project. The criteria for selection of DERs were the ability to generate/consume reactive power by generators/inverters installed on DERs and willingness of DER owners to cooperate on this topic with CEZ Distribuce under the InterFlex project. DER owners are not project partners, they cooperate on voluntary basis. CEZ Distribuce does not pay any OPEX for this type of volt-var control operation. All DER owners listed below have already confirmed participation in WP6 on volt-var control.

WP6 selected 4 different types of DERs with different technology (wind, PV, biogas and small hydro) in order to prove interoperability of designed solution.

PV Zamberk	1.1 MWp
Wind park Koprivna	4.6 MW
Biogas station Deten-ice	1.25 MW
Small hydro Vydra	6.4 MW

Figure 19 - DERs recruited for volt var control

The installation and commissioning of volt-var control systems at PV Zamberk and Wind park Koprivna was finished in 2017 while small hydro Vydra was retrofitted for this purpose in November 2018. Implementation of volt-var control at biogas station Detenice is expected before the end of 2018.

Once the volt-var control system is implemented, DER installations included in the InterFlex project will be actively participating in voltage regulation on regular basis thus helping to increase DER hosting capacity in selected areas.

Small hydro Vydra 6.4MW:

Figure 20 – Small hydro Vydra 6.4 MW

CEZ Distribuce, as the DSO together with CEZ Obnovitelne zdroje as the owner of small hydro Vydra decided to test volt-var control in order to secure improved integration of the DER to the distribution network. Small hydro Vydra is a specific DER which is normally connected to the HV distribution network 110kV through 110/22/6kV transformer installed in primary substation. However in the case of a 110kV line shutdown, there is a possibility to connect to the distribution network via 22/6kV transformer. In that case, the small hydro causes a very high increase of voltage during its operation. In order to minimize the negative effect of the production on the voltage level, volt-var control system was implemented and commissioned in 2018. The system consists of local control RTU called ARN located in the primary substation which is connected with the local control RTU called SRU which is installed on small hydro side. CEZ Distribuce can send voltage set points from SCADA through ARN to the SRU. Based on the difference between voltage set point and the instantaneous measured voltage level in 22kV feeder, the SRU sends reactive power set points to the two synchronous generators in order to change their reactive power output and thus regulates the voltage in the 22kV line. This system secures mitigation of high voltage increase caused by small hydro thus increasing of the DER hosting capacity in the area is possible. CEZ Distribuce could also send a reactive power set point in case that small hydro Vydra is connected through the 110/22/6kV transformer. This could be used for losses minimization. Volt-var control system at primary station and small hydro was implemented by EGÚ Praha Engineering, a.s. company. Diagrams, load flow model, figures of ARN and SRU devices and SCADA command window for volt-var control are listed below.

Figure 21 – Small hydro Vydra 6.4 MW – 2 generators which are used for volt/var control (nominal installed power of each generator is 3.2 MW)

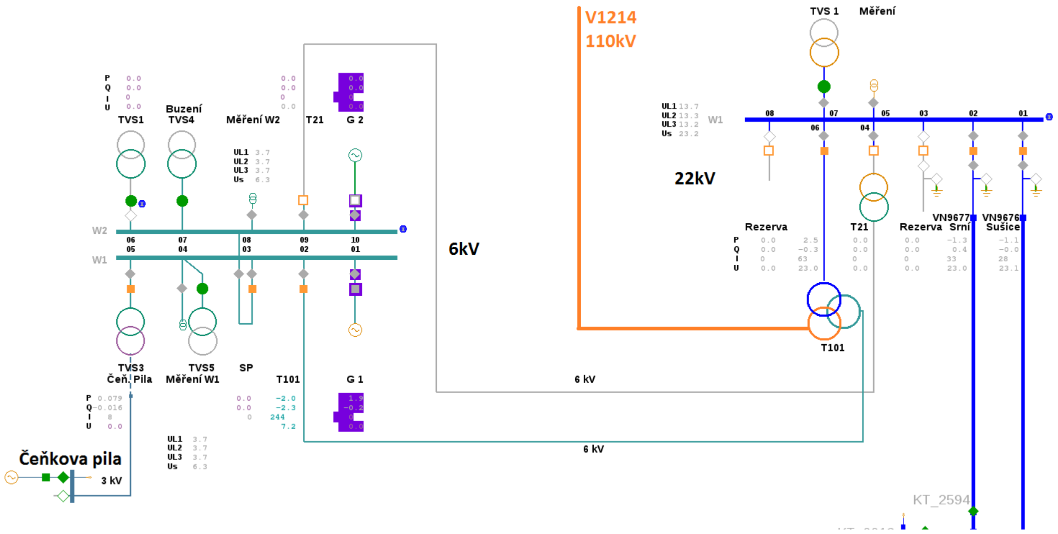

Figure 22 – Single line diagram for small hydro Vydra 6.4 MW connected to the HV or MV distribution network

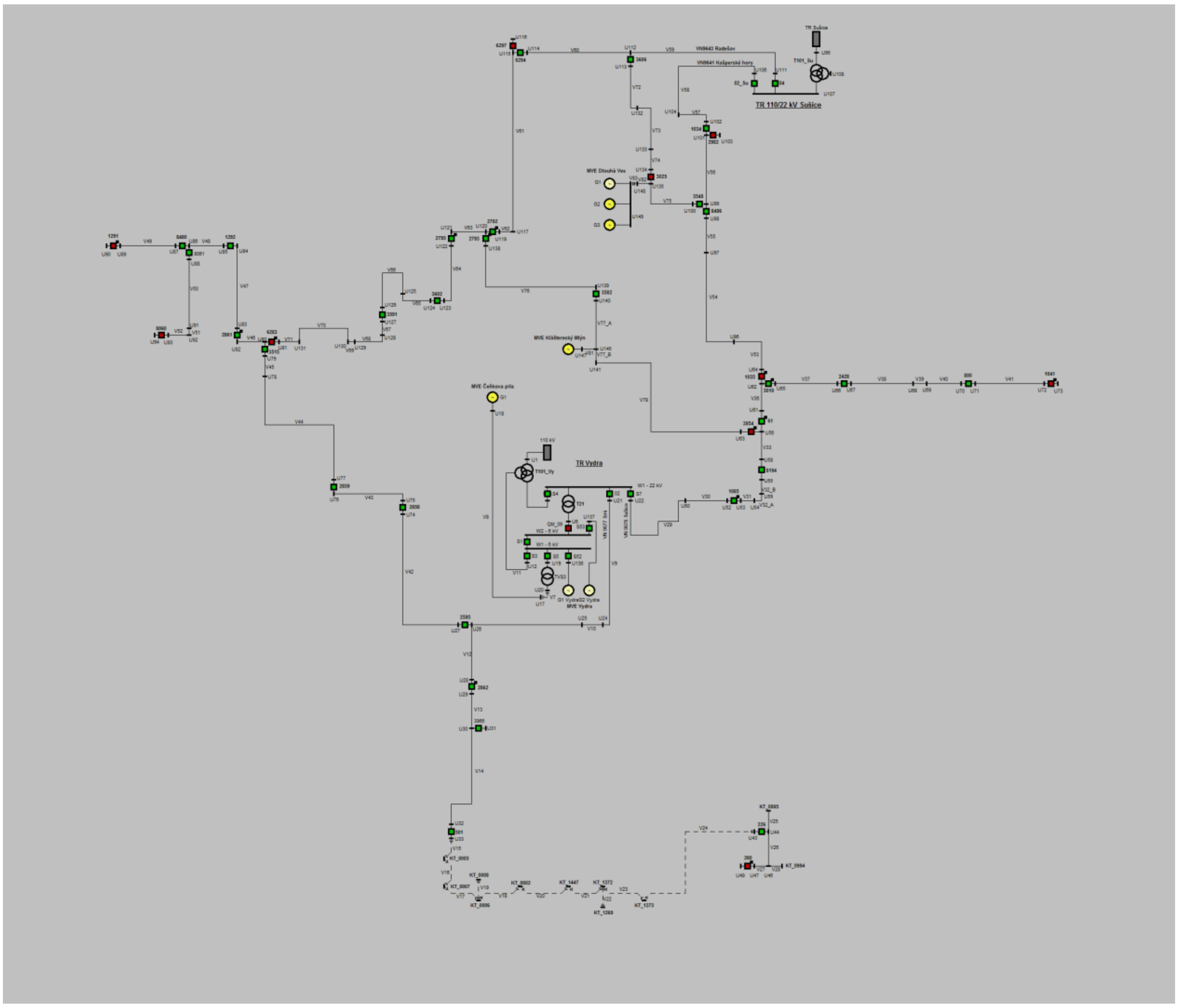

Figure 23 – Topology of HV and MV distribution network where small hydro Vydra 6.4 MW is connected (DNCalc model)

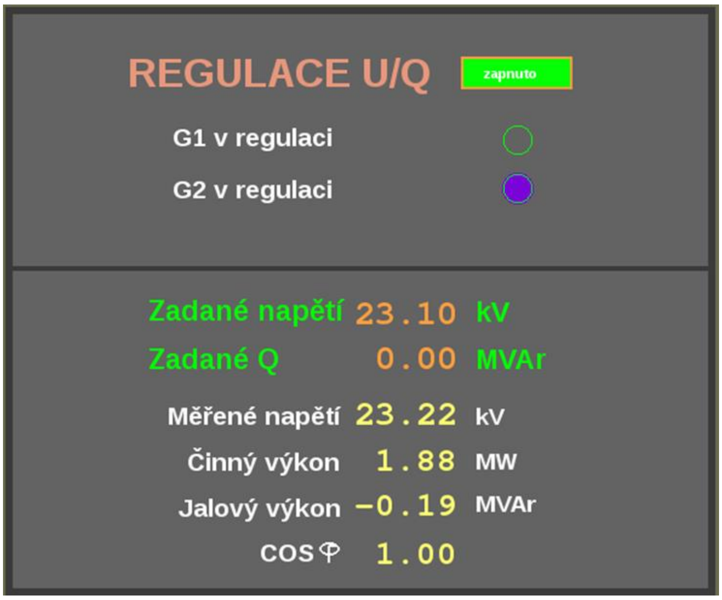

Figure 24 – CEZ Distribuce DMS (SCADA) – command tool for volt-var control for small hydro Vydra 6.4 MW

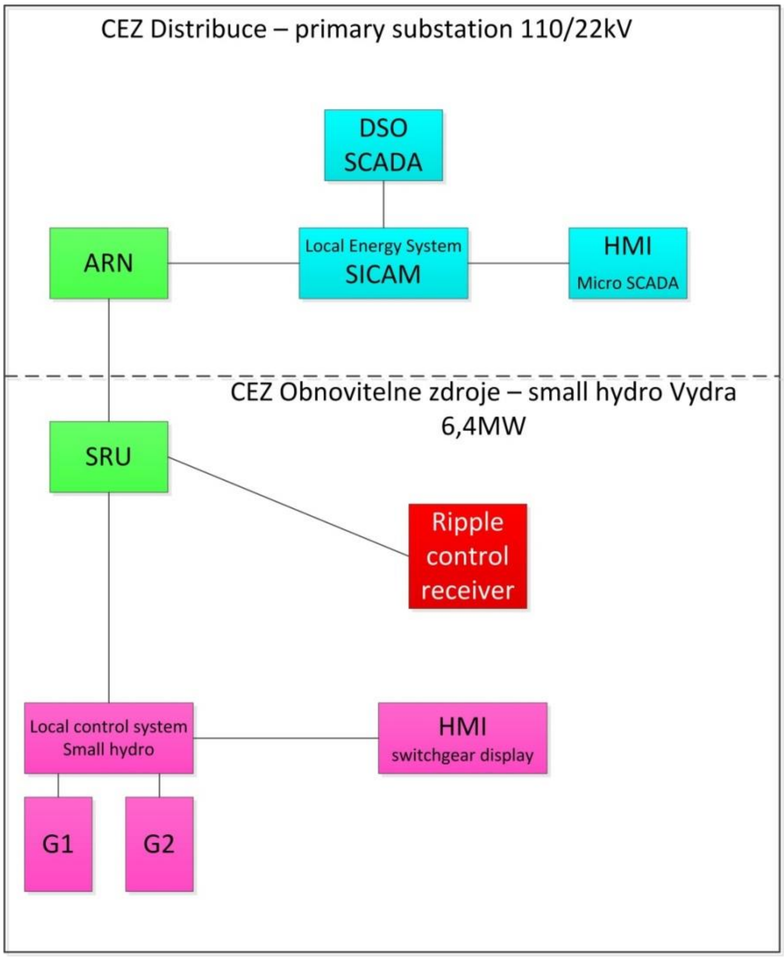

Figure 25 – Topology of control systems for volt-var control at small hydro Vydra 6.4 MW

Figure 26 – CEZ Distribuce – local control system ARN (master) used for sending commands towards volt-var control system (SRU) at small hydro Vydra 6.4 MW

Figure 27 – CEZ Obnovitelne zdroje – local control system SRU (slave) used for volt-var control at small hydro Vydra 6.4 MW

<u>PV Zamberk 1,1MWp:</u>

PV Zamberk is a solar park connected to the 35kV distribution network. PV is equipped with SMA central inverters which are able to provide reactive power. Volt-var control system on this PV consists of algorithm in local RTU which has a GPRS/LTE communication towards DSO SCADA. Via this connection, CEZ Distribuce is able to send voltage set points. Local RTU determines and then sends power factor set points to the central SMA inverters in order to secure regulation of the voltage in the network based on the voltage set point. Volt-var control system on PV Zamberk was implemented by CEZ Solarni who is a project partner. Diagrams and load flow model are listed below.

Figure 28 - PV park Zamberk – 1.1 MWp of installed capacity

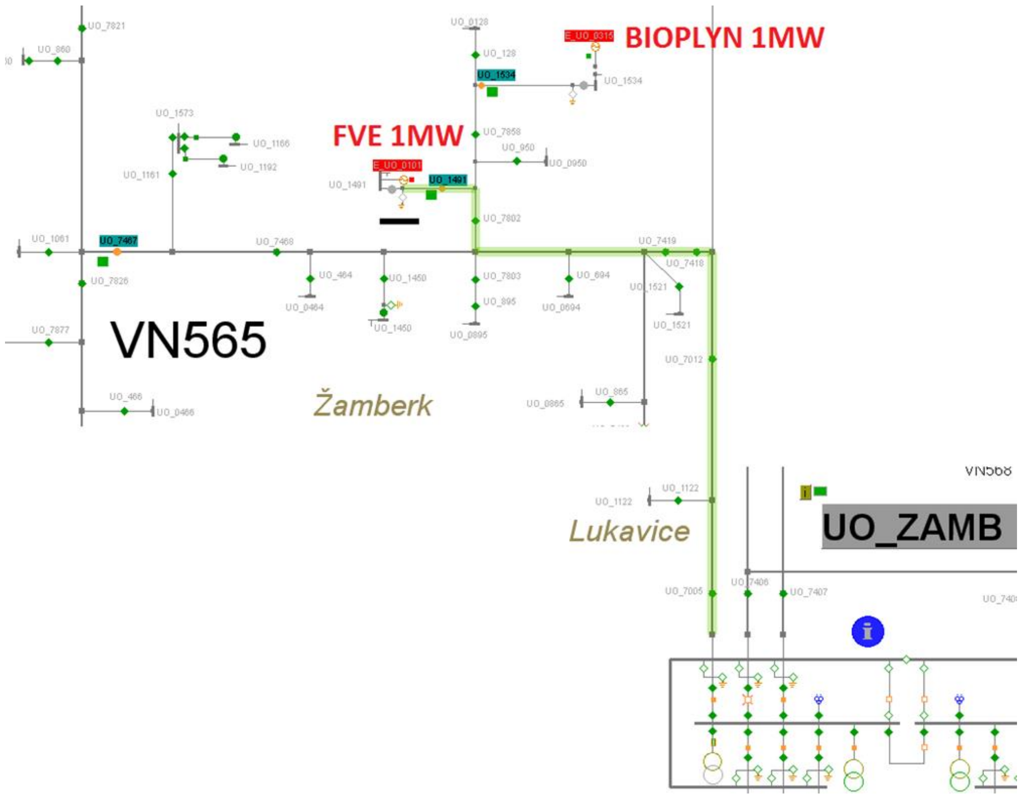

Figure 29 – Single line diagram for PV Zamberk 1.1 MWp connected into the MV distribution network

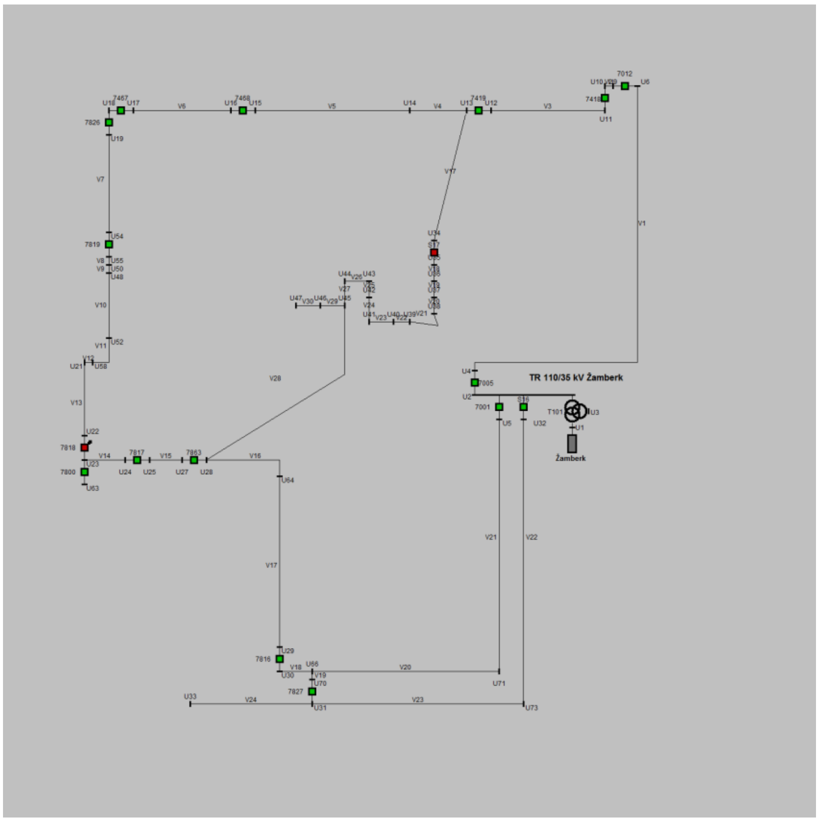

Figure 30 – Topology of MV distribution network where PV Zamberk 1.1 MWp is connected

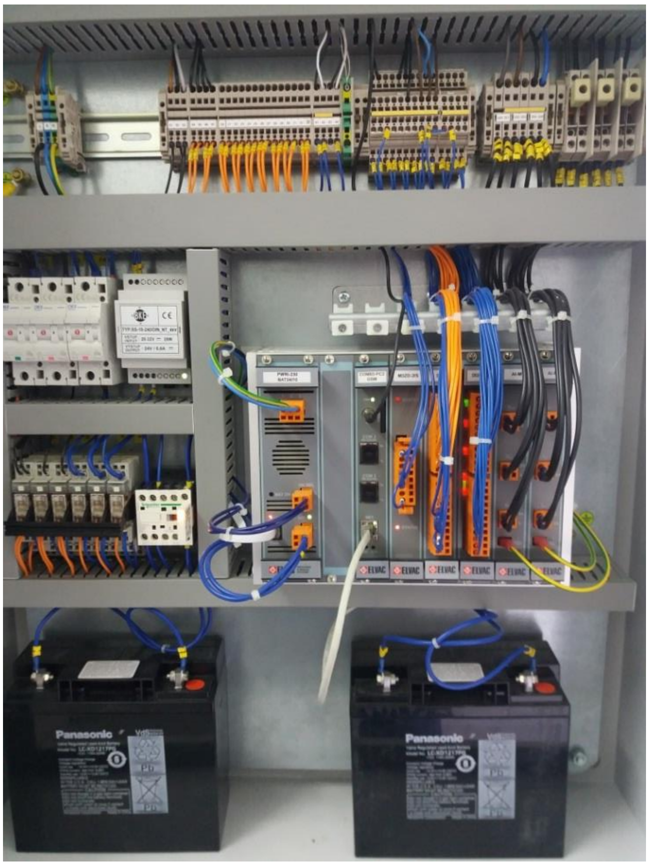

Figure 31 – PV Zamberk 1.1 MWp - LV cabinet with RTU which has GPRS/LTE connection towards CEZ Distribuce SCADA and which includes volt-var control algorithm

<u>Wind park Koprivna 4.6 MW:</u>

Wind park Koprivna is connected to the 22 kV distribution network. Wind park is equipped with two wind generators which are able to provide reactive power. Volt-var control system on this wind park consists of local RTU which has a GPRS/LTE communication towards DSO SCADA. Via this connection, CEZ Distribuce is able to send voltage set points. Local RTU has also connection towards local volt-var control RTU which determines and then sends reactive power set points to the control system of the generators in order to secure regulation of the voltage in the network based on the voltage set point. Volt-var control system on wind park Koprivna was implemented by EGÚ Praha Engineering, a.s. Diagrams and load flow model are listed below.

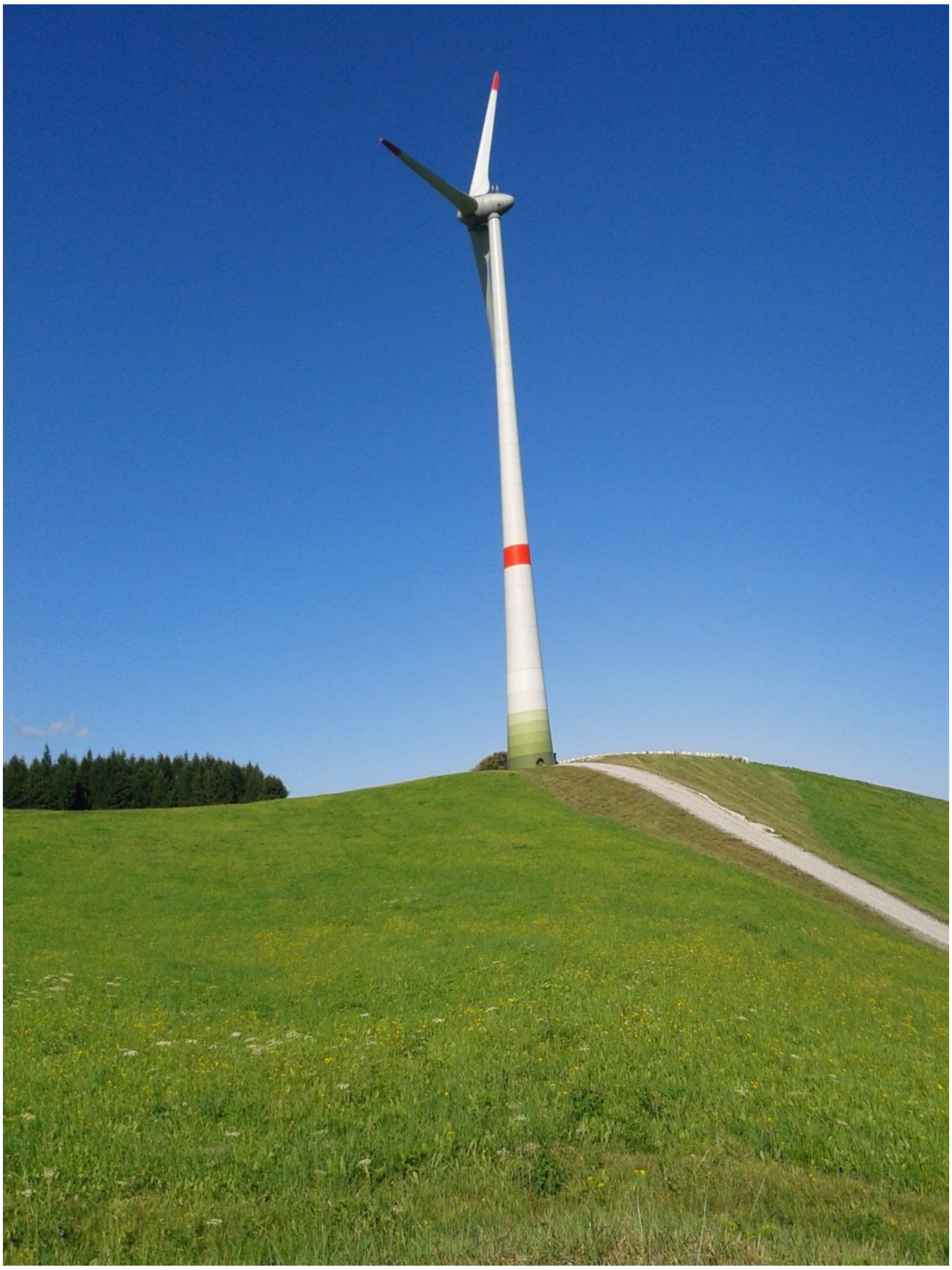

Figure 32 - wind park Koprivna – 4.6 MW of installed capacity

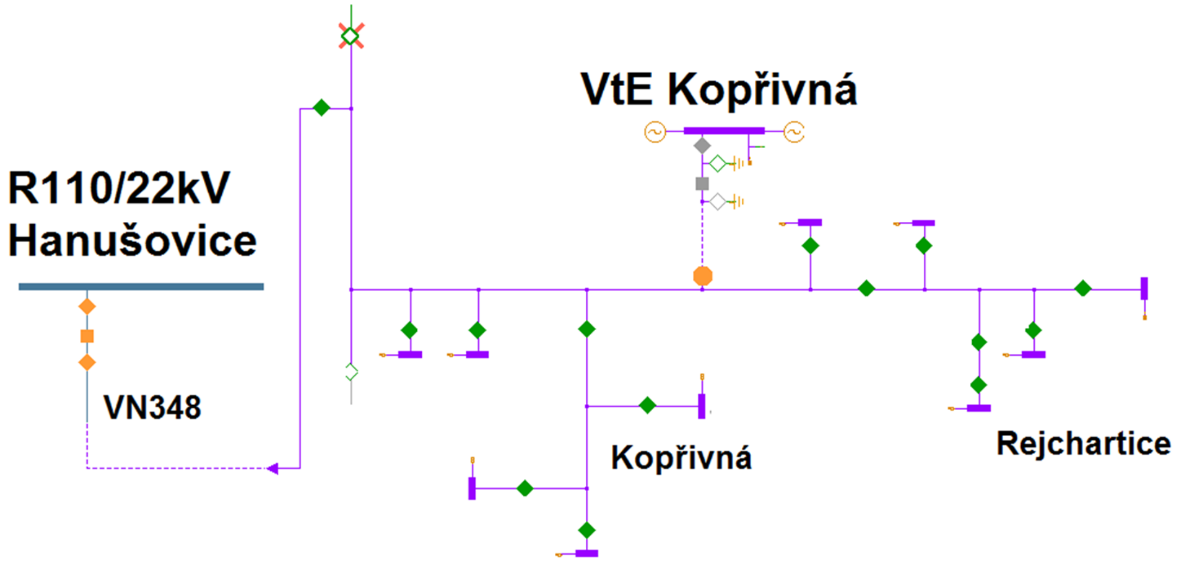

Figure 33 – Single line diagram for wind park Koprivna 4.6 MW connected into the MV distribution network

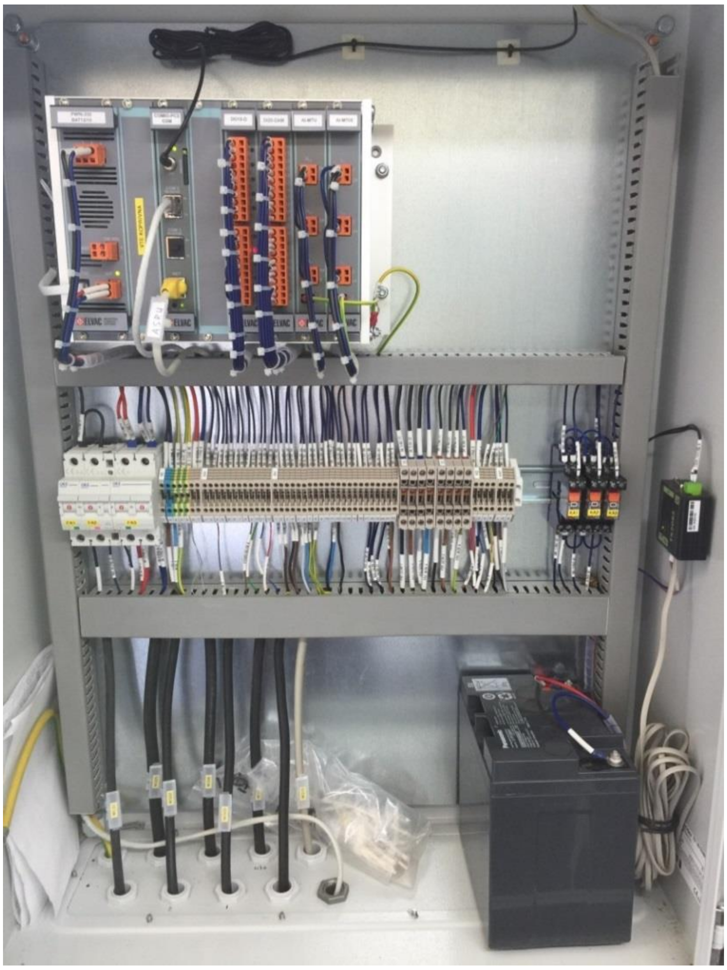

Figure 34 – wind park Koprivna 4.6 MW - LV cabinet with RTU which has GPRS/LTE connection towards CEZ Distribuce SCADA and RS485 connection with control system which secures volt-var control at targeted voltage set point

Figure 35 – wind park Koprivna 4.6 MW - LV cabinet with control system which control reactive power of wind park generators and which secures volt-var control at targeted voltage set point

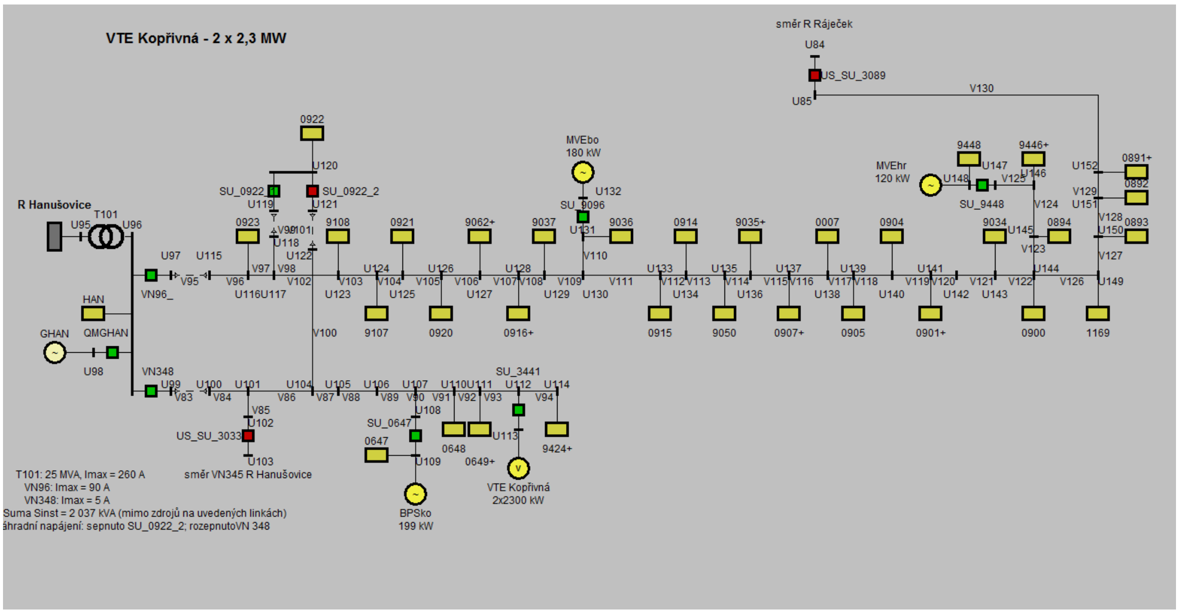

Figure 36 – Topology of MV distribution network where wind park Koprivna 4.6 MW is connected (DNCalc model)

Biogas Detenice:

Biogas station Detenice is connected to the 35 kV distribution network and is equipped with four synchronous generators which are able to provide reactive power. Volt-var control system on this biogas station will consist of local RTU which has a GPRS/LTE communication towards DSO SCADA. Via this connection, CEZ Distribuce will be able to send voltage set points. Local RTU has also connection towards local volt-var control system which will determine and then send reactive power set points to the control system of the generators in order to secure regulation of the voltage in the network based on the voltage set point. Volt-var control system on biogas station Detenice will be implemented by the owner of the installation together with its service partners. Diagrams and load flow model are listed below.

Figure 37 - biogas station Detenice – 1.25 MW of installed capacity

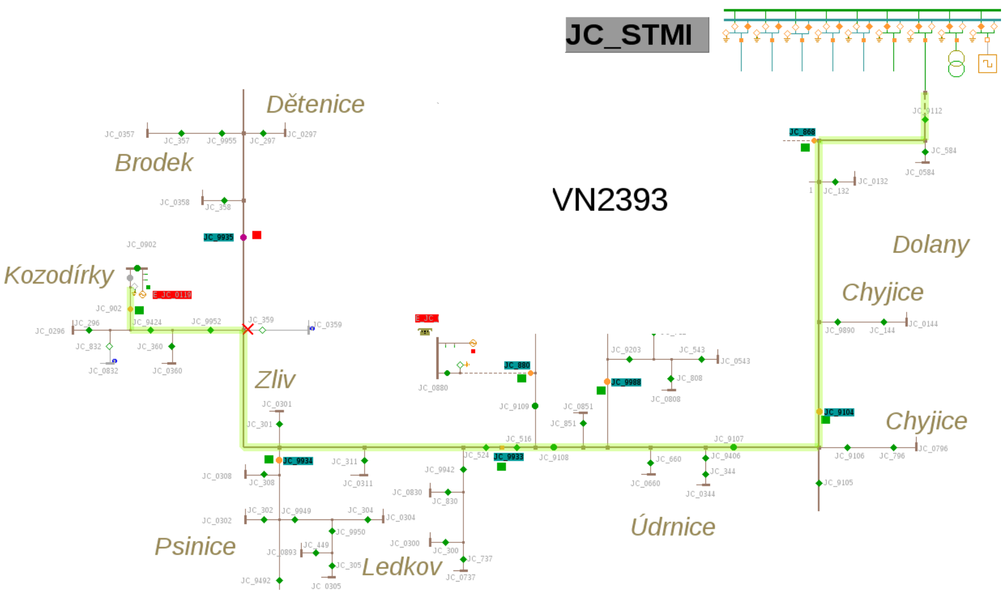

Figure 38 – Single line diagram for biogas station Detenice 1.25 MW connected into the MV distribution network

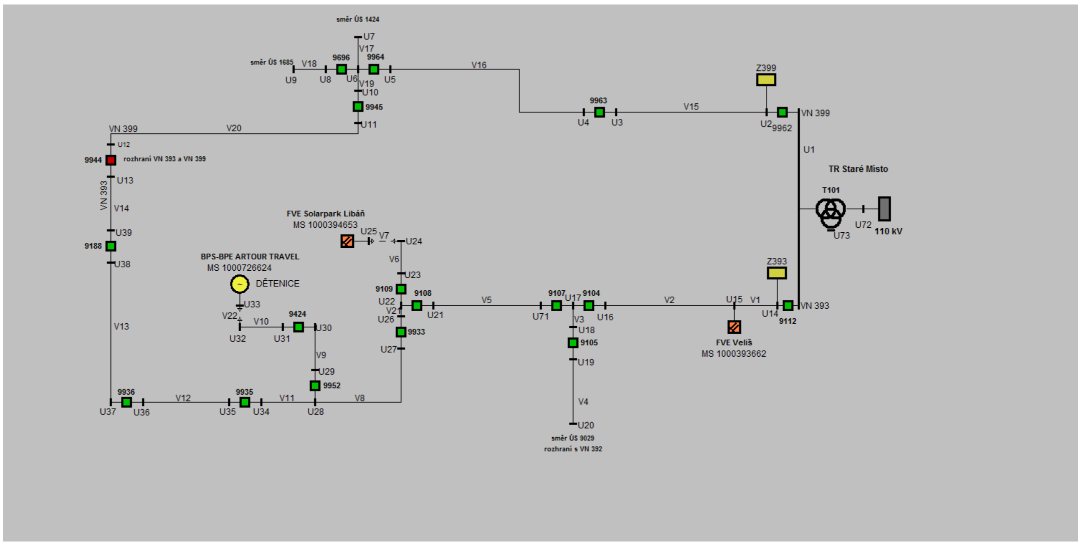

Figure 39 – Topology of MV distribution network where biogas station Detenice 1.25 MW is connected (DNCalc model)

2.3. Use case WP6_3 - Smart EV charging

For the demonstration of EV smart charging concept and its effect on the distribution grid flexibility in case of emergency, CEZ Distribuce installed non-public smart charging stations in two CEZ Distribuce private areas (Hradec Kralove and Decin). Charging stations are used only for charging of CEZ Distribuce EVs because operation of public charging stations is foreseen to be forbidden for DSOs in Europe based on the proposal of the Clean Energy Package (proposal of the European Commission).

Smart charging stations under the use case WP6_3 are installed and implemented according to SGAMs which are described in D6.1 Design of solutions.

Charging stations installed in Hradec Kralove area are provided by Schneider Electric using local RTU with voltage and frequency measurement which has a direct connection with the ripple control receiver in the station. RTU has also direct connection towards digital inputs on both charging stations. Charging stations could be pre-parametrized to reduce its charging power when receiving signal on a dedicated digital input. The first charging station in Hradec Kralove (smart wallbox) has a limitation for charging power set to 0% of nominal power in case of under-frequency, under-voltage or in case of receiving ripple control signal from CEZ Distribuce. In case of need, the EV driver could cancel the limitation of charging power by pressing the dedicated button which is a part of the smart wallbox. The second charging station in Hradec Kralove (EVlink Parking) has the limit set to 50% of nominal charging power for the same conditions (under-frequency, under-voltage or when receiving ripple control signal). Charging stations in Hradec Kralove area were installed and commissioned in January 2018 and since this time the solution is used for the demonstration.

Figure 40- Smart charging stations in Hradec Kralove area provided by Schneider Electric (each with 1 x Mennekes connector 3x32A/400V + home socket 1x10A/230V)

Figure 41- LV cabinet with billing meter, ripple control receiver, RTU and two MEg38 power quality measurement devices in Hradec Kralove

Charging stations provided by Siemens use a local RTU with voltage and frequency measurement which has also a direct connection with ripple control receiver in the station. The Siemens solution uses GPRS/LTE and cloud environments for sending control signal for charging power reduction between RTU and charging station. The charging station in Decin (Ducati) has a limitation for charging power set to 50 % of nominal power in case of under-frequency, under-voltage-frequency or in case of receiving ripple control signal from CEZ

Distribuce. The charging station in Decin area was installed and commissioned in May 2018 and since this time it is used for the demonstration.

Figure 42- Smart charging station in Decin area provided by Siemens with 2 x Mennekes connectors (with 3x32A/400V each)

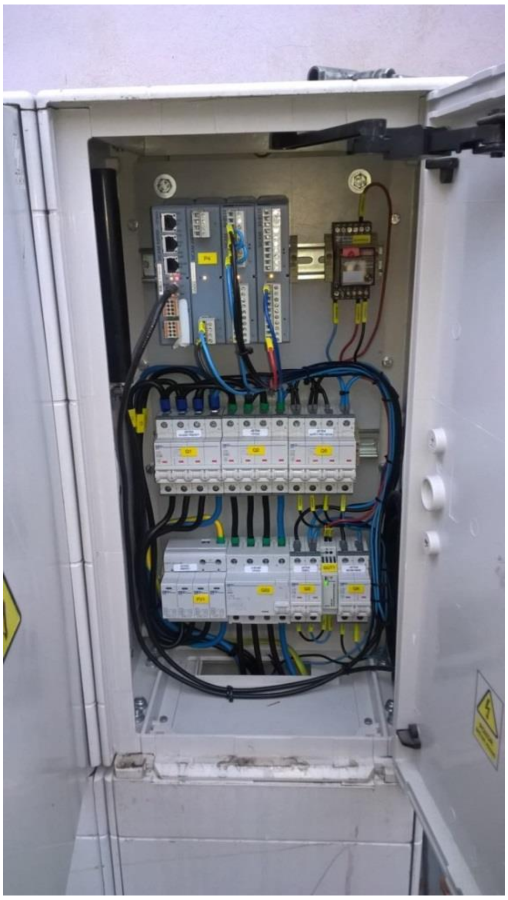

Figure 43- LV cabinet with ripple control receiver and RTU in Decin

All charging stations installed and used within the project are monitored with MEg38 power quality devices with GPRS. Data is used for the evaluation of the demonstration.

2.4. Use case WP6_4 - Smart energy storage

CEZ Distribuce and its partners aim at demonstrating how the combination of new smart PV inverters with residential storage batteries, under real operating conditions within LV distribution networks, can increase the DER hosting capacity and flexibility in case of grid constraints. A successful demonstration requires appropriate conditions for testing residential PV systems using smart PV inverters with residential batteries installed under preselected MV/LV secondary substation. Areas with high penetration of PV systems and residential batteries compared with baseline scenario were needed. In order to obtain high penetration of installations in selected LV network, CEZ Solarni secured customer recruitment and later installation of rooftop PV systems with smart PV inverters and residential storage batteries.

<u>Smart energy storage functions which are being implemented:</u>

a) in case voltage in the point of PV inverter + battery connection is lower than predefined value, the PV inverter + battery will discharge – this will help to increase the voltage in the point of connection
b) in case frequency in the point of PV inverter + battery connection is lower than predefined value, the PV inverter + battery will discharge – this will help to increase the frequency
c) in case of emergency, the DSO dispatcher will decide to discharge the battery and sends a command through narrow band simple one way PLC communication, based on that signal, PV inverter + battery will discharge and this will help to reduce load in the selected area. Detail of function is included in attachment
d) Limitation of active power feed-in from the PV system with the battery to the distribution network (limitation is set to 50 % of the PV installed capacity) which increases DER hosting capacity

For use case WP6_4, CEZ Solarni recruited customers in one selected area – Luzany. The installation of PV systems with smart PV inverters and home energy storage systems (batteries) will be finished in 2018 (as it is foreseen according to DoW). However the demonstration already started with systems which are completed and in operation.

<u>Rooftop PV installations included in the project:</u>

Below listed selected customers (please see figure 45) provide sufficient installed capacity of PV systems which is needed for demonstration of WP6 solution and KPIs fulfilment in selected area (Luzany). The reason is that existing DER hosting capacity in selected area is very low due to very long LV feeders with very thin cross sections of cables/overhead lines. LV feeder in Luzany is app. 1000 m long with 25AlFe6_25 at the end of the feeder. Methodology for hosting capacity calculation is defined by Czech grid code ("Pravidla Provozovani Distribucni Soustavy" or "PPDS"). For LV networks the main constraint is usually the voltage increase caused by DERs and the maximum limit is set to 3 % as it is written in grid code. CEZ Distribuce allowed connection of more PV installed capacity compared with existing grid code as it is shown in the table below.

	Hosting capacity calculated according to the Czech grid code [kWp]	Installed capacity of PVs within InterFlex project [kWp]	Voltage increase caused by PVs within InterFlex project (calculated with power factor = 1) [%]
Luzany	21.8	29.1	4.17

Figure 44 - Comparison of hosting capacity calculated according to the grid code and real installed capacity in selected areaa (for dedicated LV feeders with PV systems)

DER hosting capacity was evaluated in SW DNCalc (standard CEZ Distribuce tool) based on the load flow analysis of selected LV networks. Load flow analysis takes into account all DER installed under selected MV/LV transformer and the topology of the distribution network.

<u>New PV installations in Luzany area participating in the InterFlex project:</u>

Luzany a)	5.2 kWp – installation finished (L1)
Luzany b)	5.2 kWp – installation finished (L12)
Luzany c)	5.2 kWp – under construction (L9)
Luzany d)	5.2 kWp – under construction (L15)
Luzany e)	3.7 kWp – under construction (L17)

Figure 45 - Customers recruited in Luzany area (with ID which corresponds with red arrows in figure 47)

Figure 46 - Rooftop PV installations in Luzany area (PV installations marked by orange are in operation, PV installation marked by blue are under construction)

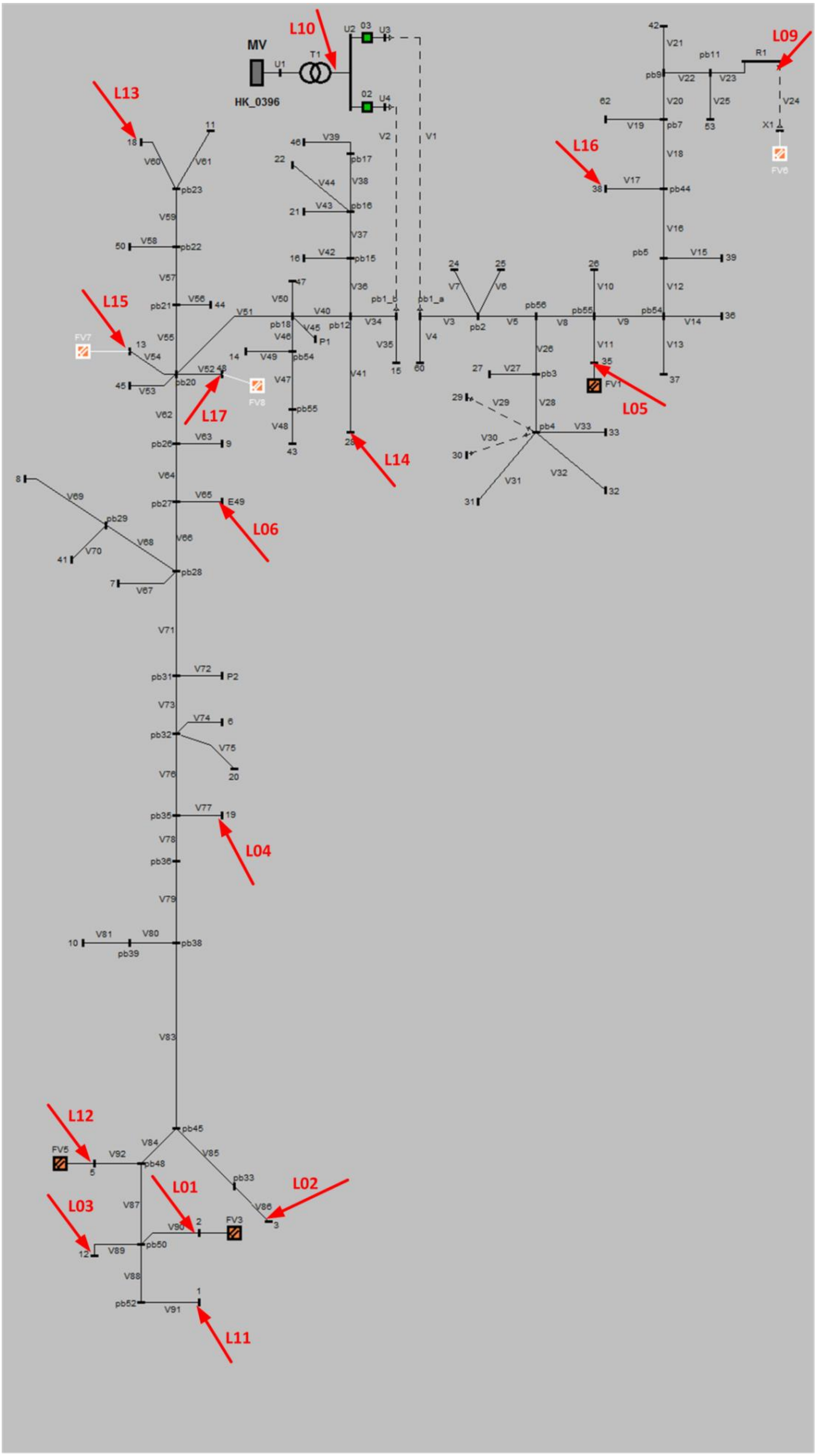

Figure 47 –LV grid topology in Luzany area (DNCalc model) with marked places for installation power quality measurement devices (red arrows)

Figure 48 – One of the rooftop PV with smart energy storage system installed in Luzany area

<u>Smart PV inverters used for the demonstration:</u>

PV inverters from Fronius and Schneider Electric are used for installations. Fronius solution is based on Symo Hybrid 5.0-3-S and Schneider Electric solution is based on Conext XW. Parametrization needed for the demonstration is set manually according to the service manual for both types of PV inverter. CEZ Distribuce supervises the parametrization of functions in order to ensure that there are no mistakes in the settings. Fronius PV inverters are (or will be soon) connected to the Fronius Solar.web portal via internet connection and this data monitoring will help to evaluate and validate the behaviour of tested functions in later stage of the project. Fronius PV inverters are connected to the Fronius 4kWh solar batteries.

Figure 49 – Fronius smart energy storage system (PV inverter, battery) installed in Luzany area

<u>Voltage regulated distribution transformers with OLTC:</u>

In order to ensure a consistent set of field data for evaluation, that are not affected by voltage fluctuations on MV, CEZ Distribuce reconstructed MV/LV secondary substation in selected area and equipped it with voltage regulated distribution transformer (OLTC) and advanced power quality measurement. Voltage regulated distribution transformer with

OLTC could be used for simulating different voltage levels in LV grid in order to check the behaviour of smart functions of energy storage (for example discharge of the battery in case of under-voltage).

Voltage regulated transformer with OLTC is manufactured and assembled by SGB company, the OLTC regulator and its control unit is manufactured by Maschinenfabrik Reinhausen company. For the remote control towards DSO SCADA, RTU with GPRS/LTE communication is used. Voltage regulated transformer with OLTC installed in Luzany area is designed as 35/0,4 kV with 400kVA of nominal power and ±4x2 % steps.

Figure 50 – Voltage regulated distribution transformer 35/0.4 kV with OLTC installed in Luzany area

<u>Power quality measurement for use case evaluation:</u>

Power quality is monitored in the LV grid through DSO power quality measurement devices MEg38 (with online remote data download using GPRS/LTE). Places where MEg38 power quality measurement devices are installed within use case WP6_4 are show on figure 46. MEg38 power quality devices are standard equipment used by CEZ Distribuce for the re-mote monitoring of the LV distribution grids.

3. LAB TESTS

The aim of lab tests at AIT (Austrian Institute of Technology), who is a partner of the InterFlex project, is to test selected devices for use cases WP6_1, WP6_3 and WP6_4. The purpose of the tests are to prove proper functionality and to confirm interoperability which thus secure that solutions are not fit to one manufacturer only and future wide scale implementation by different manufactures and market competition is possible. WP6_2 use case is out of lab test scope (as it is defined in DoW).

As the demonstration of WP6 solutions is foreseen as a dynamic process, testing of other selected devices (or finalization of test reports) for WP6_1, WP6_3 and WP6_4 in 2019 is foreseen (additional testing is confirmed as an amendment of GA). This additional testing will not affect demonstration or KPI evaluation.

Within 2018, AIT did additional testing of Schneider Electric devices under use cases WP6_1 and WP6_3. Tests confirmed that Schneider Electric solutions for both use cases comply with requirements for the demonstration. Detailed test report is included in attachment.

AIT also provided draft of test reports for other devices from Fronius (use case WP6_4), Schneider Electric (use case WP6_4) and Siemens (use case WP6_3). Final reports will be available after the due date of D6.2 deliverable, thus the submission of final results will be included in D6.3 deliverable which due date is in 2019.

4. APPENDICES

4.1. Lab test results UC1 & UC3 Additional document

Project InterFlex
WP6 CZ Demo

Lab test results
UC1 & UC3
Additional Document

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Date: 09.08.2018

Version: 0.3

Revison	Date	Author	Change
0.1	03.07.2018	Catalin Gavriluta	First version with test results
0.2	30.07.2018	Christian Seitl	Added additional details regarding testing procedure and used parameters.
0.3	09.08.2018	Catalin Gavriluta	Included feedback from Schneider

Content

1 Documents

This report is an additional document for the *“Lab Test Results”* document for InterFlex WP6 CZ Demo UC1 and UC3. Since several concerns were raised by the project partners regarding the correct operation of the devices and the consistency of the previously obtained results, additional tests were performed. The testing procedure recommended in the *“Test procedure for the lab tests”* document was followed as closely as possible. However, in some cases, device parameters or settings had to be changed in order to complete the tests. Additional explanations are provided when deviations from the test procedure had to be employed.

2 Testing infrastructure

The detailed information on the equipment used can be found in “*Test procedure for the lab tests*” document for the project InterFlex CZ demo chapter 3.

3 Equipment under test

For the UC1 tests, the device used was the **Conext RL 3000 E**, a single-phase PV inverter. A detailed description of this device can be found in the *“InterFlex CZ Demo Lab tests - Results UC 1”* document. Meanwhile, for the UC3 tests, two devices were used, namely the **Smart Wallbox** and the **EVLink Parking**. Both devices are three phase EV charging station and their detailed description can be found in the *“InterFlex CZ Demo Lab tests - Results UC 3”* document.

4 Results – UC 1

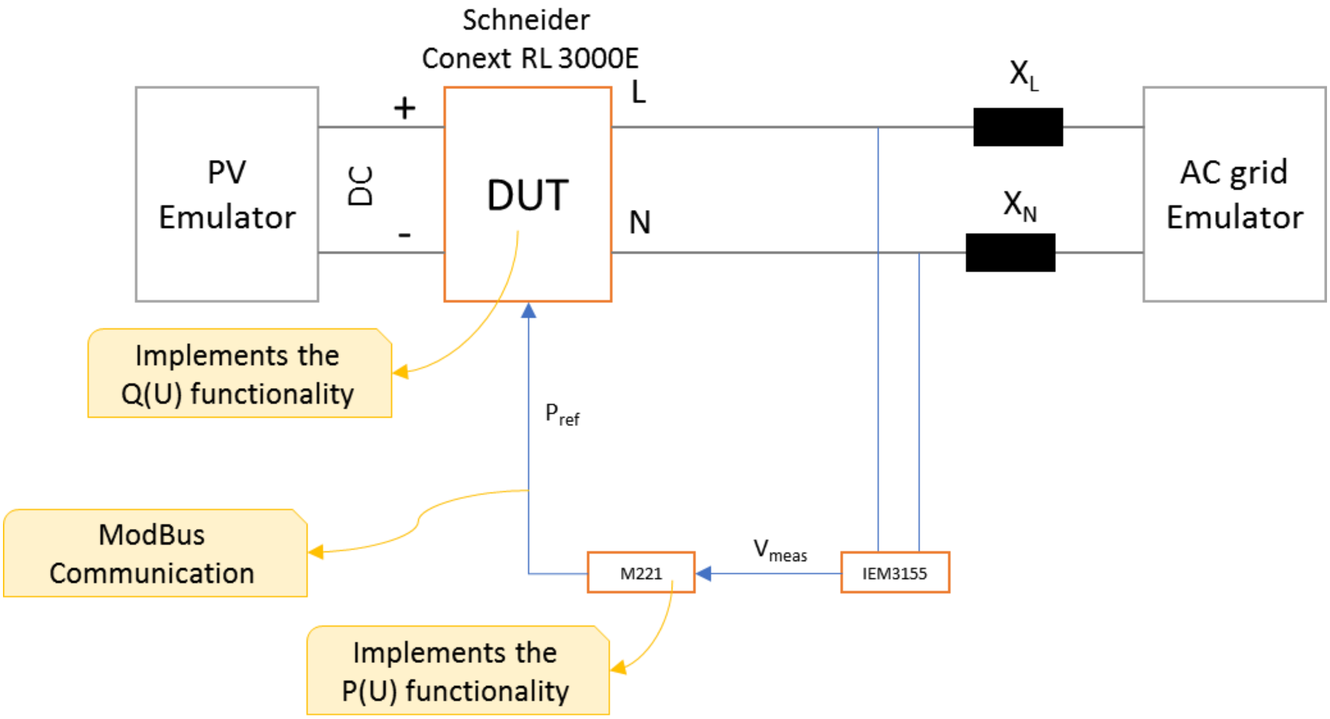

Figure 1 Diagram of the laboratory setup used for evaluating the Schneider Conext RL 3000 single phase PV inverter.

4.1 Establishing the correct settings for Q(U) control

As the correct sign of the reactive power was one of the main concerns in the previous results, we started the tests by first establishing whether the Q(U) controller has been properly configured. In order to verify or disprove this concern, the following procedure was employed:

1. An additional impedance of $X_L = 0.156 + i0.158$ and $X_N = 0.096 + i0.102$ was connected between the inverter and the grid simulator as shown in Figure 1.
2. With the Q(U) control **disabled** the active power of the converter was set to 80% and the difference between the voltage at the inverter's terminals and the voltage at the grid simulator's terminal was noted
3. The Q(U) control was **enabled** with the settings from the last tests via the control panel of the inverter:
    - **Upper: 44% Capacitive**
    - **Lower: 44% Inductive**
4. The voltage of the grid simulator was set below the nominal operating band so that the Q(U) control activates.
5. The active power was set to 80% and the two voltages, i.e., the inverter voltage and the grid voltage, were once again monitored.

Measurements showed that instead of increasing the voltage the inverter decreased the voltage even further. Hence, the Q(U) control was configured wrong.

Thus, the parameters of the Q(U) control were changed to

- **Upper: 44% Inductive**
- **Lower: 44% Capacitive,**

and the steps described above were repeated.

This time, the Q(U) control had the expected effect on the voltage. Therefore, all the following tests were performed with these settings.

4.2 UC1-TC1, P(U) disabled: Characterisation of the control accuracy

As described in the *“Test procedure for the lab tests”* document, in the first test case, the control accuracy of the Q(U) control needs to be evaluated. To this end, two tests were run, i.e., one with the inverter running with an 80% active power reference and one with 100%. For both tests, only the Q(U) control is active and the voltage is varied in steps across the operating region.

Figure 2 and Figure 3 show the results for the test performed at 80% active power. For figures that present multiple plots on the same time axis an additional label is added in order to distinguish between the different subplots. For example, the voltage at the inverter output is shown in the Figure 2a (top subplot of Figure 2) with a solid black line. Horizontal blue dotted lines mark the low and high voltage bands. These are the bands where the Q(U) control should be in the droop area. The solid horizontal red line marks the nominal voltage. Vertical blue dotted lines mark the events when the voltage crosses the band limits. Figure 2b shows the reactive power response of the inverter, and Figure 2c shows the active power.

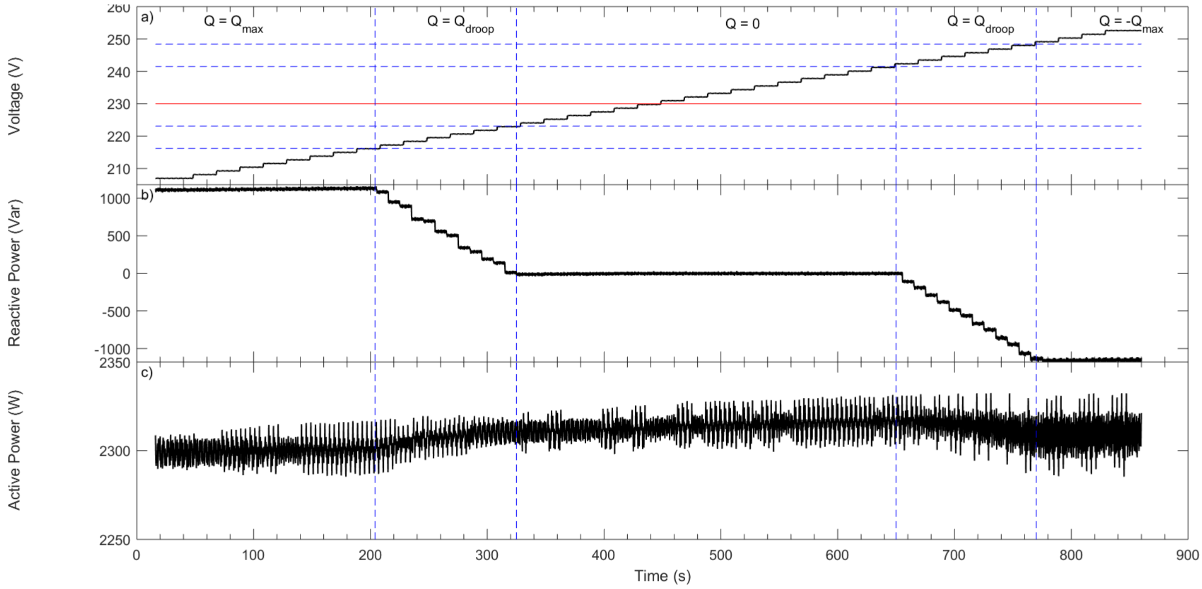

Figure 2 Conext RL 3000 – response to voltage sweep. Voltage, reactive power, and active power time series. P = 80% of the nominal apparent power.

Figure 3 displays the Q(U) characteristic with voltage on the horizontal axis and reactive power on the vertical axis. The dotted red line represents the desired characteristic while the scattered black points represent the real operating points of the converter.

$$\Delta Q = \frac{Q_{act} - Q_{exp}}{S_{max}} \quad (1)$$

The relative difference between the actual reactive power and the expected reactive power can be computed according to equation (1), taken from the evaluation section of UC1-TC1. Using this value, one can calculate the average deviation from the expected value as

$$\Delta Q_{avg} = avg(abs(\Delta Q)) = 3.45\%.$$

The maximum deviation from the expected value is

$$\Delta Q_{max} = \max(abs(\Delta Q)) = 11.14\%.$$

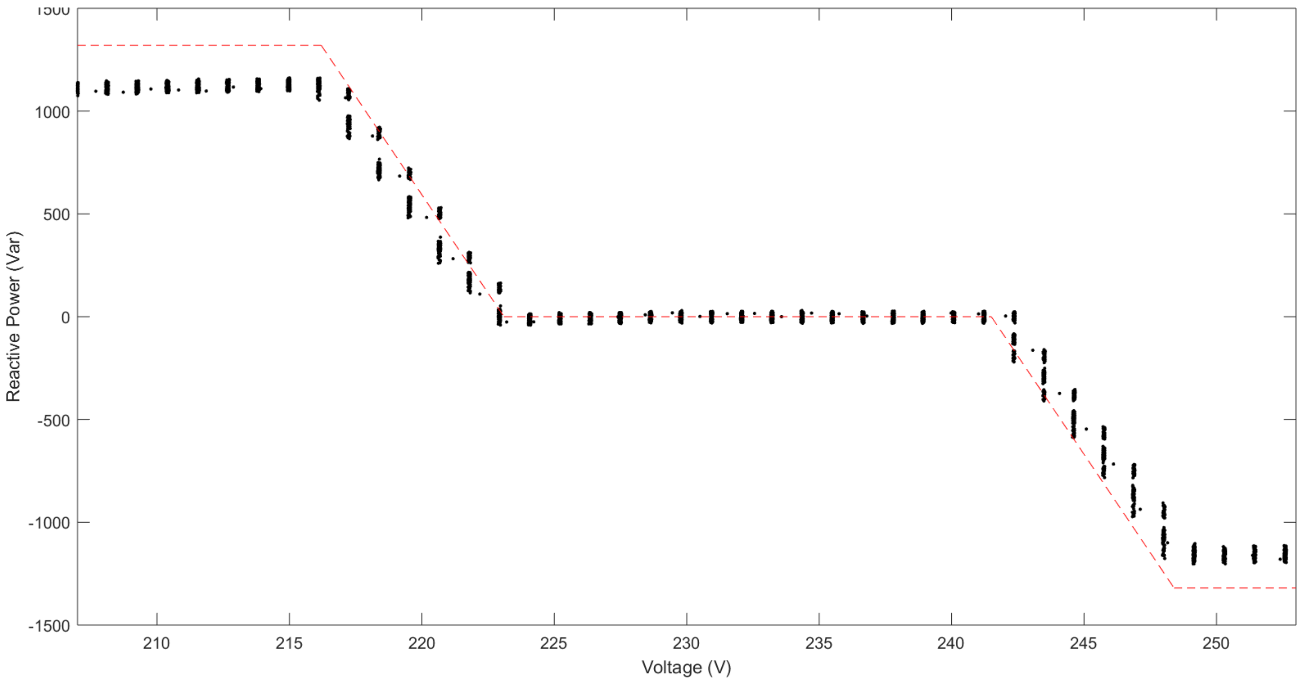

Figure 3 Conext RL 3000 – response to voltage sweep. Droop characteristic. P = 80% of the nominal apparent power.

Figure 4 and Figure 5 display the results for the case with 100% active power. One can see from Figure 4c that when the inverter reaches apparent power saturation, with a priority of reactive power if the voltage is outside the nominal operating band. Using the same formulas as before, the values obtained for the controller accuracy are

$$\Delta Q_{avg} = 3.25\% \text{ and } \Delta Q_{max} = 11.41\%.$$

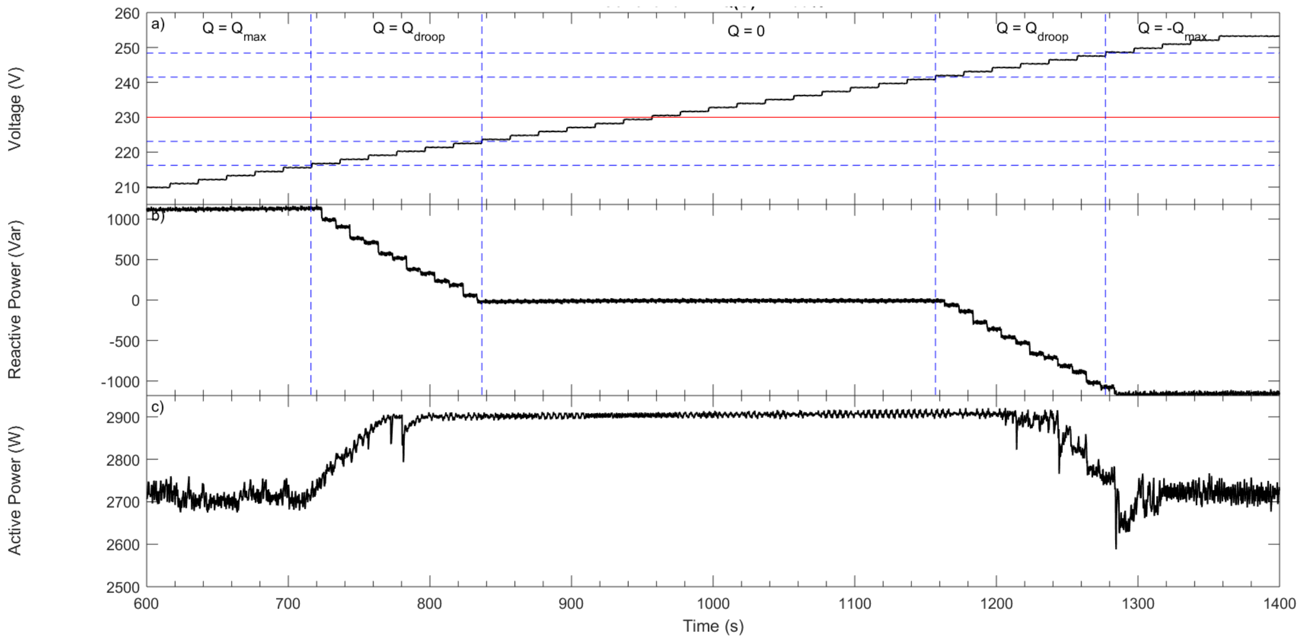

Figure 4 Conext RL 3000 – response to voltage sweep. Voltage, reactive power, and active power time series. P = 100% of the nominal apparent power.

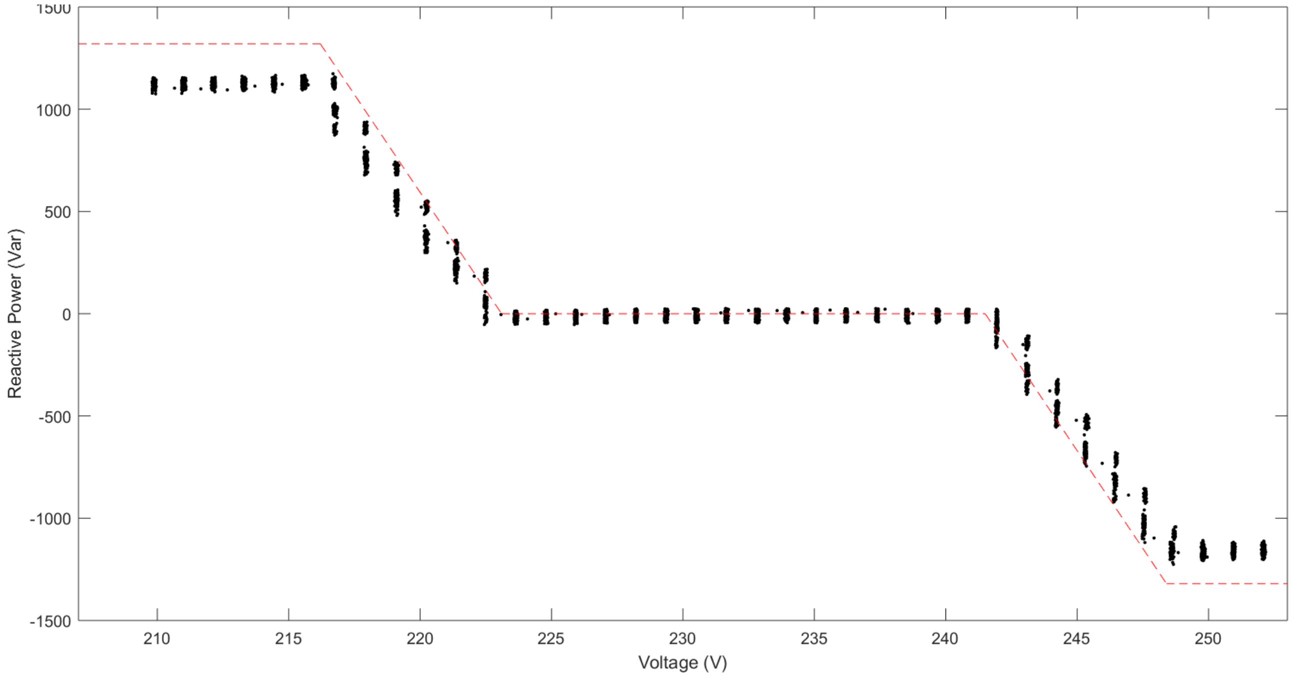

Figure 5 Conext RL 3000 – response to voltage sweep. Droop characteristic. P = 100% of the nominal apparent power.

As can be clearly seen from Figure 3 and Figure 5, it that the inverter does not reach the desired maximum reactive power reference.

One possible explanation for this could be the misguided configuration of the converter. It is not clear from the documentation of the device if the set value of 44% in the control panel is with respect to the nominal apparent power of the inverter, or with respect to its maximum reactive power (which is equal to 80% of the nominal apparent power).

In order to test if the inverter is able to inject more reactive power, the setting for the Q(U) control was increased from 44% to 53%. This is the maximum value that could be set from the control panel and close to the desired reactive power $Q_{max} = 0.43 \cdot S_{nom} \approx 0.53 \cdot 0.8 \cdot S_{nom}$. The results of this test with the active power set at 80% can be seen in Figure 6 and Figure 7. The inverter was able to provide the desired reactive power of 43% of S_{nom}. Hence, an improvement in the controller accuracy can be seen in Figure 7, as well as in the two indicators previously calculated:

$$\Delta Q_{avg} = 1.47\% \text{ and } \Delta Q_{max} = 7.72\%.$$

However, the next test cases where performed with the original setting to follow the specifications of the *"Test procedure for the lab tests"* document.

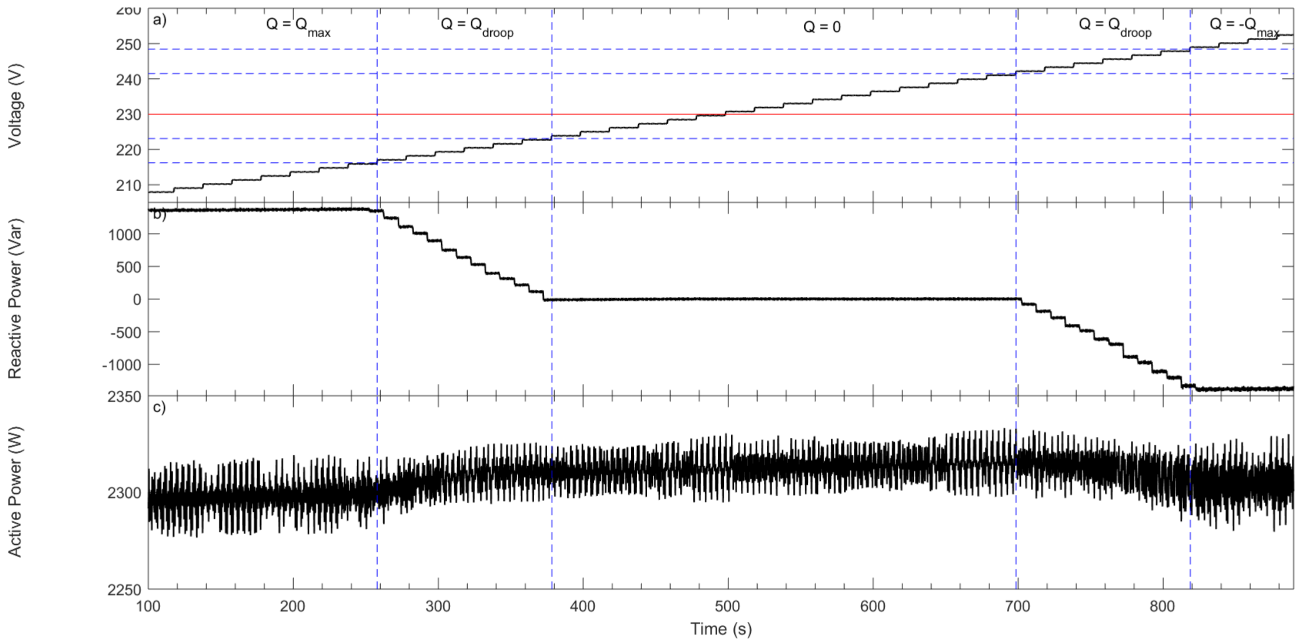

Figure 6 Conext RL 3000 – response to voltage sweep. Voltage, reactive power, and active power time series. P = 80% of the nominal apparent power. The setting for Q_{max}(%) was increased to 53% from the previous value of 44%

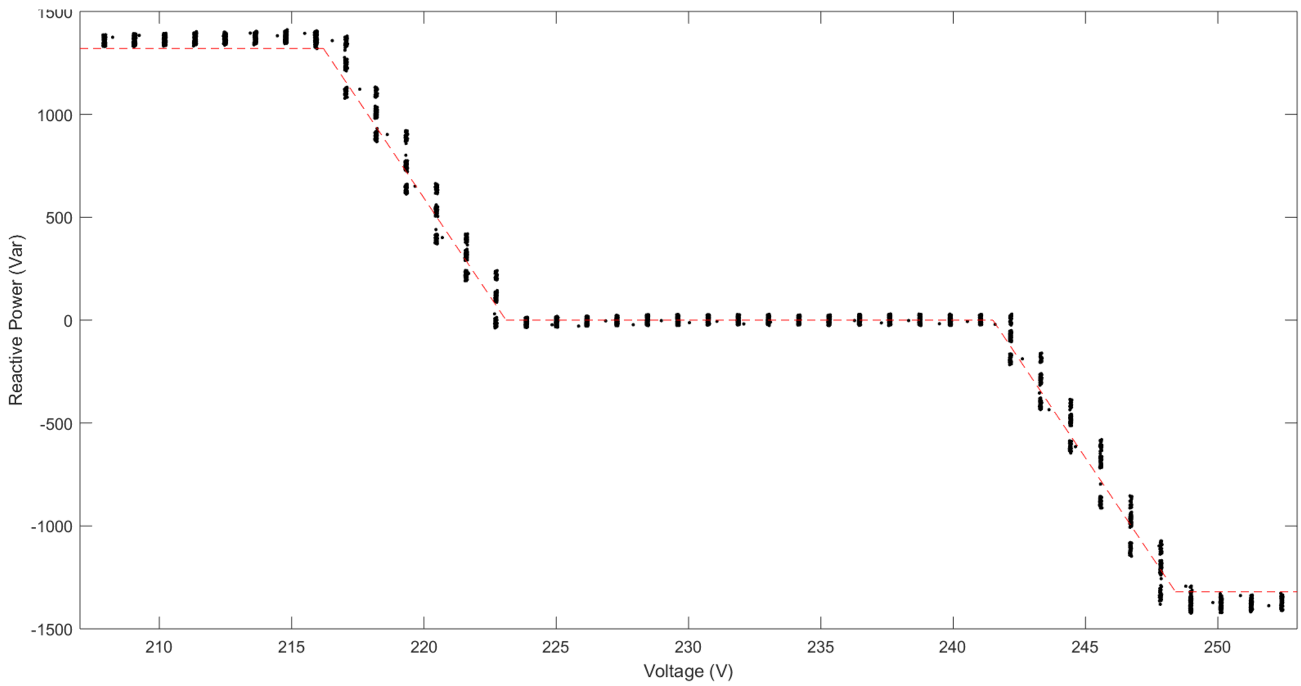

Figure 7 Conext RL 3000 – response to voltage sweep. Droop characteristic. P = 80% of the nominal apparent power. The setting for Q_{max}(%) was increased to 53% from the previous value of 44%

4.3 UC1-TC2, P(U) disabled: Characterisation of the time behaviour

For the second test case, the time behaviour of the Q(U) controller was of interest. For this, several voltage steps in and out of the high and low voltage limits were applied at the inverter output as described in the *"Test procedure for the lab tests"* document. Once again, the tests were performed at 80% and 100% active power reference and the P(U) control was deactivated.

The results for this test are shown in Figure 8 and Figure 9. The signals of interest are presented in the same order and with the same color-scheme as in the previous section.

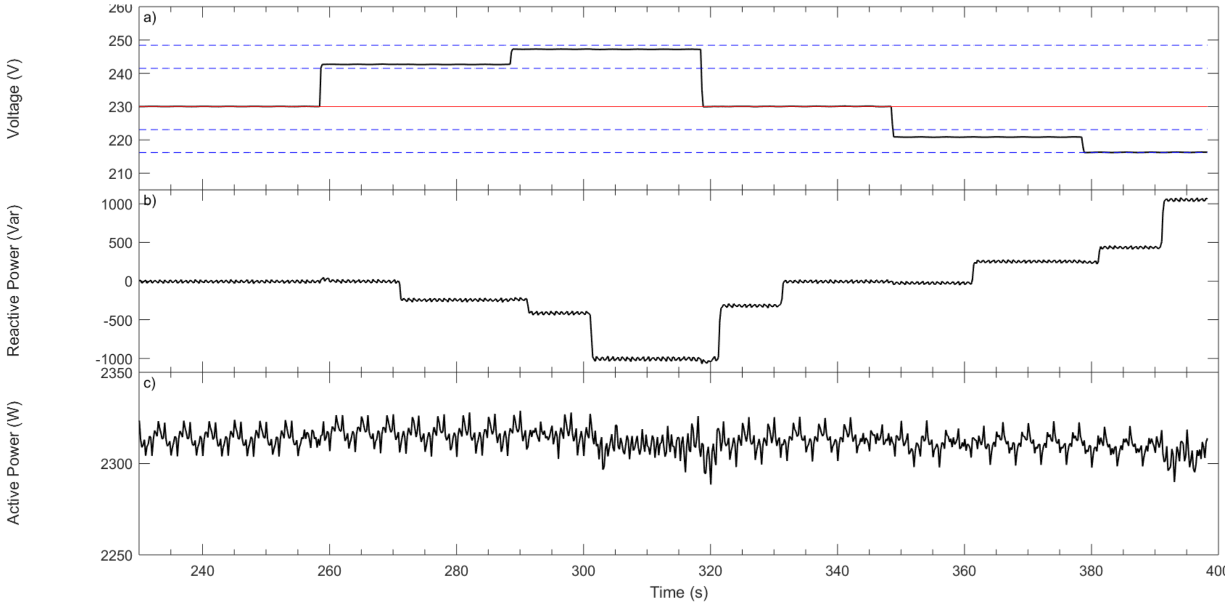

Figure 8 Conext RL 3000 – response to voltage steps. P = 80% of the nominal apparent power.

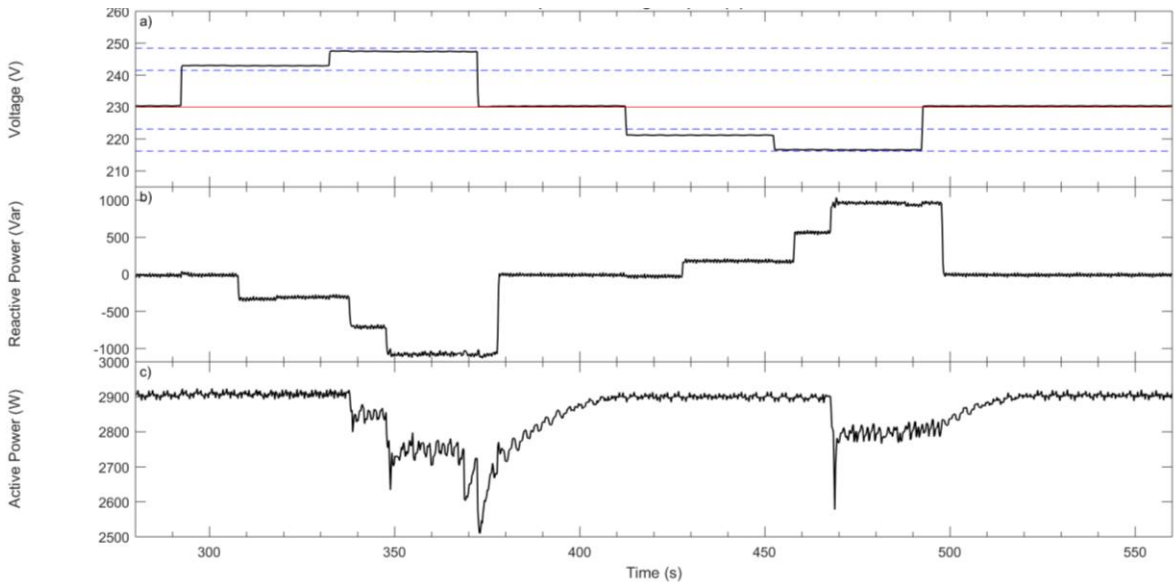

Figure 9 Conext RL 3000 – response to voltage steps. P = 100% of the nominal apparent power.

One thing to be noted is that the inverter changes the reactive power in steps. As can be seen from Figure 8b and Figure 9b, sometimes the inverter will take on step to reach the new setpoint, and at other times it will take two steps to get to the new reference. Also, the time behaviour is different whether the previous operating point was at $Q = 0$ or $Q \neq 0$.

The min, max, and average time difference between the moment the voltage changes and the moment when the reactive power reaches its expected value (±5%) are:

P/S_{nom}	ΔT_{min}	ΔT_{avg}	ΔT_{max}
80%	12.20 s	12.48 s	12.60 s
100%	5.60 s	13.82 s	16.1 s

4.4 UC1-TC3, P(U) disabled: Investigation of the stability under worst-case conditions

Test case 3 investigates the behaviour of the converter under a worst-case condition scenario. The *"Test procedure for the lab tests"* document describes several factors that could have a negative impact on the Q(U) control. Three worst case scenarios were tested:

- An additional impedance between the inverter and the grid,
- steep slope for the droop curve,
- a final case with both these factors enabled.

For the first case, an impedance of $X = X_L + X_N = 0.387 + i1.019$ was connected between the inverter and the grid simulator. Afterwards a voltage step in the upper voltage limit was applied at the inverter output with the help of the grid simulator. As shown in Figure 10 the inverter reaches a stable operating point. In contrast to test procedure document, the step duration was increased since after the proposed 40 s it was not clear whether the operating point stable or not.

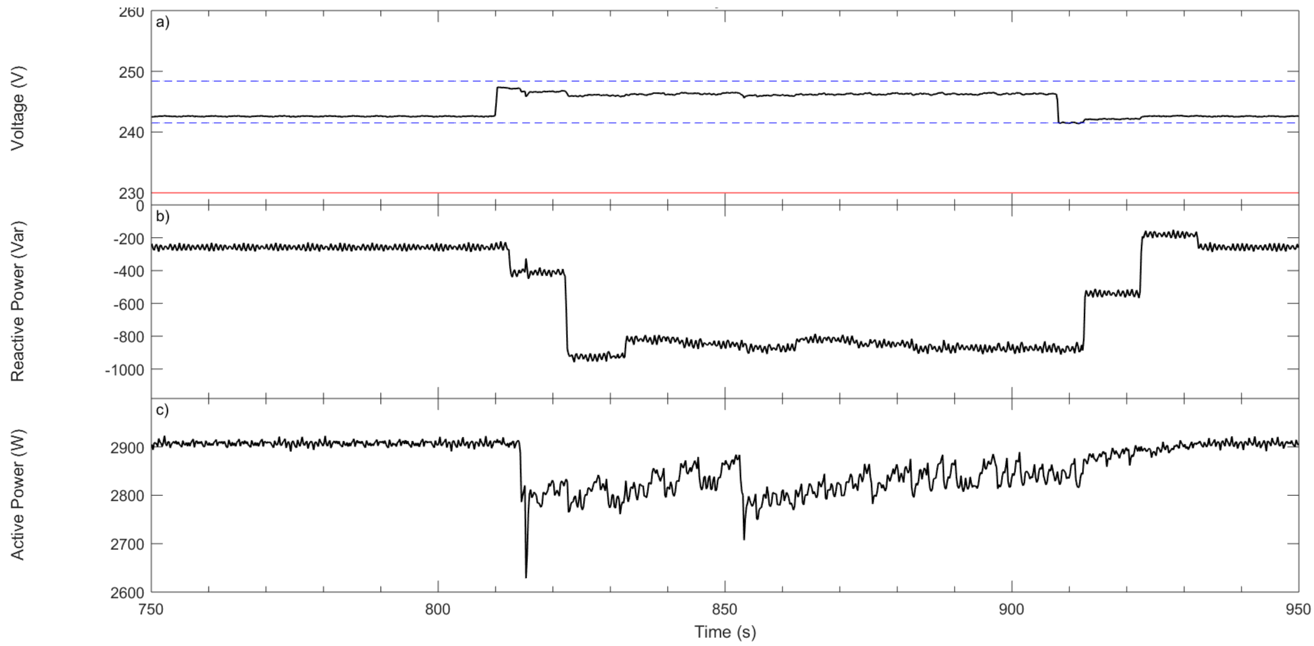

Figure 10 51 Conext RL 3000 – response to voltage step. Worst case scenario – additional impedance between the inverter and the grid simulator $X = 0.387 + i1.019$. P = 100% of the nominal apparent power.

For the second case, the impact of a steep droop curve on the converter stability was investigated. The droop characteristic of the Q(U) controller was changed to a one with a steeper slope. More specifically, the voltage at which the droop starts was set to $V_3 = 244V$ and the voltage at which the droop saturates was set to $V_4 = 246V$ following the specification where the “width of the droop area should not be larger than 1 % of the nominal voltage”. As seen in Figure 11 the inverter reaches a stable operating point.

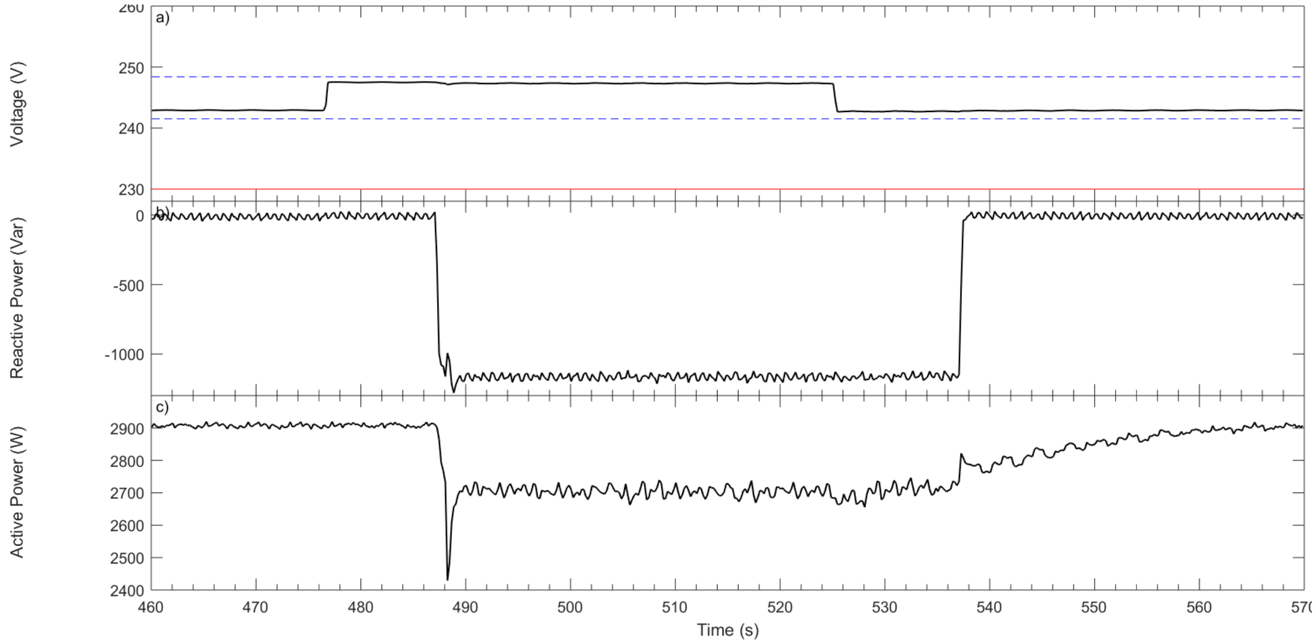

Figure 11 Conext RL 3000 – response to voltage step. Worst case scenario – steep droop curve. The voltage at which the droop starts was set to $V_3 = 244V$ and the voltage at which the droop saturates was set to $V_4 = 246V$. P = 100% of the nominal apparent power.

For the last worst-case test, the additional impedance and the steep droop tests were combined. The results of this test are shown in Figure 12. It can be seen, that under these circumstances the inverter was not able to find a stable operating point and presented sustained oscillations between zero and max-reactive power.

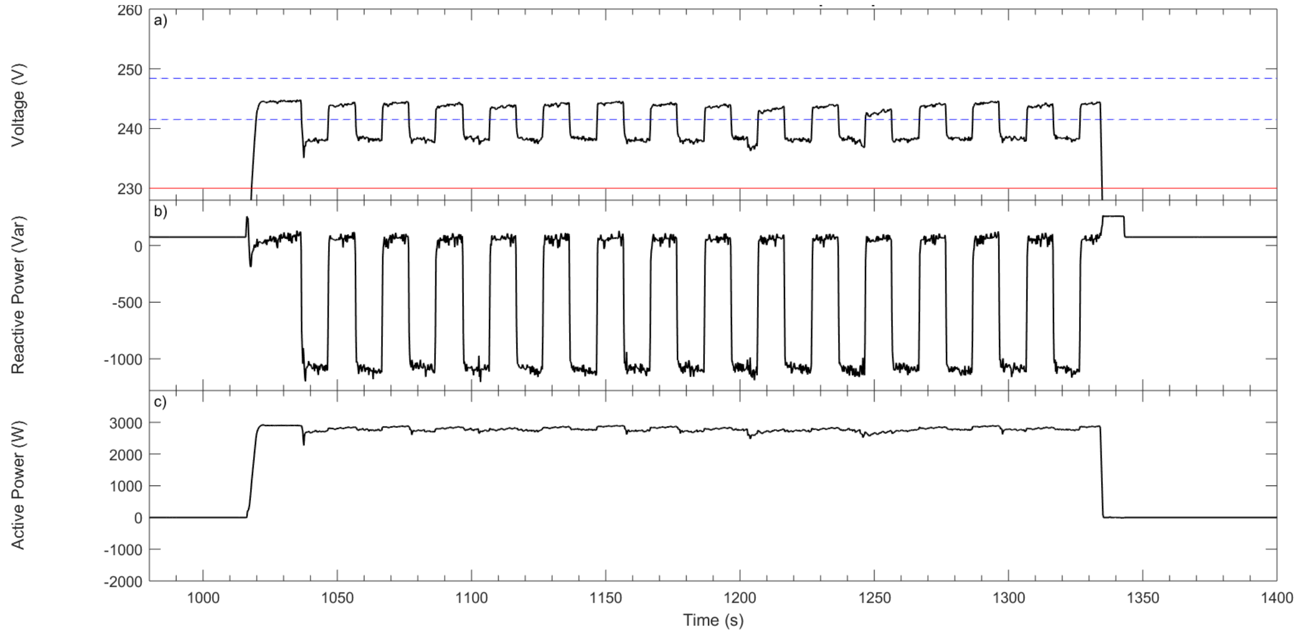

Figure 12 Conext RL 3000 – response to voltage step. Worst case scenario – both additional impedance and steep droop curve.

4.5 UC1-TC1, P(U) enabled: Characterisation of the control accuracy

In order to test the coordination between the Q(U) controller and the P(U) controller test case 1 was performed again, but this time with P(U) enabled.

As depicted in Figure 1, while the Q(U) control logic is implemented internally in the firmware of the inverter, the P(U) controller is implemented on an external PLC, namely the Schneider M221. This device then communicates via Modbus the new power reference to the inverter.

Figure 13 presents the results of this test. A horizontal green dotted line was added to Figure 13 to mark the voltage limit when the P(U) control should start acting.

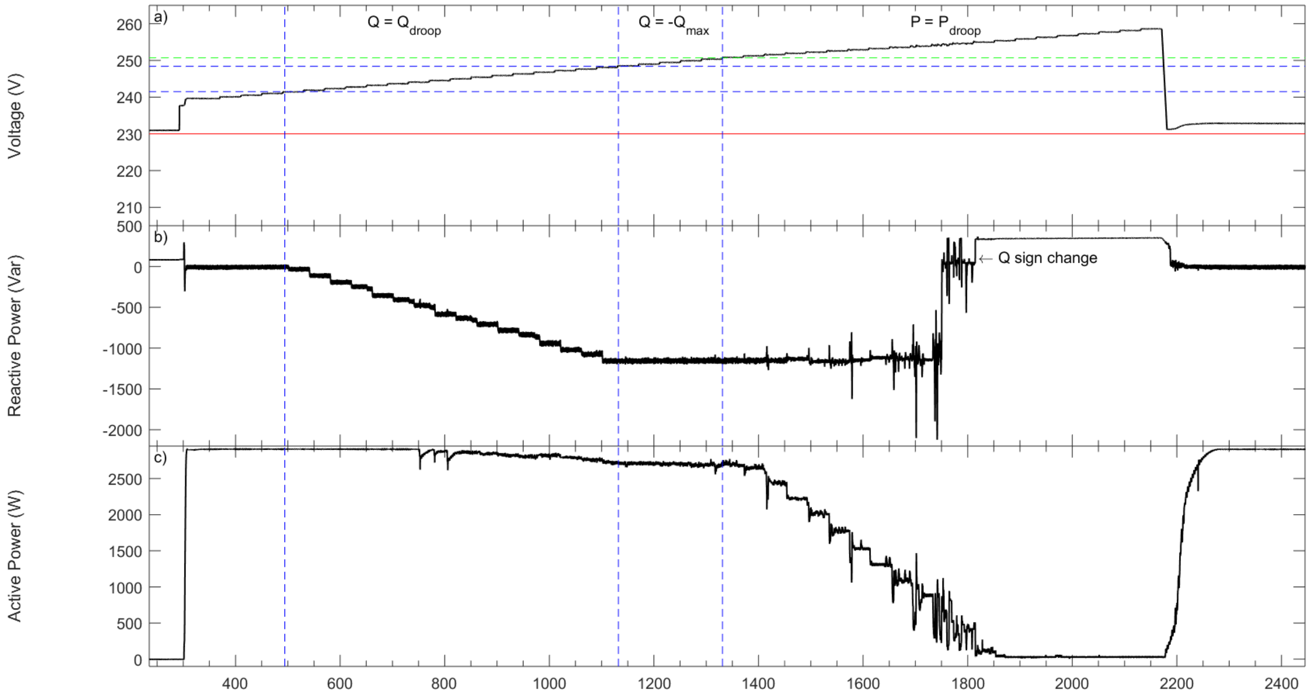

Figure 13 Conext RL 3000 – response to voltage sweep. Voltage, reactive power, and active power time series. Both Q(U) and P(U) controllers are enabled. P = 100% of the nominal apparent power.

As seen from Figure 13, the P(U) control is activated correctly. However, the time response is extremely noisy and oscillatory. One possible explanation for this could be the fact that the P(U) control is implemented on an external device and not internally as the Q(U) controller. The additional communication between the voltage measurement (IEM3155) and the PLC as well as between the PLC and the inverter will yield a very slow control loop for the P(U), which can be an explanation for the oscillatory behavior.

Another unwanted behavior can be seen at $t \approx 1800$ s. The P(U) control limits the output power and the inverter cannot provide the desired reactive power anymore which is a typical behavior. Increasing the voltage even further causes the sign of the reactive power to suddenly flip (see the labeled marker in Figure 13b) and the inverter provides roughly 300 Var which would increase the over voltage even more.

Figure 14 shows the P(U) droop characteristic of the P(U) controller. As in the case of Q(U) control, the inverter seems to have trouble its rated power as active power only. Moreover, there is a large variance in the operating points. Using equation (2)

$$\Delta P = \frac{P_{act} - P_{exp}}{P_{max}} \quad (2)$$

which was extracted from the evaluation section of the test case, the following performance indicators can be calculated:

$\Delta P_{avg} = avg(abs(\Delta P) = 5.30\%$ and $\Delta P_{max} = max(abs(\Delta P) = 38.37\%$.

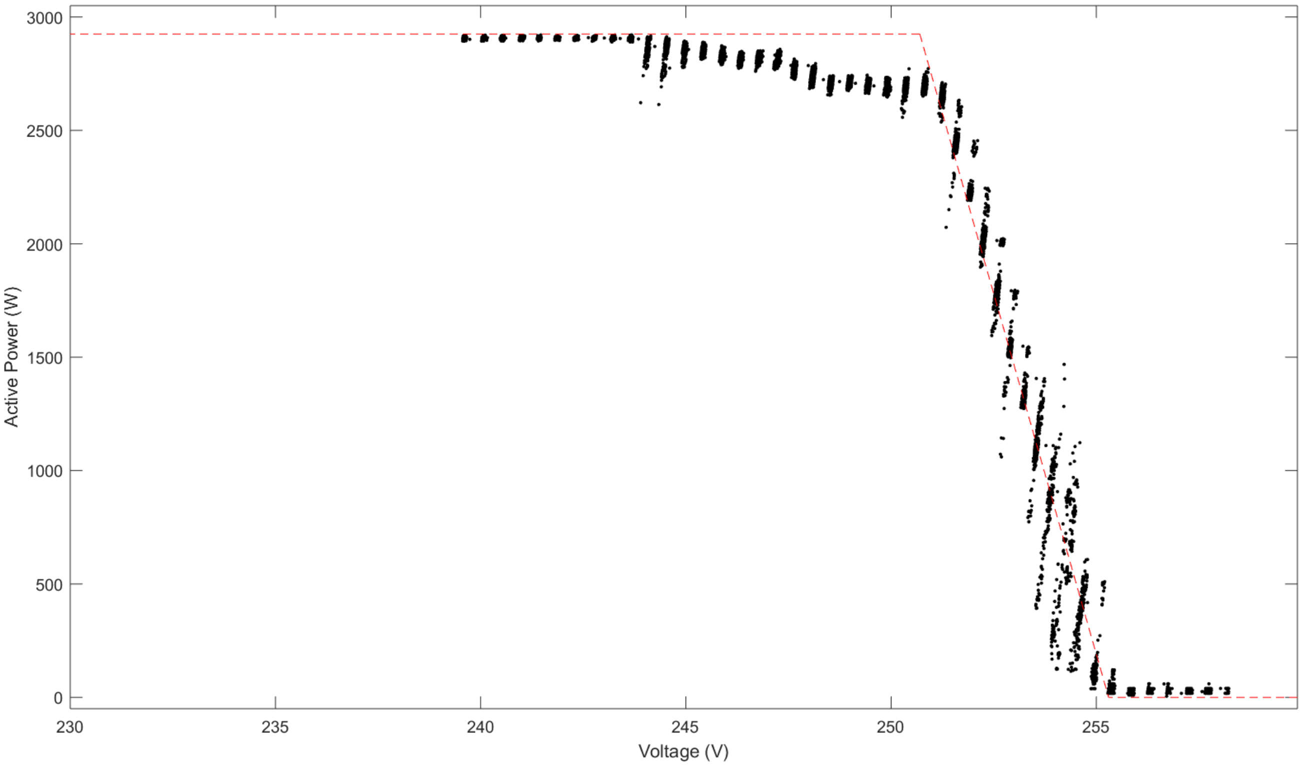

Figure 14 Conext RL 3000 – response to voltage sweep. P(U) droop characteristic.

4.6 UC1-TC2, P(U) enabled: Characterisation of the time behaviour

The purpose of TC2 is to investigate the time behaviour of voltage control. This time, besides the Q(U) control the P(U) control was also activated.

While performing this test, it was observed that the controller exhibits unpredictable behaviour. In some cases, the controller behaved as expected (e.g. a measurement shown in Figure 15). Whereas in other cases, the system showed an unstable behaviour (cf. Figure 16). This occurred within several minutes without adding any change to the system.

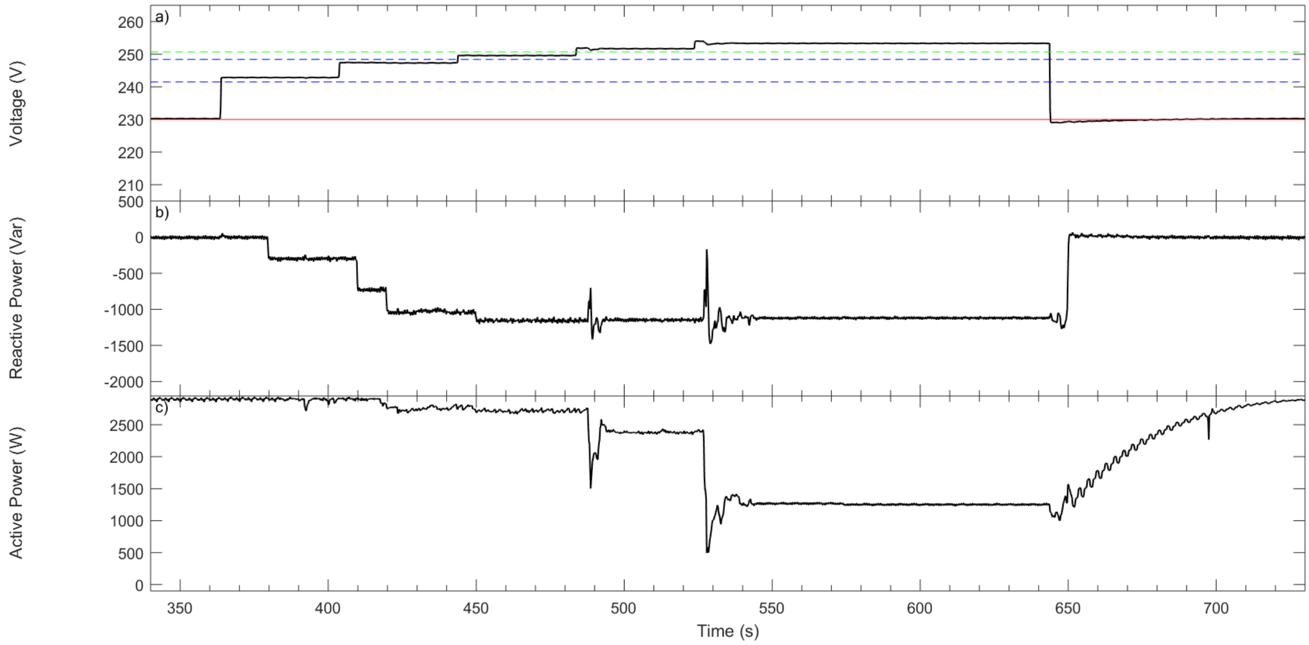

Figure 15 Conext RL 3000 – response to voltage steps. P(U) enabled. P = 100% of the nominal apparent power. Stable response.

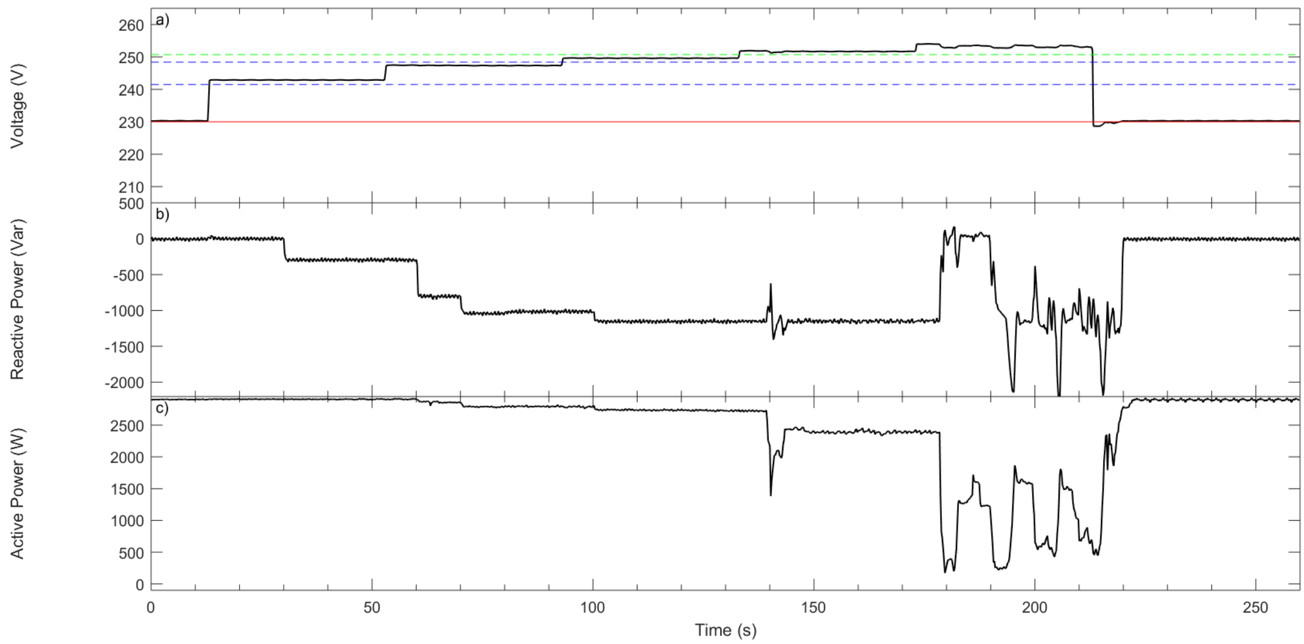

Figure 16 Conext RL 3000 – response to voltage steps. P(U) enabled. P = 100% of the nominal apparent power. Unstable response.

Since the reason of this behavior could neither be identified nor stabilized, the time behavior was not calculated.

4.7 UC1-TC3, P(U) enabled: Investigation of the stability under worst-case conditions

Given the unpredictable behaviour of the P(U) control to voltage steps observed in the previous section, it was considered futile to run the worst-case scenarios with the P(U) enabled. Therefore, given also the limited amount of time that we had available to run the tests, it was decided to not perform any additional tests with the P(U) control enabled.

5 Results – UC 3

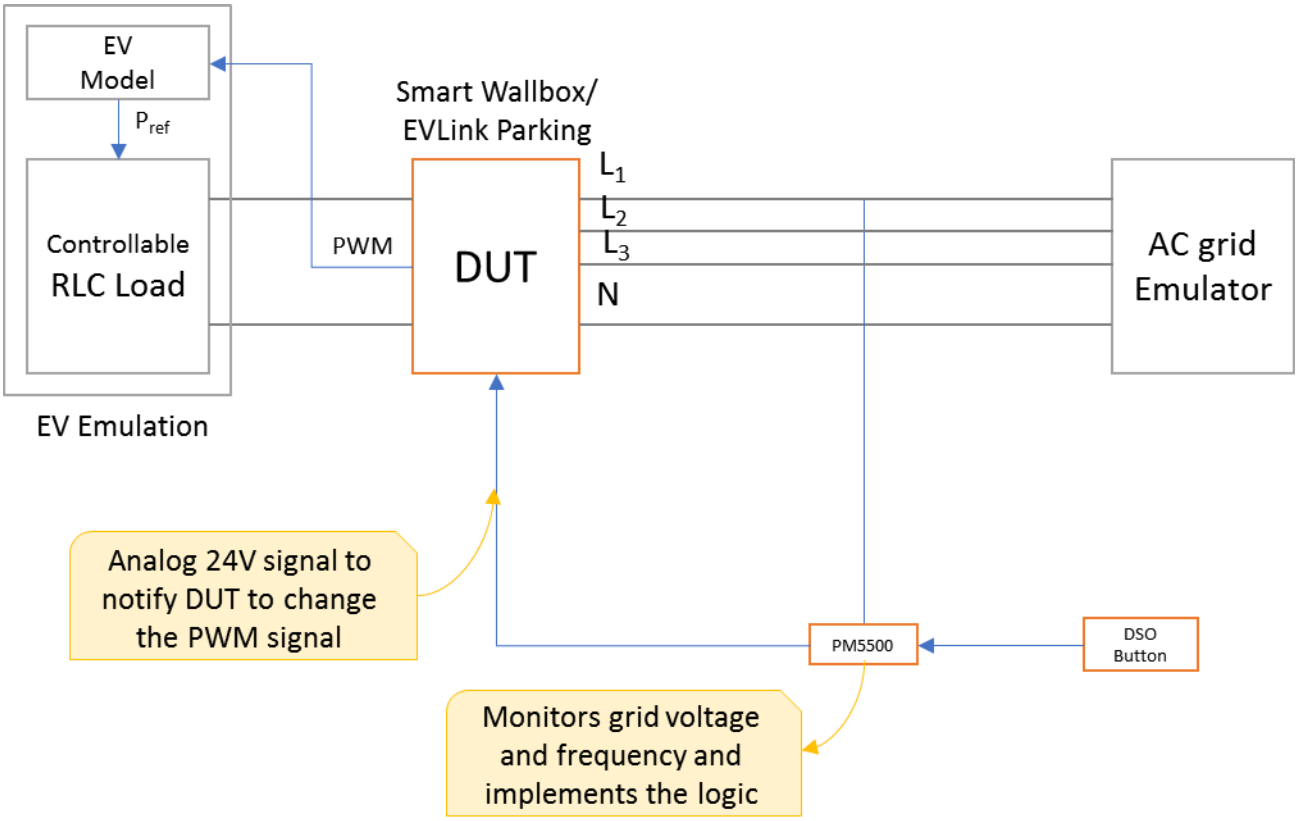

Figure 17 Diagram of the laboratory setup used for evaluating the *Smart Wallbox* and the *EVLink* Parking three phase EV charging station.

Two devices were tested for UC3, namely the Smart Wallbox and the EVLink Parking. Both are three phase EV charging stations. The diagram of the laboratory setup used for the tests in UC3 is shown in Figure 17. The logic for power reduction is implemented in the PM5500 unit. This external device monitors the grid frequency and grid voltage and signal the charging station whether to modify the PWM signal.

Three tests were run for each of the devices, i.e., the Smart Wallbox and the EVLink Parking. Since the results are very similar for the two devices we are going to detail only the ones for the Smart Wallbox.

The first test evaluates the response of the charging station to a low frequency scenario. The results are shown in Figure 18 (respectively Figure 21 for EVLink Parking). The horizontal dotted red line in Figure 18a marks the frequency threshold at which the DUT should reduce its power. The three vertical blue lines mark the events of interest in the scenario, mainly the event when the frequency goes below the threshold, the one when it goes above the threshold, and finally the event when 5 minutes have passed since the frequency has recovered.

Figure 18b shows a 100 ms block wise average of the PWM signal. It can be seen that the change of the PWM signal due to falling below the frequency threshold is almost instantaneous. However, due to the EV model and the way the EV is emulated, the change in the actual power (Figure 18c) is delayed a few additional seconds.

A similar behaviour can be observed as a response to a low-voltage scenario in Figure 19 (Figure 22 for the EVLink Parking).

The response of the system when the DSO requires a change in power, i.e., the DSO button is pressed, can be seen in Figure 30 (Figure 23 for the EVLink Parking). Again, both charging station act as desired.

One of the main concerns regarding the previous results for UC3 were some large power overshoots and oscillations at the moment of charging power set value changes. As can be seen, these surges are not present in the present results. We suspect that this behaviour was present in the previous tests as a side-effect of the RLC load controller used in the EV emulation. In the meantime, this controller has been adapted to avoid overshoots.

To sum up, PM5500 recognizes under frequency and voltage situations as requested, sends a signal to the charging station and both tested charging stations react with an adapted PWM signal to the EV.

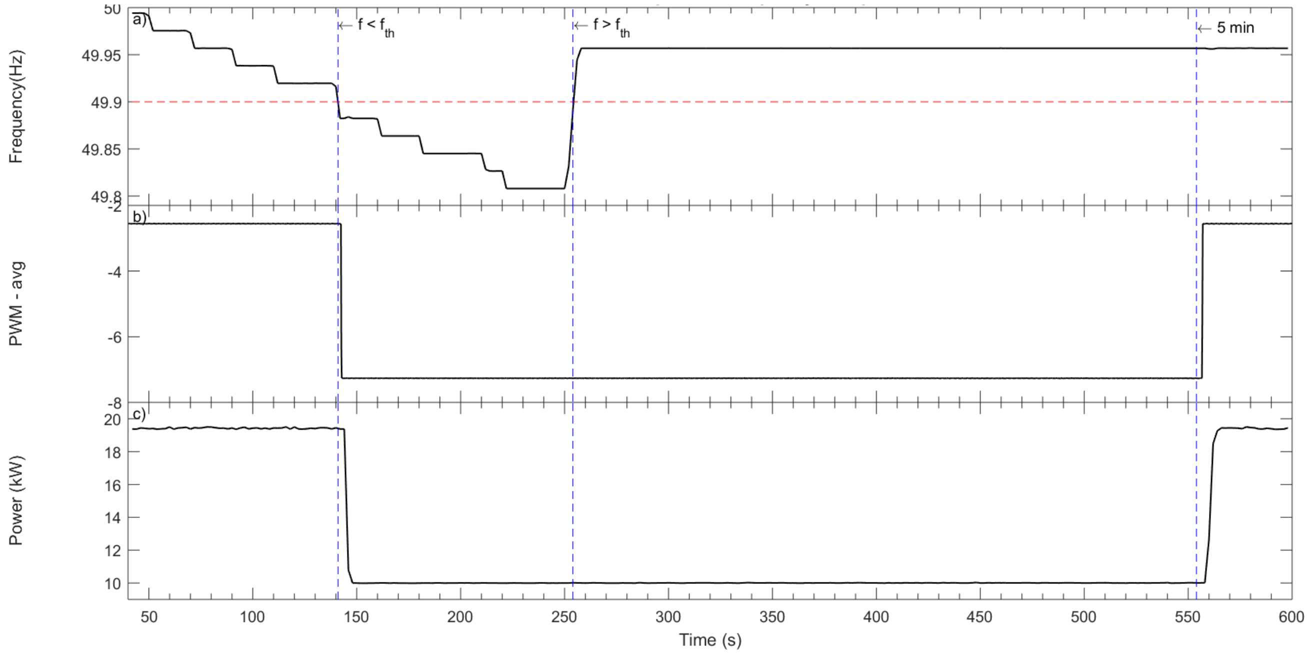

Figure 18 Smart Wallbox – response to frequency sweep.

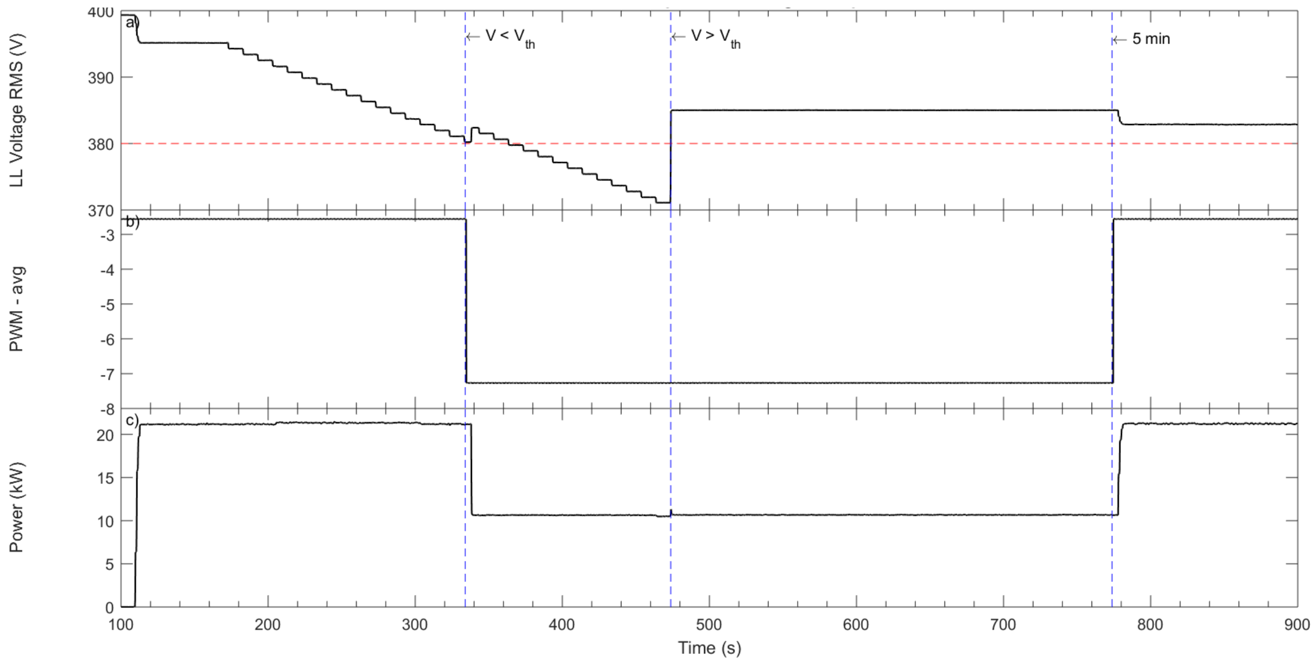

Figure 19 Smart Wallbox – response to voltage sweep.

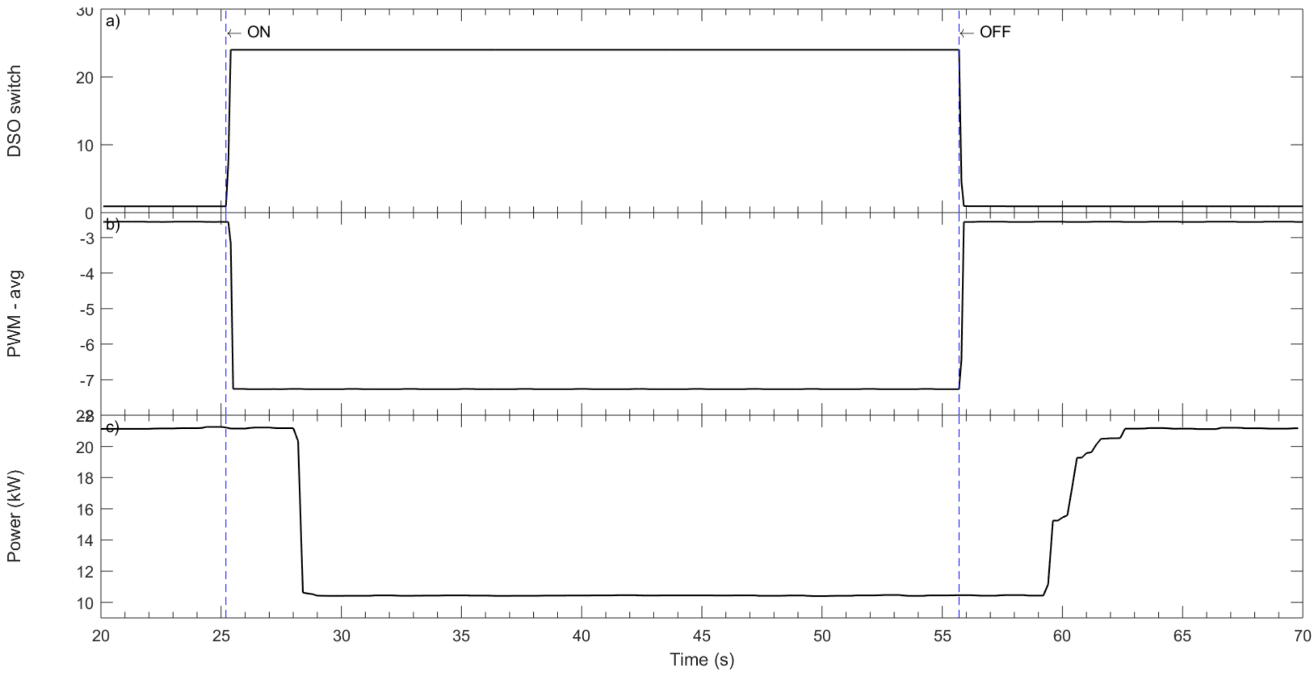

Figure 20 Smart Wallbox – response to DSO switch.

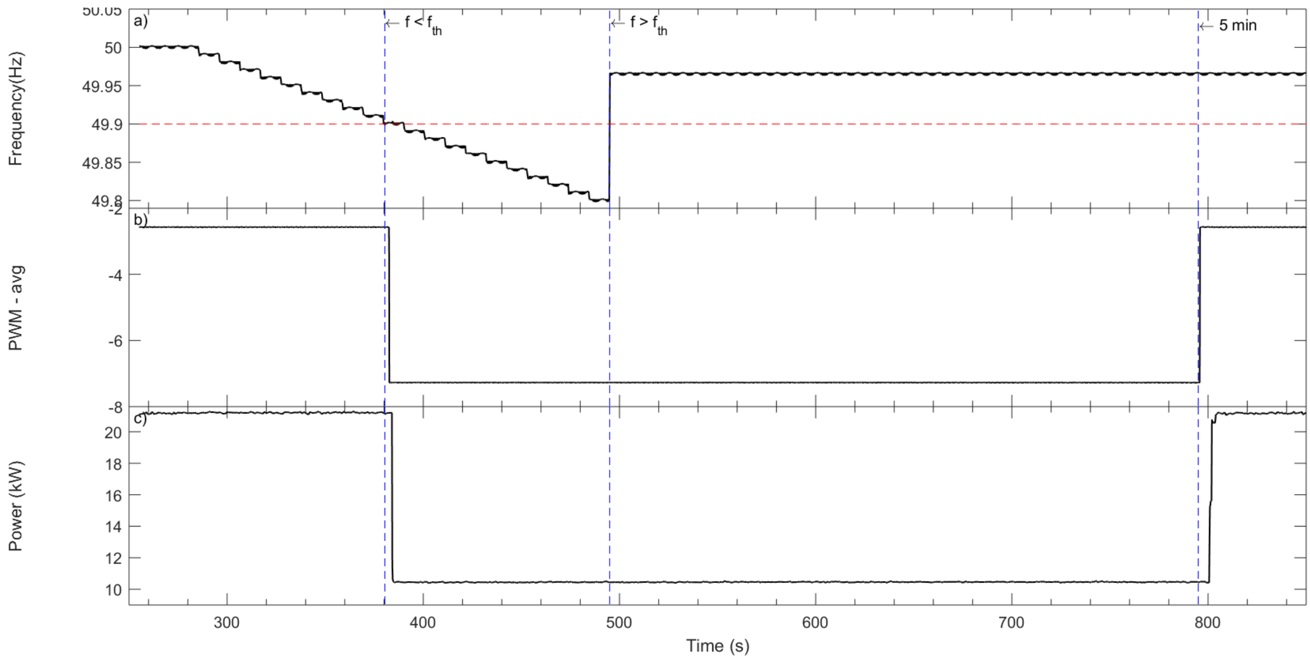

Figure 21 EVLink Parking – response to frequency sweep.

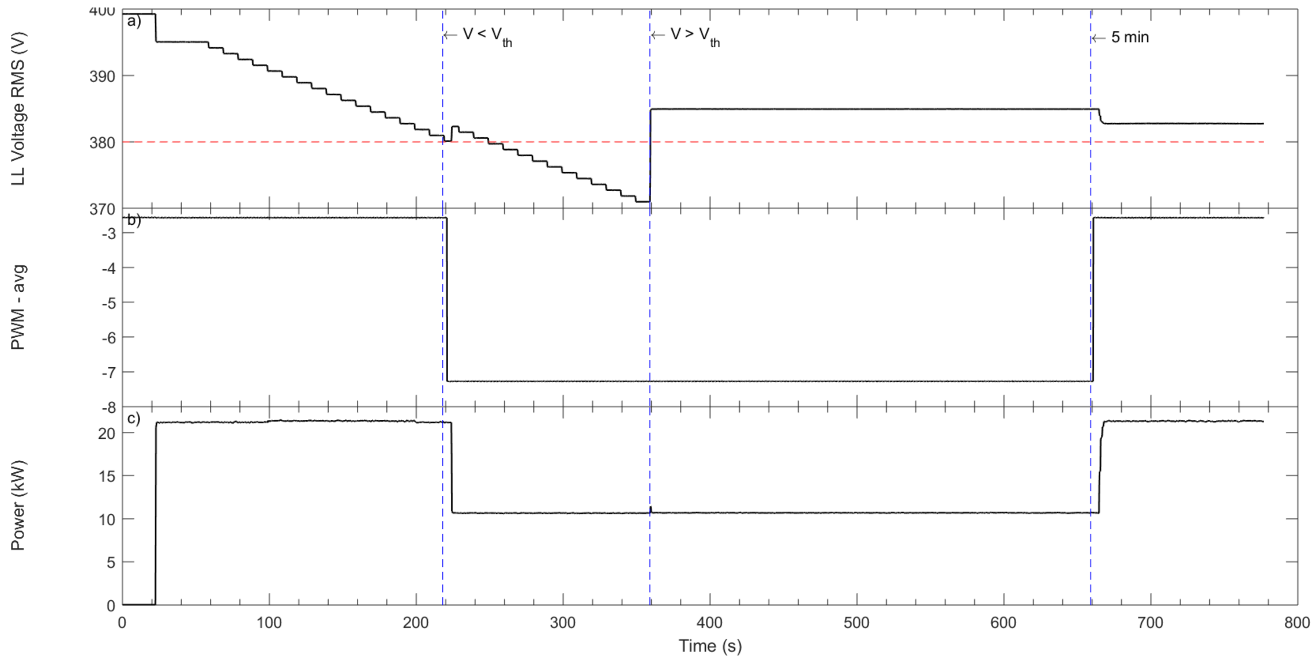

Figure 22 EVLink Parking – response to voltage sweep.

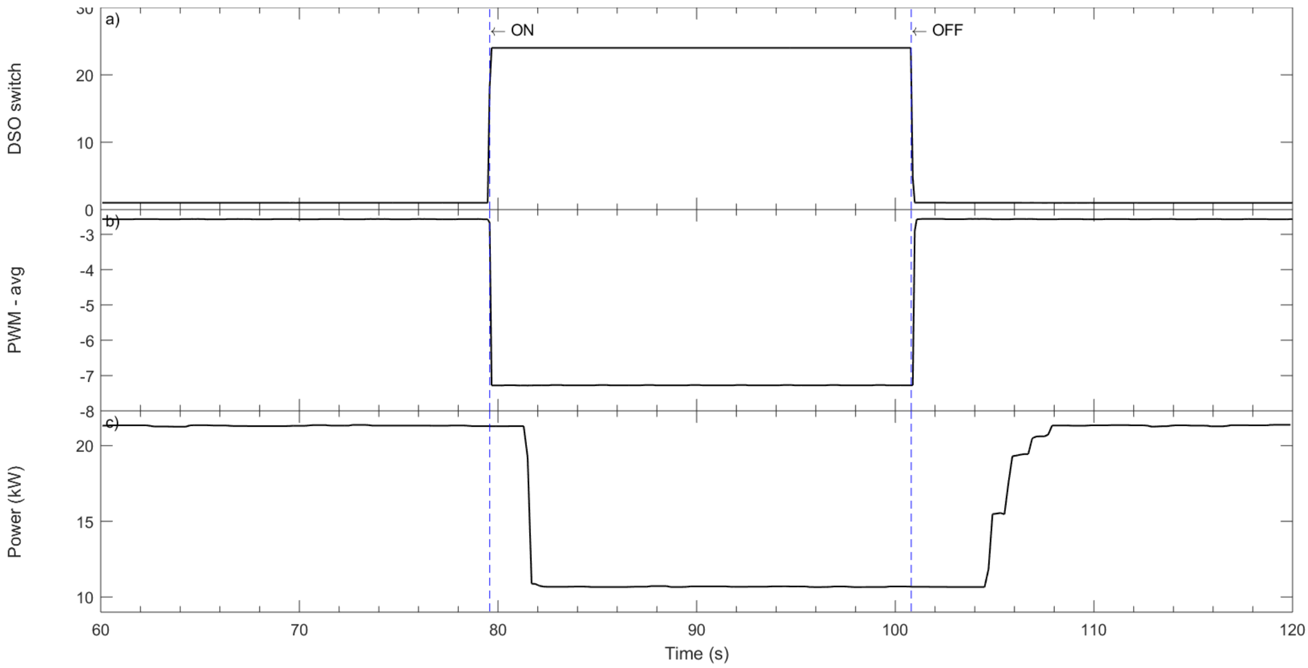

Figure 23 EVLink Parking – response to DSO switch.

6 Conclusion

The tests described in this report were performed to clarify some of the concerns and the questions raised regarding the results of the previous tests.

For the UC1, the inverter was initially configured with a Q(U) droop characteristic that had the wrong sign. This aspect was changed and the tests were performed again. This time, the results are closer to the expected values. The value initially used for tests was 44%, but it has been determined and verified that a more suitable setting is 53% in the configuration of the Q(U) controller. With this setting of $Q_{max} = 53\%$, the average difference between the expected reactive power and the measured reactive power is $\Delta Q_{avg} = 1.47\%$.

For the worst-case scenario, the Q(U) control remains stable for the case with additional impedance and for the steeper droop curve. However, when the two are combined the controller becomes unstable.

While the Q(U) control (after proper parameter adjustments) performance is inside the acceptable limits, the P(U) control presents several issues. We suspect that the slow P(U) control loop is to blame for this behaviour.

For the UC3 tests, both charging stations behave as desired. The PWM signal changes prompt. The power overshoots recorded in the previous tests are no longer present and we suspect that they occurred due to the controller used in the emulation of the EV and not due to wrong PWM signals.