Design of solution V1.0

Deliverable D6.1

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Short Description

Deliverable 6.1 contains detail design of technical solutions of all WP6 use cases, results of customer's recruitment, lab tests results and KPIs definition.

Revision history

Version	Date	Modifications' nature	Author
V0.1	8.9.2017	First concept	Stanislav Hes
V0.2	04.12.2017	Draft for TC review	Stanislav Hes
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Owner/Main responsible

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Enexis	Willems

Approver(s): company name(s)

Company	Name(s)
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Work Package ID	WP 6	**Task ID**	T6.1 – T6.10

EXECUTIVE SUMMARY

This report (deliverable) named D6.1 Design of solution is deliverable of WP6 within InterFlex H2020 (project co-founded by the European Commission). CEZ Distribuce as WP6 leader aims to perform demonstrations 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_1 Design of solutions contains detail design of technical solutions of all WP6 use cases, results of customer's recruitment, lab tests results and KPIs definition.

This report describes in detail the design of solutions for WP6 that will be implemented in next stage of the project and then reported in D6.2 Implementation of solution (deliverable due date 12/2018).

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

TABLE OF CONTENT

LIST OF FIGURES

1. INTRODUCTION

1.1. Scope of the document

This document named D6_1_Design of solution contains detail design of technical solutions of all WP6 use cases (WP6_1, WP6_2, WP6_3, WP6_4) including use cases description and SGAMs, results of customer's recruitment, lab tests results and KPIs definition. Use cases detailed description, full SGAMs, detailed KPIs definition and Lab tests complex report 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
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
RCS	Ripple Control System
RTU	Remote Terminal Unit
S	Apparent power
SGAM	Smart Grid Reference Architecture
SRA	Scalability and Replicability Analysis
TC	Technical Committee
U	Voltage
UI	User Interface
WP	Work Package

Figure 1 – List of acronyms

2. DESIGN OF SOLUTIONS

The Czech demonstration project WP6 is located in several areas in Czech Republic where CEZ Distribuce operates distribution networks. The demonstration is not concentrated to one region in order to prove replicability and interoperability of designed solutions.

The demonstration project will be partially built on the experience gained in the GRID4EU/ Smart Region Vrchlabí (a European project in the field of smart grids, renewable energies and energy transition which was finished in January 2016).

WP6 is focused on the implementation of solutions which are not so far usual in distribution systems but which have a strong potential for future roll out. Tested solutions within WP6 cover the most urgent challenges of DSOs (increasing DER hosting capacity, EV charging stations implementation and energy storage). Beyond the technical developments, WP6 also aims to propose grid codes and standards updates in order to secure future smoother integration of selected smart grid solutions

WP6 objectives:

a) to increase DER hosting capacity in LV distribution networks using smart PV inverter functions (demonstration of the role of Q(U) and P(U))
b) to increase DER hosting capacity in MV distribution network using volt-var control (U/Q regulation)
c) to quantify the impacts of the Smart charging of EVs onto the distribution grid flexibility
d) to quantify the Smart energy storage functions onto the distribution grid flexibility

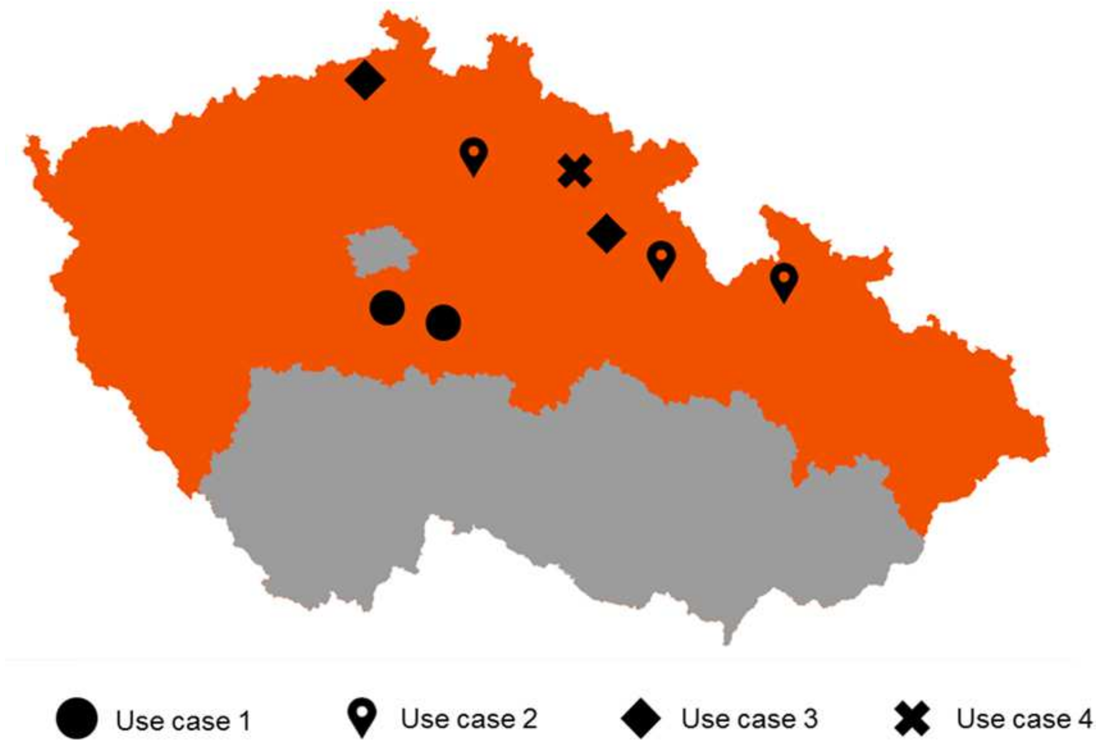


Figure 2 – WP6 demonstration areas in Czech Republic (CEZ Distribuce regions are coloured in orange)

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

CEZ Distribuce foresees results which will significantly help to solve European DSO's challenges for future DER, electric vehicles and energy storage integration.

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

Scope:
The aim of the use case is field demonstration of smart PV inverters functions which enables increasing of DER hosting capacity in two different areas with different LV grid topology.

Objective:
Increase of DER hosting capacity in LV grids by 40% thanks to the installation of smart PV inverters and securing the power quality defined in EN 50160 standard (check that smart solution is not negatively affecting power quality).

Description:
CEZ Distribuce and its partners aim at demonstrating how the combination of new smart PV inverter functions Q(U) and P(U) under real operating 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 2 MV/LV secondary substations. Two areas with different topologies with high penetration of PV systems compared with baseline scenario are needed. Crucial tasks for this use case are the recruitment of an appropriate number of customers (PV plant operators) within the selected areas, the installation of PV systems with smart PV inverters and the delivery of technical operational data and results from the PV inverter monitoring systems with the customer's consent. In selected areas, CEZ Distribuce will allow the connection of significantly more installed capacity in PV systems compared with existing evaluation approach. Number of PV systems which will be included in WP6 for demonstration are listed in Chapter 4 - Customers recruitment.

CEZ Distribuce together with partners will demonstrate the full potential of the combination of new smart PV inverters functions Q(U) and P(U) in real operation under real condition within LV distribution networks. In order to have appropriate conditions for testing, residential (roof-top) PV systems with smart PV inverters (fulfilling the EN 50438 ed.2 standard) must be installed in large concentration under selected 2 MV/LV secondary substations.

2 different areas with different type of topology and with high penetration of PV systems are necessary:

1 x MV/LV secondary substation with LV cable network with long feeders (500m or more)
1x MV/LV secondary substation with LV overhead lines with long feeders (500m or more)

For this use case, customer participation is be secured by a recruitment process which is the responsibility of CEZ Solární as a project partner. Locations for project were specified in cooperation with CEZ Solarni (based on the recruitment success in areas with long LV cable and overhead line feeders and based on detail existing grid topology).

Q(U) function:

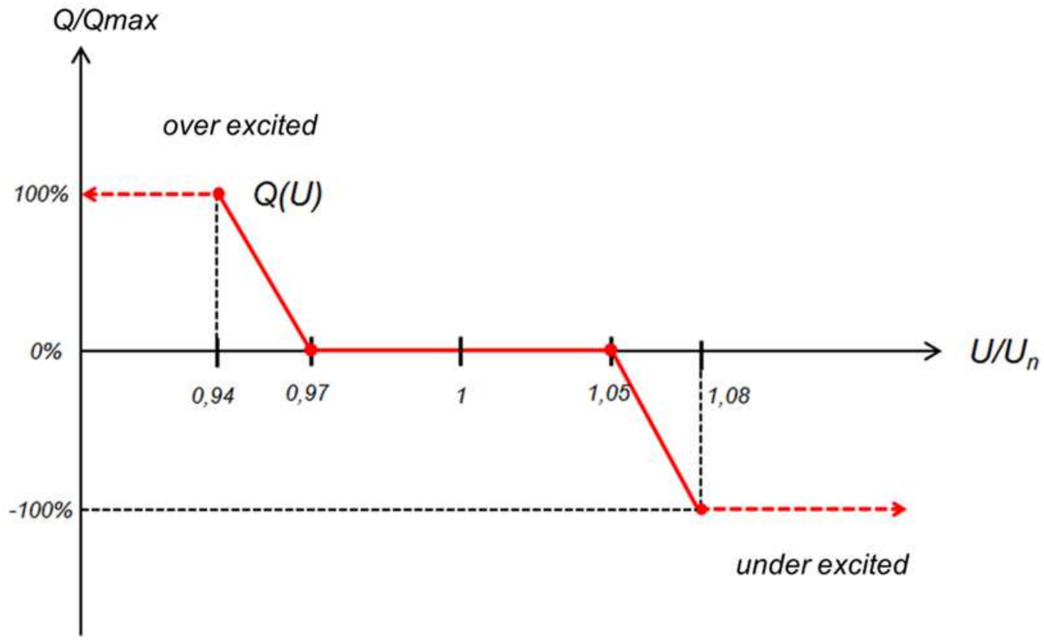


Figure 3 - Autonomous Q(U) function with set points used in WP6

P(U) function:

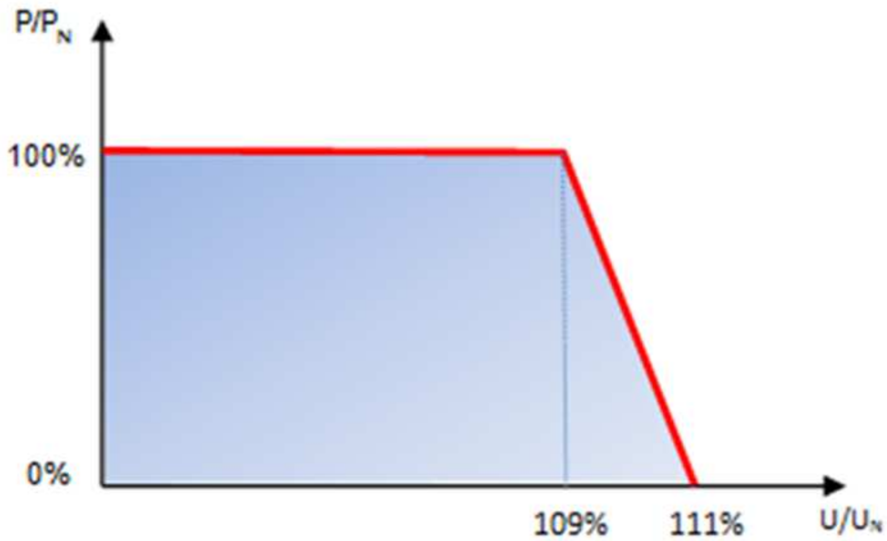


Figure 4 - Autonomous P(U) function with set points used in WP6

In case voltage is higher than threshold, PV inverter starts is set to underexcited mode thanks to Q(U) function as it is shown on figure 3, in case the voltage rise even more, PV inverter starts to reduce active power production thanks to P(U) function. In case voltage is lower than threshold, PV inverter starts to generate reactive power thanks to Q(U) function. Both functions stabilize voltage in the LV grid and thus significantly increase DER hosting capacity.

All PV inverters in WP6_1 will have Q(U) and P(U) functions included. Both functions will be configured set into operation during the commissioning of each PV inverter.

Two different LV grids for demonstration of WP6_1 use case were selected – Divisov and Teptin. Grid topology of both LV grids is depicted below:

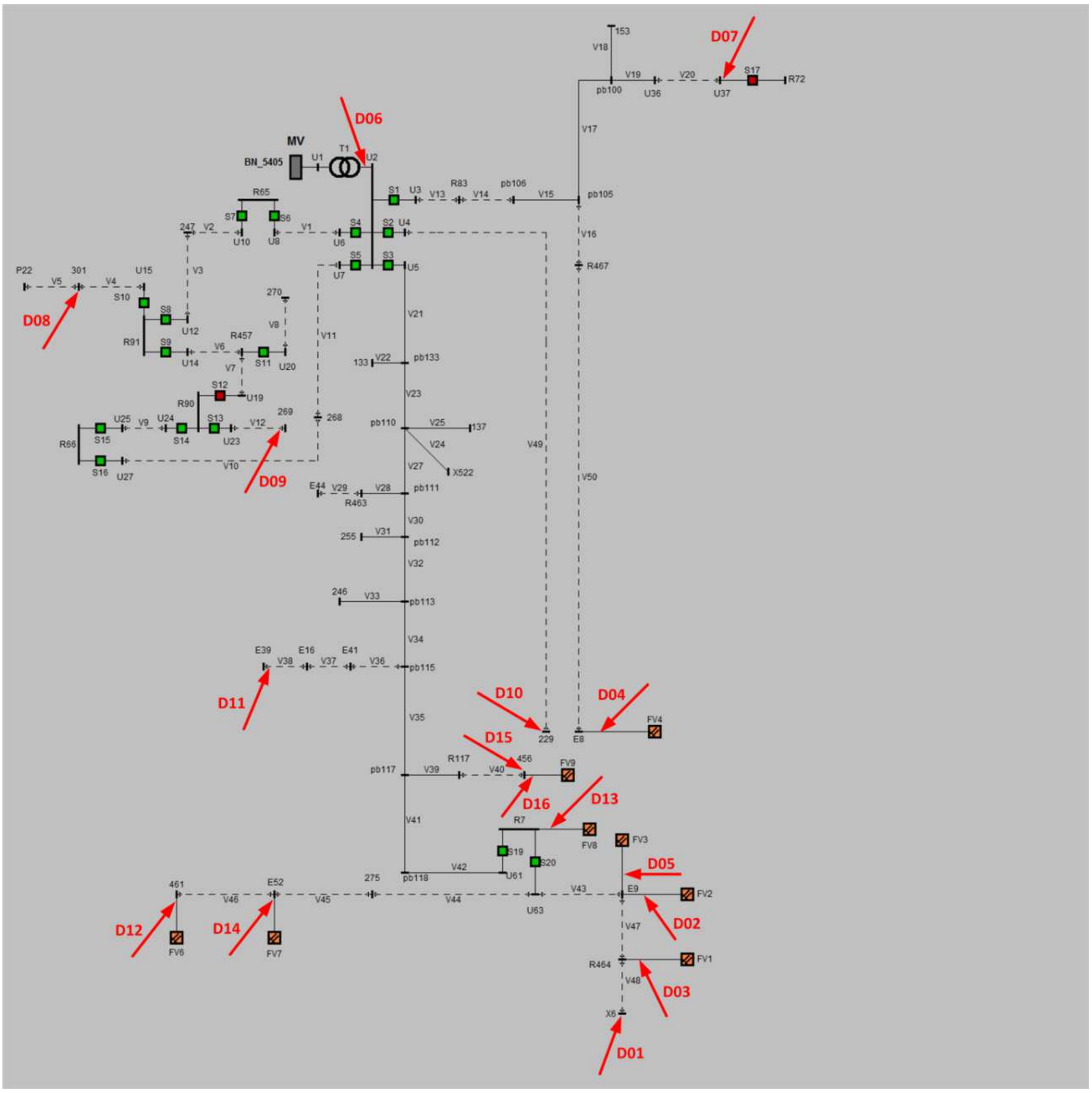


Figure 5 – Use case WP6_1 – LV grid topology in Divisov area with marked places for installation power quality measurement devices (red arrows)

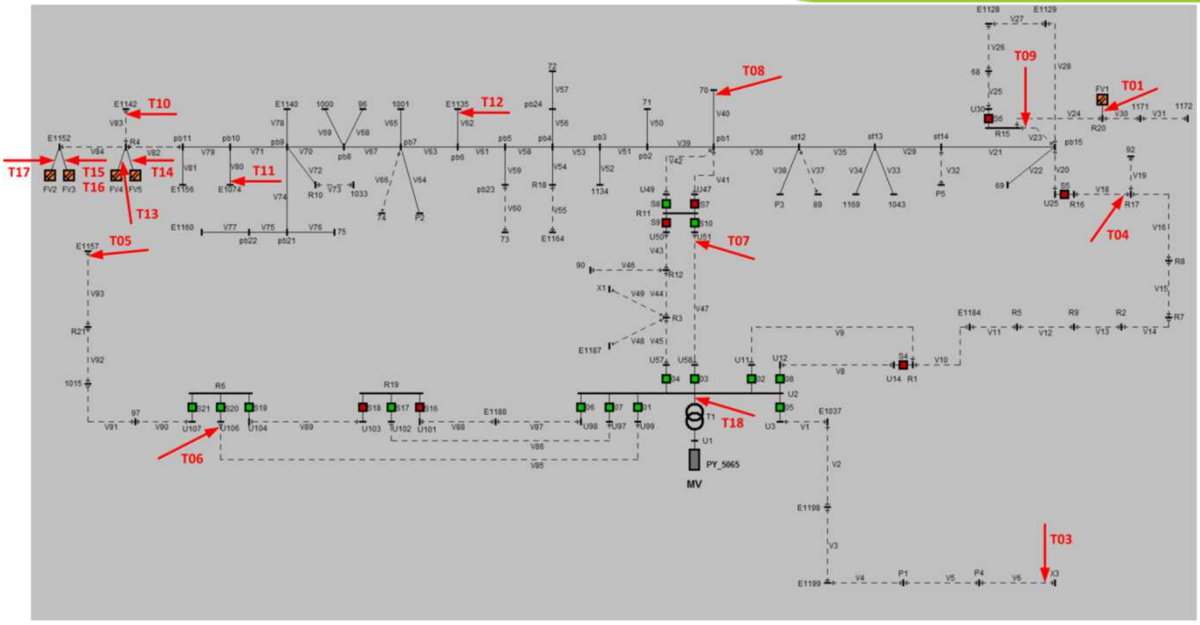


Figure 6 – Use case WP6_1 – LV grid topology in Teptin area with marked places for installation power quality measurement devices (red arrows)

In order to have also a consistent field data for evaluation, that are not affected by voltage fluctuations on MV, CEZ Distribuce will reconstruct both mentioned MV/LV secondary substation and equip them with voltage regulated distribution transformers (OLTC) and advanced power quality measurement. OLTC could be also used for simulating different voltage levels in LV grid in order to check behaviour of Q(U) and P(U) functions. Testing of potential of smart PV inverters functions will help to determine how much is possible to increase DER hosting capacity in LV networks thanks to Q(U) and P(U) functions without the need of expenses for new interconnections and reconstructions caused by requests for DER connection.

Power quality will be monitored in the LV grid through DSO power quality management system (online remote data download using GPRS/LTE). For use case evaluation also data from DSO billing system could be used (online remote data download using GPRS/LTE). Data from PV inverters could also be used for use case evaluation (with customers consent).

Figure 7 – Meg38 power quality measurement device

Descriptions and SGAMs are separated for option a) Fronius and b) Schneider Electric.

<u>SGAM – Fronius:</u>

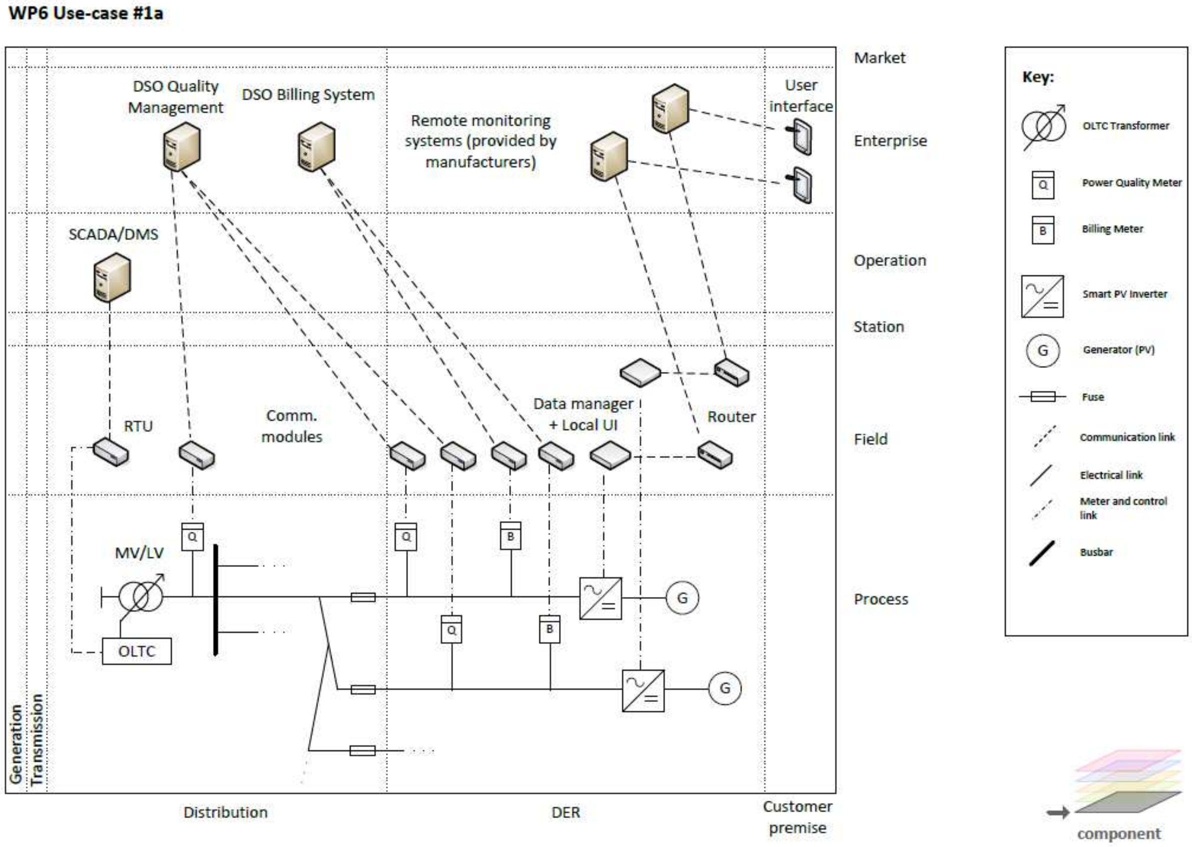


Figure 8 - SGAM for WP6_1 use case (component layer) - Fronius

Figure 9 - PV inverter used in WP6_1 - Fronius Symo Hybrid serie (three - phase)

Figure 10 - PV inverter used in WP6_1 – Fronius Symo serie (three - phase)

Fronius Symo and Symo hybrid series which will be used for WP6_1 demonstration have already Q(U) and P(U) functions in default firmware. Both functions work autonomously based on the local voltage situation. For application together with the pre-existing Czech country setup, commissioning of functions must be done manually via display.

<u>SGAM – Schneider Electric:</u>

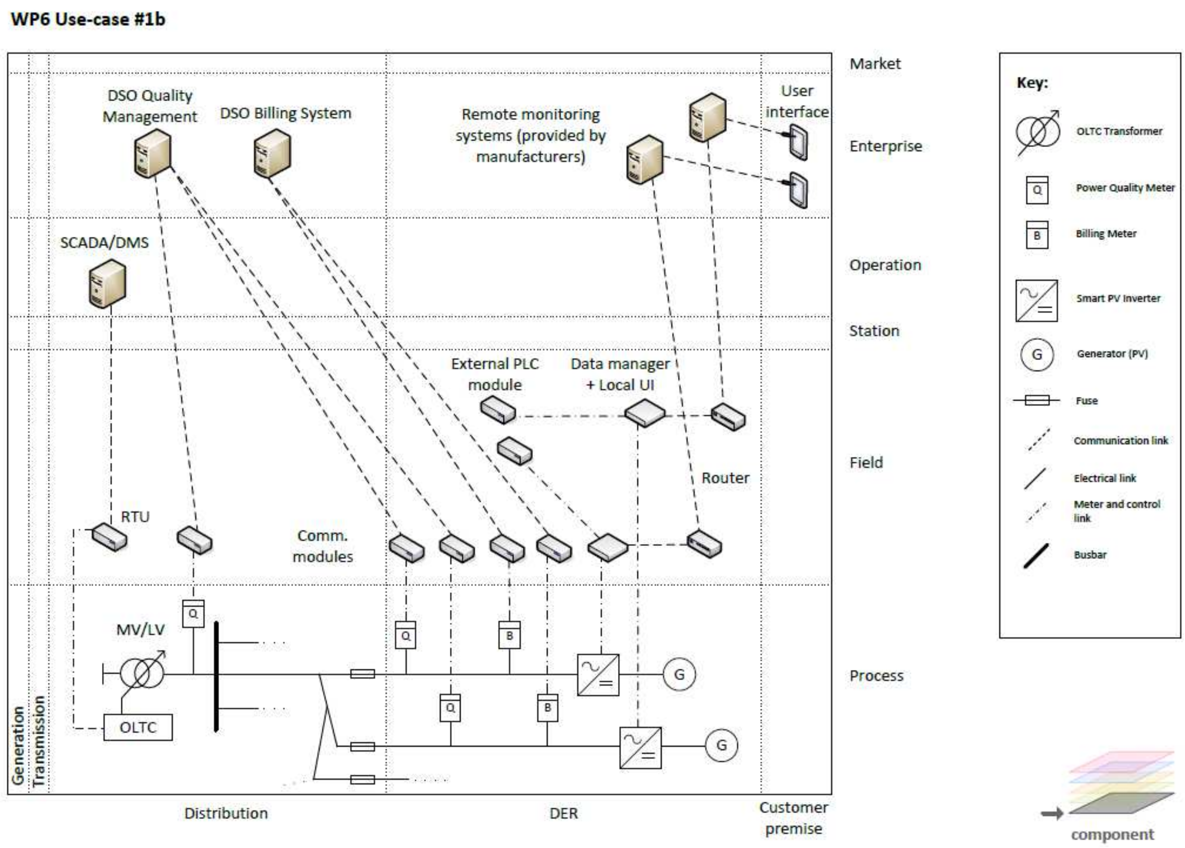


Figure 11 – SGAM for WP6_1 use case (component layer) – Schneider Electric

Figure 12 - PV inverter used in WP6_1 - Schneider Electric Conex RL 3kW (single phase)

In order to secure P(U) function, Schneider Electric Conex RL 3kW inverter cooperates with external PLC (TM221C16R - PLC Modicon M221, 100-240VAC, 9DI, 7DQ (relay), 1x serial com. port, 1x miniUSB, with SD slot). Q(U) function is already included in default firmware.

Note:
Detail WP6_1 use case description is included in annex 6.1 of this deliverable.
Detail SGAM for solution with Fronius PV inverters is included in annex 6.2.
Detail SGAM for solution with Schneider Electric PV inverters is also included in annex 6.2.

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

Scope:
The aim of the use case is field demonstration of volt-var control system which enables increasing of DER hosting capacity in three different areas with three different DER (PV, Wind, Biogas) connected to the MV grid.

Objective:
Increase of DER hosting capacity in MV grids thanks to the installation of smart PV inverters and securing the power quality (voltage levels) according to EN 50160 standard (check that smart solution is not negatively affecting power quality).

Description:
CEZ Distribuce integrates selected DER connected to MV networks into volt-var control system (PV: 1.1MW, biogas station: 1.25MW, wind: 4.6MW). The DSO can send required voltage set points from its SCADA to DER unit, which then react and regulate at the required voltage set points (thanks to reactive power generation/consumption. For this volt-var control strategy, CEZ Distribuce leans on existing DER over 100kW with RTU and communication capabilities (usually GPRS) towards the DSO dispatching control system (SCADA).

DSO dispatcher sends command for start of volt-var control of DER together with required voltage set point.

In case instantaneous measured voltage in the point of DER connection is not according to the DSO dispatcher needs, DSO dispatcher sends command for the start of volt-var control together with the voltage set point. In case that voltage set point is higher than actual measured voltage value, the DER will start to generate reactive power in order to increase the voltage. In case that voltage set-point is lower than actual measured voltage value, DER will start to consume reactive power in order to decrease the voltage. DER control system continuously evaluates difference between the voltage set point command and DER voltage measurement in the point of connection and sends adequately calculated command for changing reactive power or power factor to generator/inverter.

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

Example of volt-var control provided by CHP connected to MV grid is shown below (CHP volt-/var control test from Demo2 under GRID4EU project):

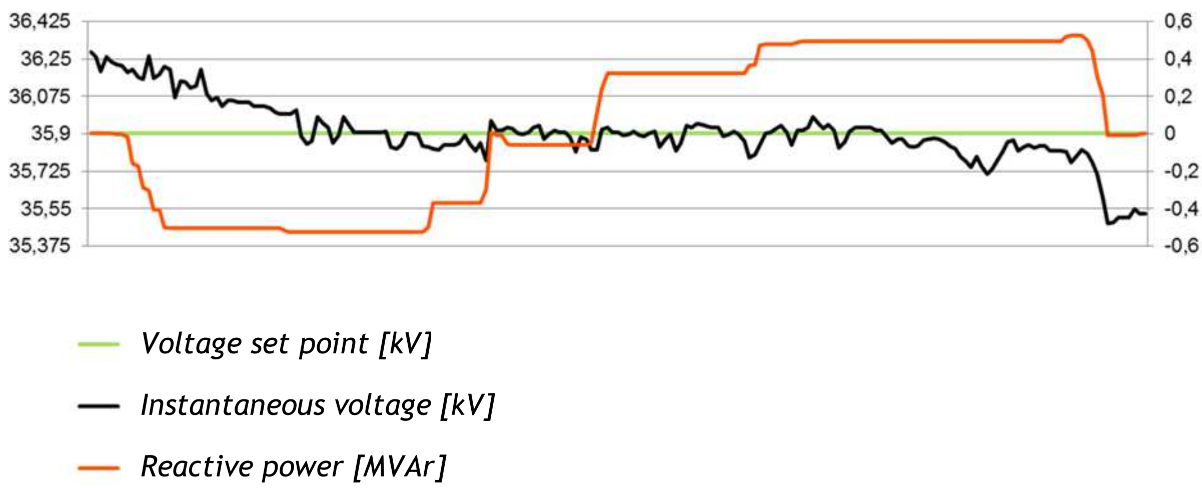


Figure 13 - Example of volt-var control with CHP unit 1,6 MW connected to MV grid

Voltage set point could be set by DSO dispatcher or could be determined by SCADA based on online load flow calculation which is shown on figure below:

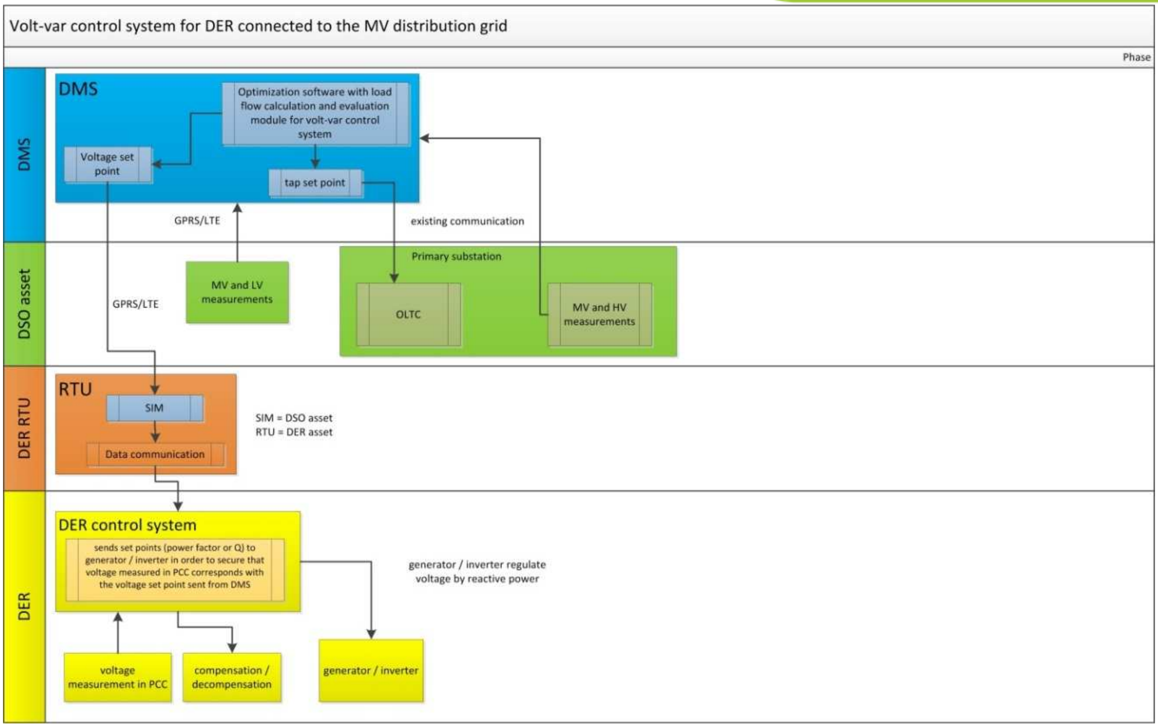


Figure 14 - Block scheme of volt-var control concept

<u>SGAM – all DERs included in WP6:</u>

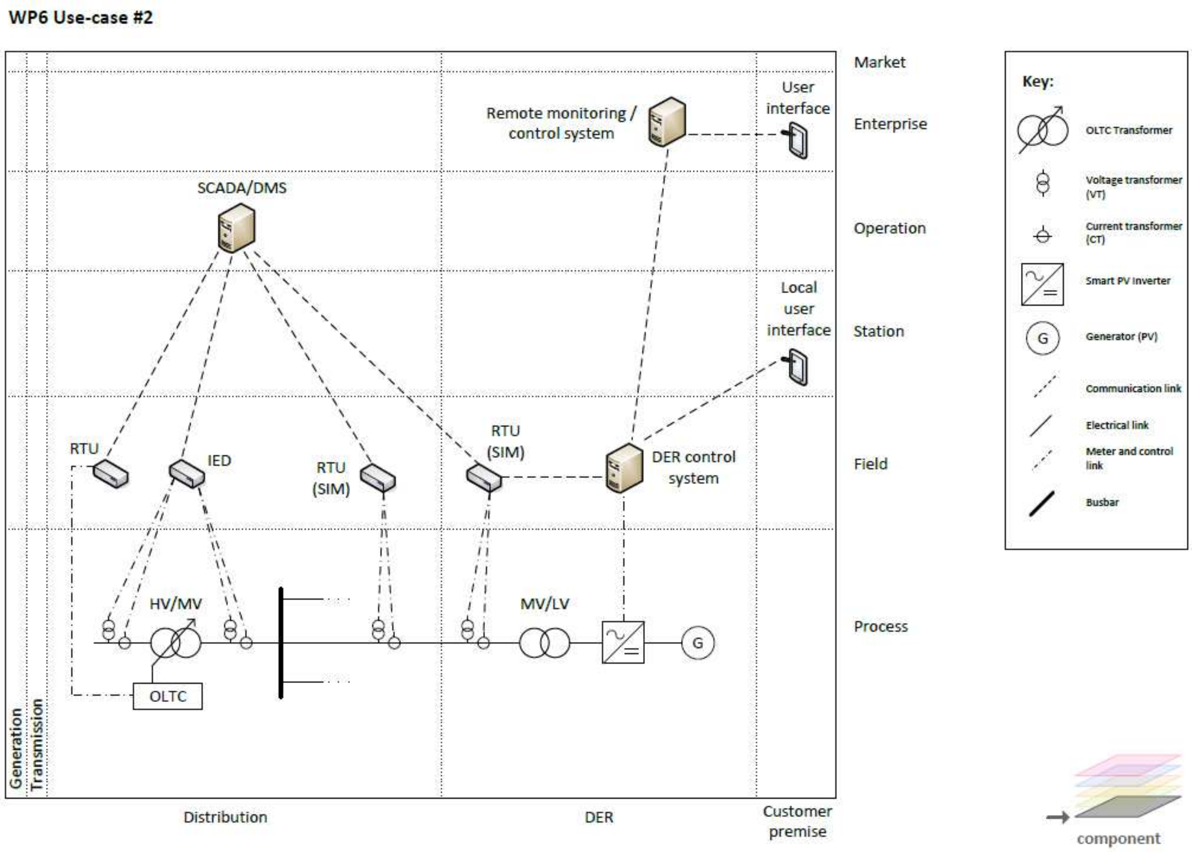


Figure 15 – SGAM for WP6_2 use case (component layer)

Note:
Detail WP6_2 use case description is included in annex 6.1 of this deliverable.
Detail SGAM for solution with all DER (PV, Wind, and Biogas) is included in annex 6.2.

2.3. Use case WP6_3 - Smart EV charging

Scope:
The aim is to quantify the impact of the Smart charging of EVs onto the distribution grid flexibility in case of emergency.

Objective:
Reduce maximum charging power of smart charging station in case of underfrequency, undervoltage or in case of receiving signal from DSO in case of emergency through narrow band simple one way PLC communication (also known as ripple control system) and power quality measurement during EV charging process (evaluated according to EN 50160).

Description:
CEZ Distribuce together with partners aims at testing the influence of smart EV charging stations functions to show their potential for increasing the network flexibility. This will be done through optimization of the future EV charging stations operation in order to prevent from power quality issues and to contribute to the system stability and flexibility without reduction of customer comfort. The Smart functions to be tested (first in a laboratory then in the field) are partial active power curtailment of EV charging in case of under frequency or under voltage in the DS and partial remote active power curtailment from DSO SCADA (through narrow band simple one way PLC communication which is a standard solution in CEZ Distribuce areas) in case of emergency.

Smart charging station solution is able to react on DSO commands and on under voltage or under frequency in distribution system:

a) in case voltage in the point of smart charging station connection is lower than predefined value, thus the smart charging station will reduce charging power – this will help to increase the voltage in the point of connection
b) in case frequency in the point of smart charging station connection is lower than predefined value, thus the smart charging station will reduce charging power – this will help to increase the frequency in the point of connection
c) in case of emergency, the DSO dispatcher will decide to reduce charging power and sends a command through narrow band simple one way PLC communication (example of connection of receiver is shown on figure 16), based on that signal, smart charging station will reduce charging power and this will help to reduce load in the selected area

Power quality during charging is monitored through DSO power quality management system (with using MEg38 devices with GPRS).

External RTUs which will be placed next to EV charging stations will provide voltage and frequency measurement (charging stations itself are not equipped with this measurement).

In terms of interoperability – WP6 will prove that flexibility provided by 2 different types of EV charging stations (together with auxiliary equipment) from 2 different manufactures will fullfill DSOs needs (curtailment of charging in case of under voltage, under frequency or in case of receiving signal form DMS). This will confirm interoperability (more manufactures are able to fulfill required functions), scalability (this solution could be integrated for every EV charging station) and replicability (could be installed anywhere). Protocols used for the Siemens solution are described in SGAM – please check annex 6.2.

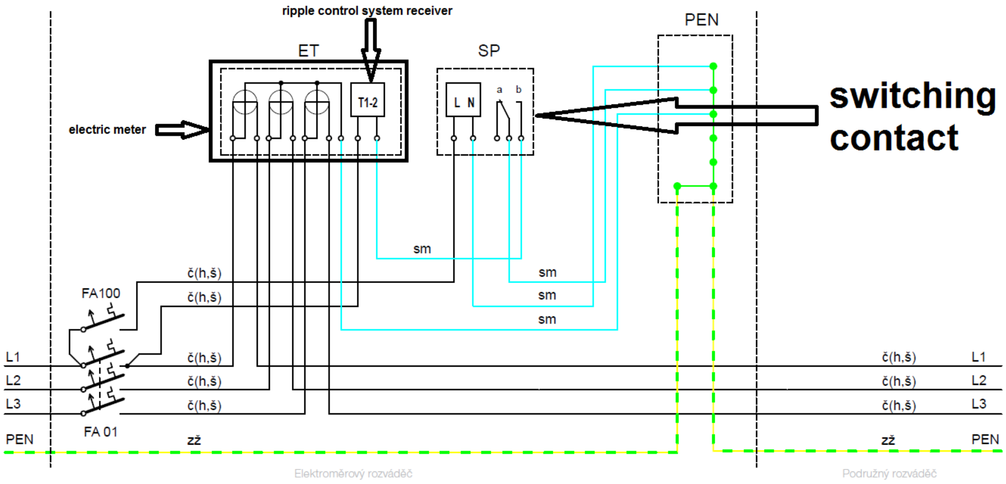


Figure 16 - Example of connection of narrow band simple one way PLC communication system used in CEZ Distribuce areas

Power quality during EV charging process will be also monitored in detail. EV charging process could reduce the power quality especially in case powerful AC single phase internal chargers in EVs are used. An example of powerful single phase charging is shown below:

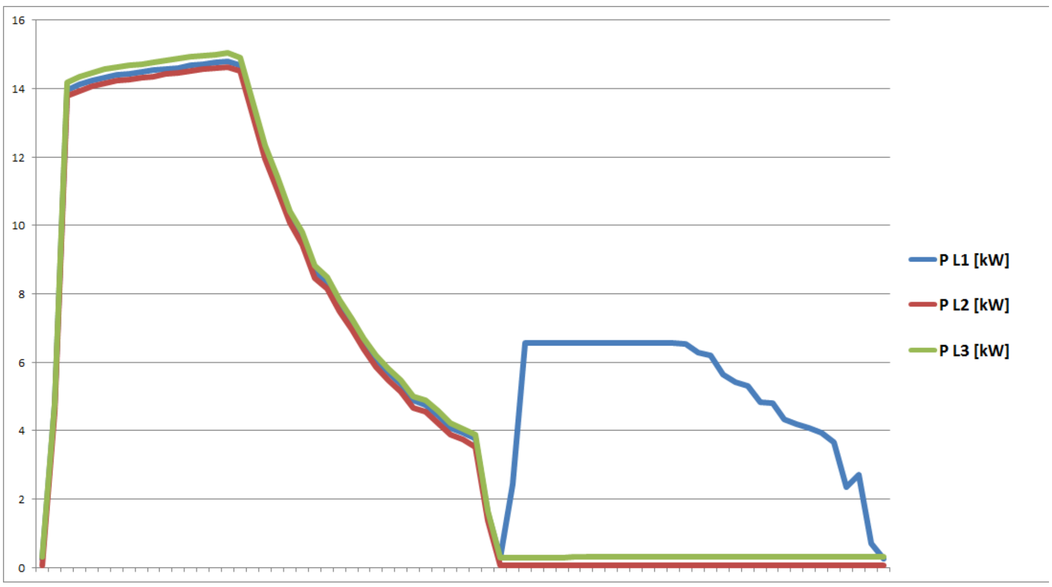


Figure 17- Example of charging process (left – DC connector powered symetricaly from 3 phases AC grid; right – AC connector powered symetricaly from 3 phase AC grid where EV contains single phase AC charger only; axis x = time, axis y = active power in kW)

For WP6_3 testing, equipment from project partners (Schneider Electric and Siemens) will be used. Charging stations used for the project will not be public as this activity (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). Charging station will be installed in two different CEZ Distribuce private areas (Hradec Kralove and Decin) and will be used only for charging of CEZ Distribuce EVs. Lab test scenarios are described in chapter 5.

SGAM – Schneider Electric

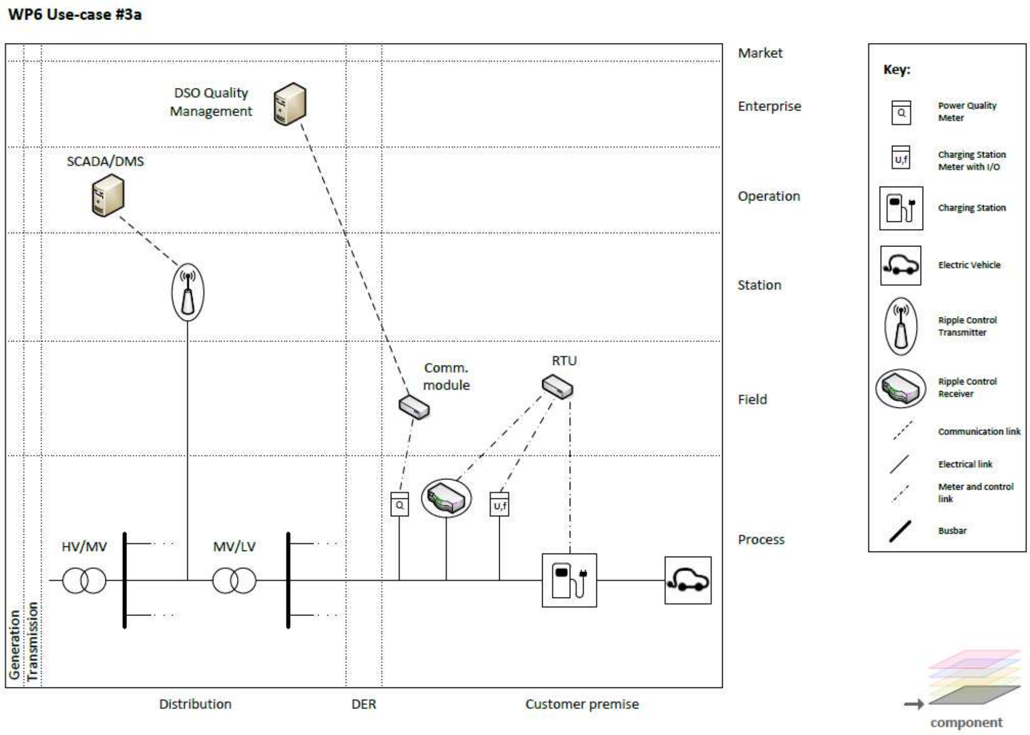


Figure 18 – SGAM for WP6_3 use case (component layer) – Schneider Electric

Figure 19 - Schneider Electric EV link parking charging station

Figure 20 - Schneider Electric EV Smart Wallbox charging station

SGAM – Siemens

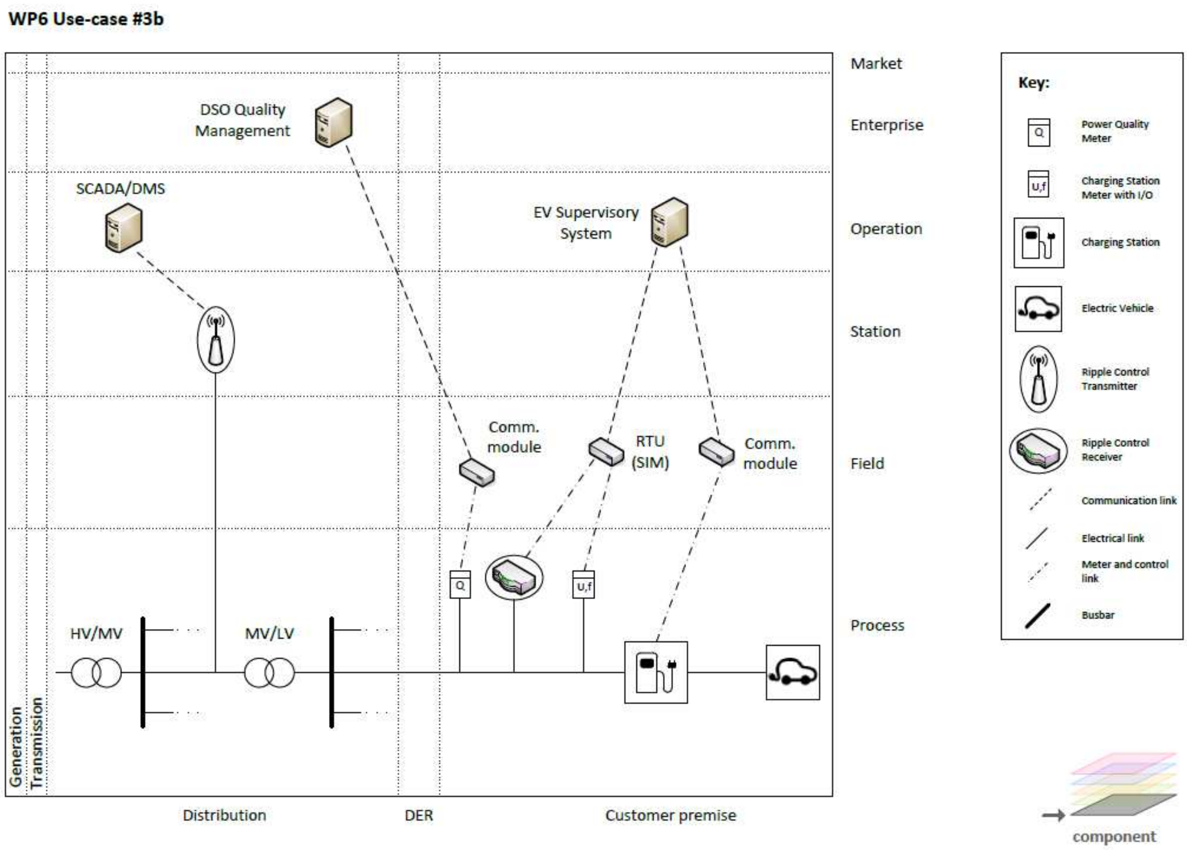


Figure 21 – SGAM for WP6_3 use case (component layer) – Siemens

Figure 22 - Siemens EV charging station (with configuration 2x22kW Mennekes connectors)

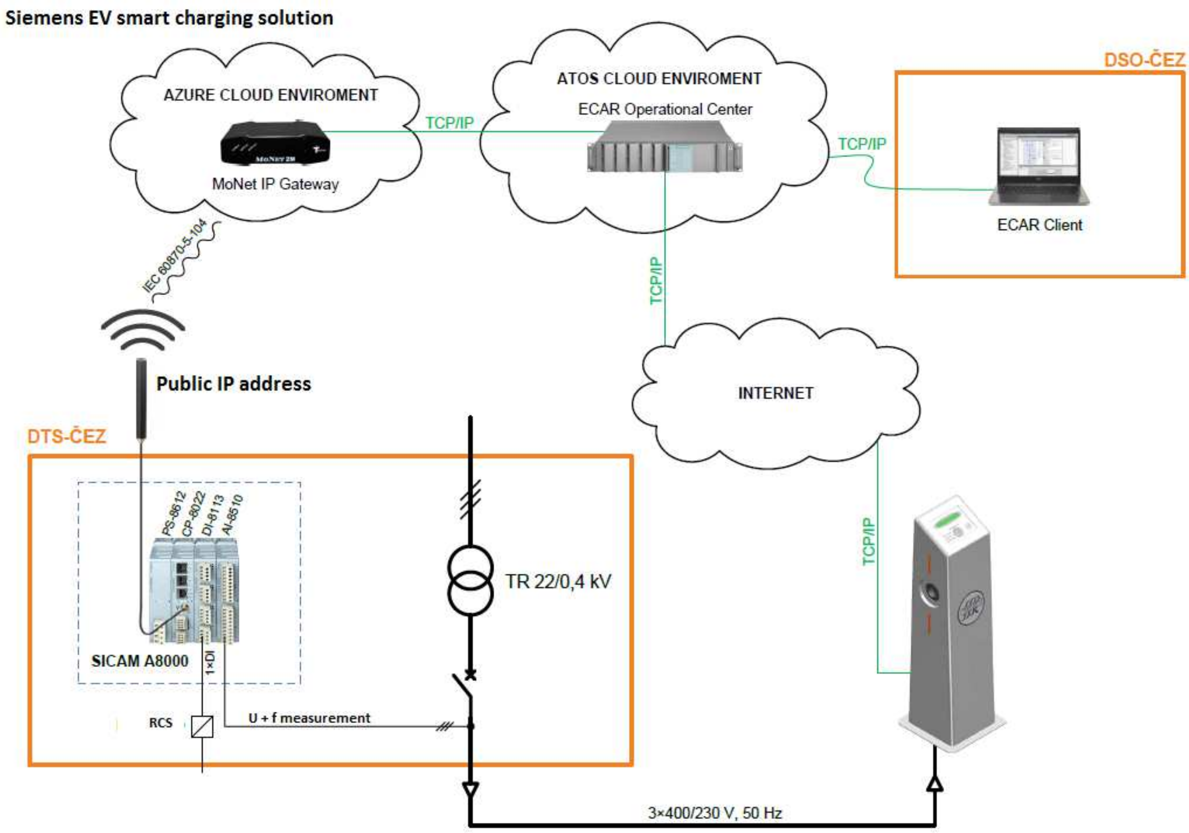


Figure 23 - Siemens EV smart charging solution

<u>Note:</u>
Detail WP6_3 use case description is included in annex 6.1 of this deliverable.
Detail SGAM for solution with Schneider Electric EV charging stations is included in annex 6.2.
Detail SGAM for solution with Siemens EV charging station is also included in annex WP6.2.

2.4. Use case WP6_4 - Smart energy storage

Scope:
The aim of the use case is field demonstration of smart PV inverters with batteries which enables increasing of DER hosting capacity in one area thanks to the peak PV feed in shaving and to demonstrate the provisioning of flexibility for DSO in case of emergency.

Objective:
Increase of DER hosting capacity in LV grids thanks to the installation of smart PV inverters with batteries (capacity between 4,5kWh to 9kWh are expected) which allow increasing self-consumption levels and peak shaving of PV production and thus securing the power quality according to EN 50160 standard. Delivery of active power from batteries in case of underfrequency, undervoltage or in case of receiving signal from DSO through narrow band simple one way PLC communication (emergency functions).

Description:
CEZ Distribuce will test the influence of using the residential energy storage systems (PV + battery) on the PV peak shaving in one LV distribution network and assesses the potential of grid-connected energy storage systems (for increasing the flexibility by providing grid services). The smart energy storage functions which are going to be tested are: active power injection in case of DSO request (remote control) and active power injection in case of under frequency or under voltage in the distribution network (autonomous, local-only control). Customer participation is essential. Testing the influence of residential energy storage systems on solar peak shaving helps determining how these systems affect the power quality and how they contribute to avoiding congestions in the distribution network.

PV + battery solution will be able to react on DSO commands and on under voltage or under frequency in distribution system:

a) in case voltage in the point of PV inverter + battery connection is lower than predefined value, thus 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, thus 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 (Use_case_WP6_4.pdf).

For remote control of battery power, Fronius develops an InterFlex-specific prototype interface (see figure 28).
Maximum feed in power of the system (PV + battery) back to the distribution grid will limited to 50 % of the PV installed capacity in order to increase utilization of production in the particular residential house with PV + battery system.

MV/LV OLTC transformer is used for simulation of different voltage levels in LV grid. Taps could be regulated through DMS.

Power quality is monitored in the LV grid through DSO power quality management system. For use case evaluation also data from DSO billing system and data from smart PV inverter could be used.

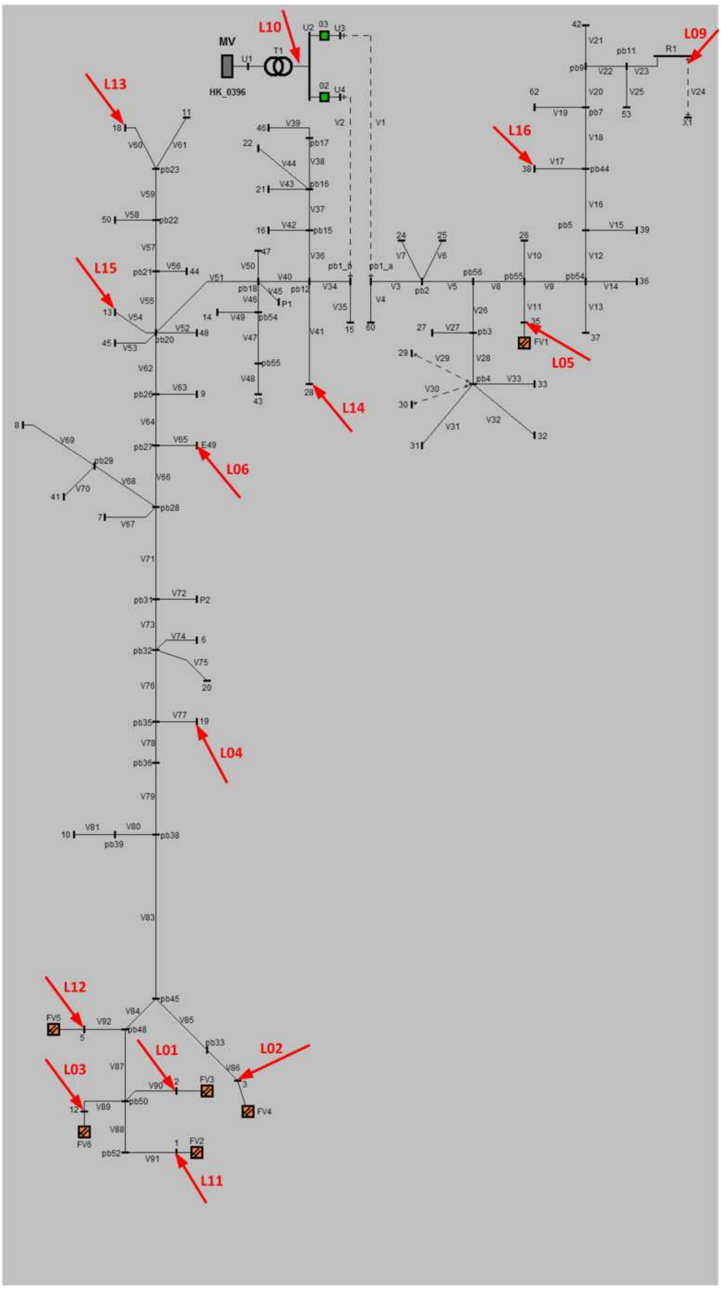


Figure 24 - Use case WP6_4 - LV grid topology in Luzany area with marked places for installation power quality measurement devices (red arrows)

For WP6_4 Fronius and Schneider Electric smart energy storage devices will be used. Number of PV systems + batteries that will be included in WP6 for demonstration are listed in chapter 4 - Customers recruitment.

<u>SGAM – Fronius</u>

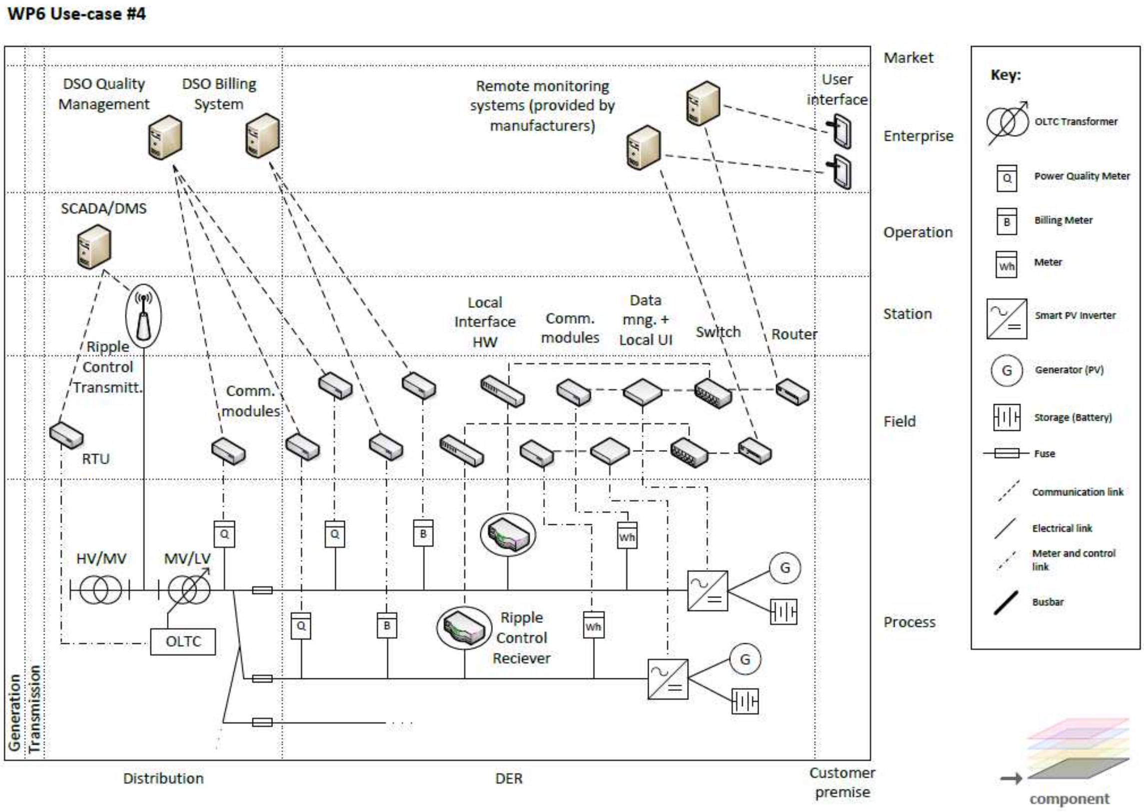


Figure 25 – SGAM for WP6_4 use case (component layer) – Fronius

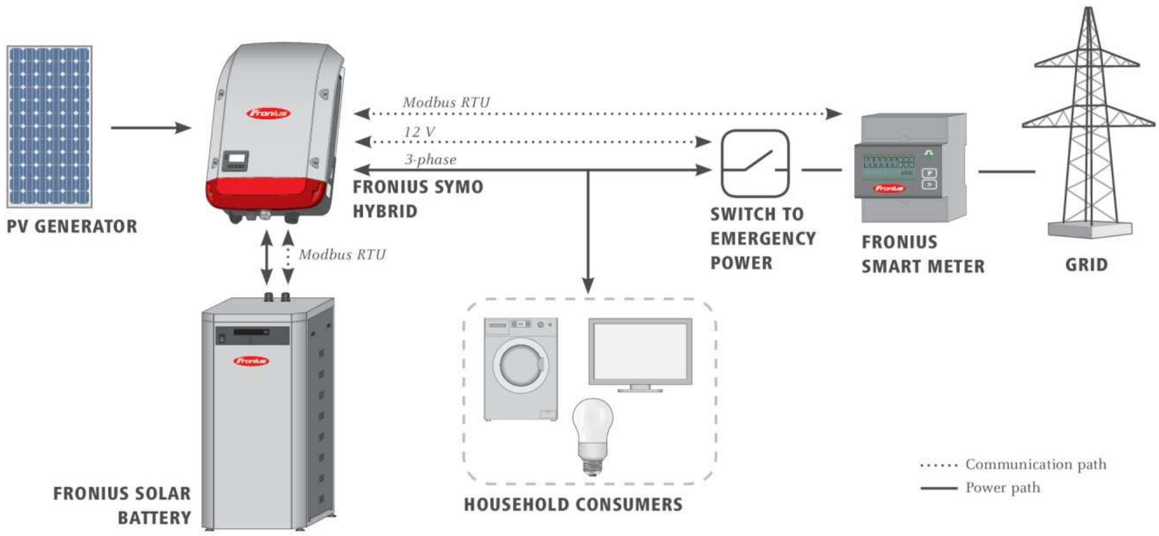


Figure 26 - Fronius energy storage system (PV inverter, battery and smart meter) – base for smart energy storage solution

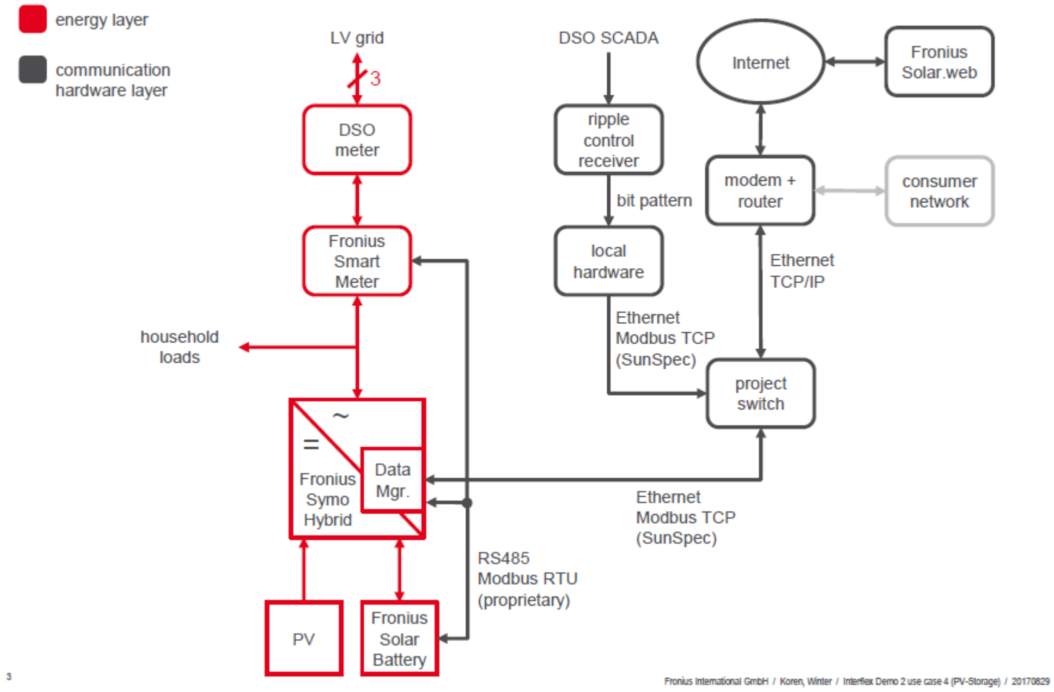


Figure 27 - Interflex-specific Fronius smart energy storage system under WP6_4 use case

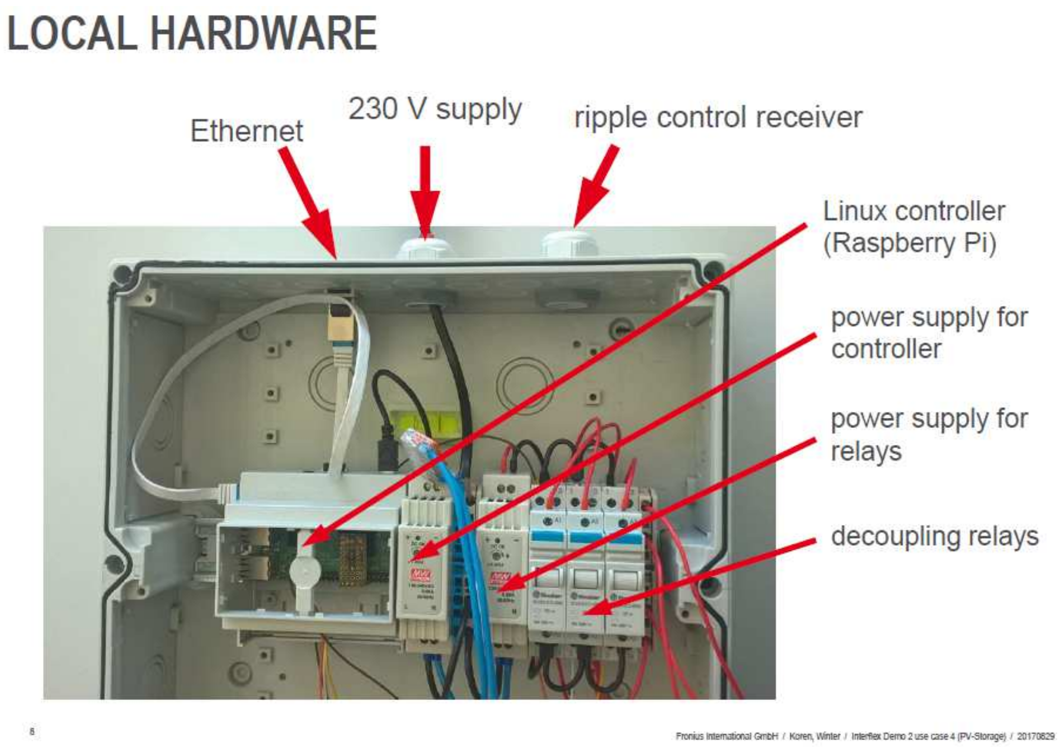


Figure 28 – InterFlex-specific Fronius local interface for remote-control of smart energy storage system under WP6_4 use case (will be used for indoor instalation)

SGAM – Schneider Electric

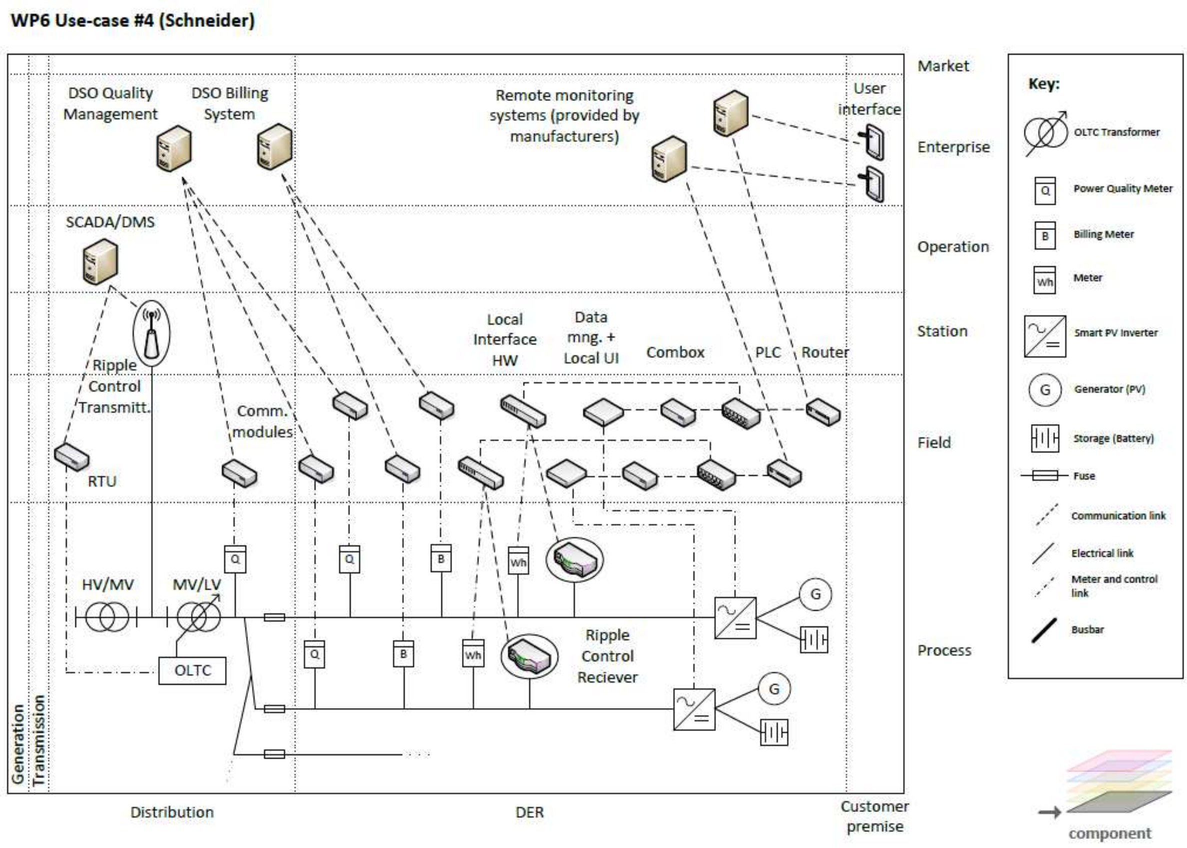


Figure 29 – SGAM for WP6_4 use case (component layer) – Schneider Electric

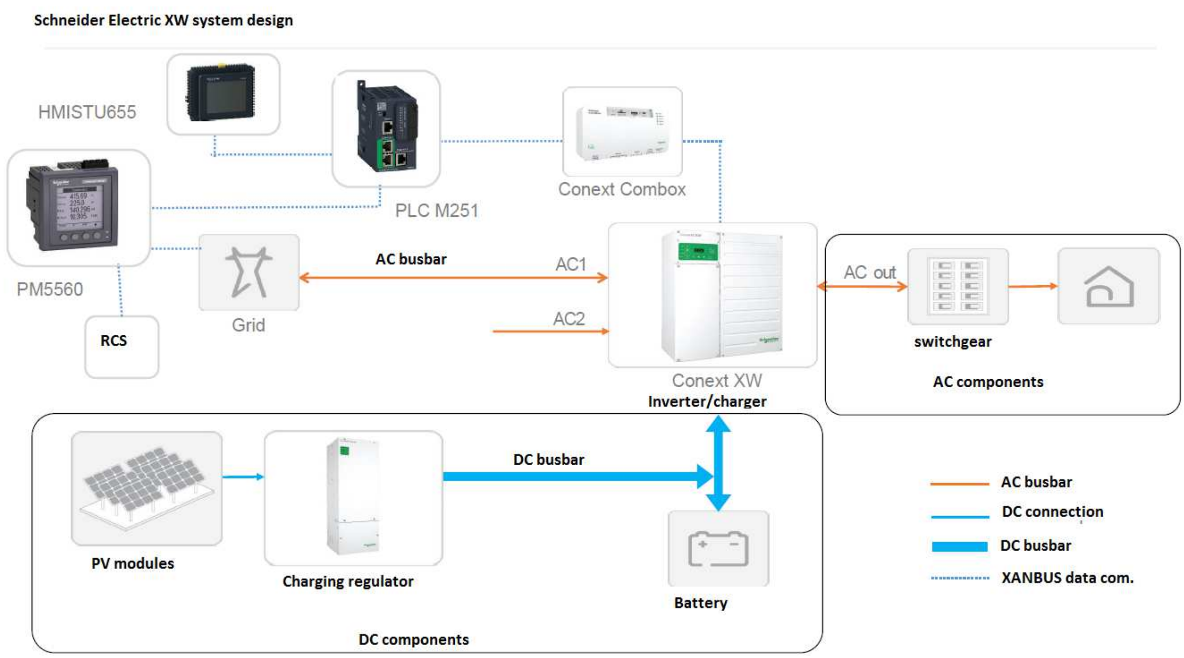


Figure 30 - Schneider Electric smart energy storage system (PV inverter, battery and smart meter)

<u>Note:</u>
Detail WP6_4 use case description is included in annex 6.1 of this deliverable.
Detail SGAM for solution with Fronius PV inverter+battery system is included in annex 6.2.
Detail SGAM for solution with Schneider Electric PV inverter+battery system is also included in annex 6.2.

3. WP6 KPI DEFINITION

The purpose of KPIs is to measure and evaluate the potential of smart solutions implemented in WP6. KPIs defined in chapter 3 are internal for WP6. According to DoW, WP6 KPIs will be evaluated at the end of InterFlex project. The full KPI definition is defined in Annex 6.3.

3.1. Increasing DER hosting capacity

Strategic objective of this KPI is to monitor increased DER integration in distribution grids.

This KPI will measure the potential increase of hosting capacity for distributed energy resources with Smart Grid solutions compared to the baseline situation where no “smart” actions are performed on the network. The indicator will give a statement about the additional DER power that can be connected to the network thanks to Smart Grid solutions without the need for conventional reinforcements (i.e. new grid lines).

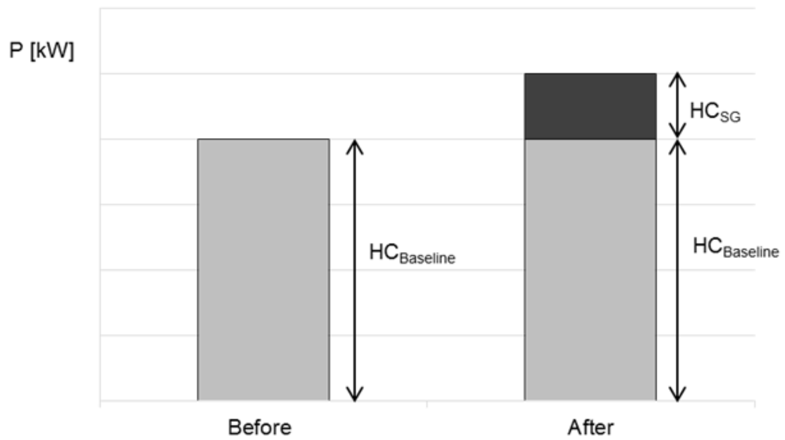


Figure 31 - Comparison of DER hosting capacity for baseline and after smart grid solution implementation

This KPI will apply on WP6_1, WP6_2 and WP6_4 use cases (separately for each use case).

$$HC_{\%} = \frac{HC_{SG} - HC_{Baseline}}{HC_{Baseline}} \times 100$$

HC_{SG}	Hosting Capacity for DER with Smart Grid solutions (kW). This hosting capacity should measure DER that can be connected (or that are already connected) to the grid after the Smart Grid solution is implemented.
$HC_{Baseline}$	Hosting Capacity for DER in Baseline situation (kW). This hosting capacity should measure DER that can be connected to the grid before the Smart Grid solution is implemented.

Note:
Positive value: HC gain
Negative value: HC loss

Expectations:
Increase of DER hosting capacity for WP6 use cases:

WP6_1: +25%
WP6_2: +25%
WP6_4: +5%

Increasing of DER hosting capacity in WP6 will not cause power quality issues (power quality limits are defined in EN 50160).

Methodology:
Evaluation of baseline DER hosting capacity will be performed by simulation in DNCalc software by using baseline grid topology data from GIS system according to the standard rules for calculation of DER hosting capacity (standard approach).

After smart solution implementation - evaluation of DER hosting capacity will be performed by simulation in DNCalc software by using grid topology data from GIS system (standard approach) and with new rules for calculation of DER hosting capacity or installed power of DER physically connected to the grid after smart solution implementation.

Data collection:
For KPI evaluation, following data will be used:

1) Number of DER which is possible to connect to the grid before smart solution implementation

2) Number of DER connected physically to the grid after smart solution implementation or hosting capacity calculated with new rules for DER hosting capacity calculation

3) Baseline grid topology for use cases WP6_1, WP6_2 and WP6_4 downloaded from GIS system.

3.2. Power quality (according to the standard EN 50160)

Strategic objective of this KPI is to monitor that power quality (voltage levels) will not be negatively affected by smart solution implementations and have to sustain within tolerance given by EN 50160 power quality standard.

With an increasing presence of DER in the LV network, line voltage profiles will vary not only because of the presence of different loads along the grid, but also the introduction of variable generation. This phenomenon must be clearly monitored and it must be ensured that desired voltage levels are kept within the defined standard limits according to the EN 50160 standard.

In this way this KPI measures the number of voltage samples fulfilling the ± 10% voltage limits, as defined in EN 50160 standard before and after the smart grid solution implementation.

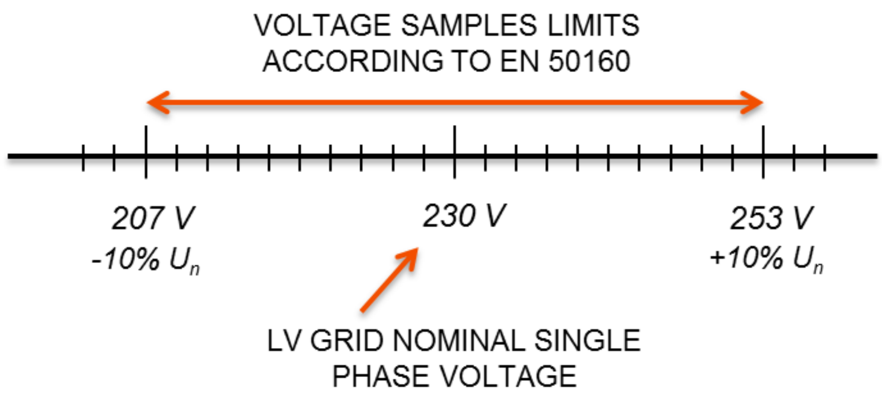


Figure 32 - Example of voltage limits according to the EN 50160 standard

This KPI will apply on WP6_1, WP6_2, WP6_3 and WP6_4 use cases (separately for each use case).

Related to percentage of measured voltage samples fulfilling the ± 10% voltage limits:

$$\Delta U_{\text{limit}\,\%} = \frac{U_{\text{limit,SG}} - U_{\text{limit,baseline}}}{U_{\text{limit,baseline}}} \times 100$$

$\Delta U_{\text{limit}\,\%}$	Percentage improvement in measured number of voltage samples fulfilling the ± 10% voltage limits, according to EN 50160 standard
$U_{\text{limit,SG}}$	Number of measured voltage samples fulfilling the ± 10% voltage limits condition according to EN 50160 standard (with smart grid solutions)
$U_{\text{limit,baseline}}$	Number of voltage samples fulfilling the ± 10% voltage limits condition as defined by EN 50160 standard (baseline situation) measured before smart grid implementation.

<u>Expectations:</u>
Number of measured voltage samples, not fulfilling the ± 10% voltage limits according to EN 50160, will not increase after implementation of smart grid solutions for all use cases (WP6_1, WP6_2, WP6_3 and WP6_4).

<u>Methodology:</u>
Baseline power quality data for evaluation of KPI for use cases WP6_1, WP6_2, WP6_3 and WP6_4 will be downloaded from power quality management system (DAM) or directly from existing power quality measurement devices installed in the grid (MEg30) or downloaded from DMS/SCADA system.

After smart solution implementation - power quality data for evaluation of KPI for use cases WP6_1, WP6_2, WP6_3 and WP6_4 will be downloaded from power quality management system (DAM) or directly from newly installed power quality measurement devices installed in the grid (MEg38) or downloaded from DMS/SCADA system.

<u>Data collection:</u>

For KPI evaluation, following data will be used:

1) Number of voltage samples fulfilling the ± 10% voltage limits condition as defined by EN 50160 standard (baseline situation) measured before smart grid implementation

2) Power quality measurements (from MEg30 devices through DAM or downloaded directly; or from DMS/SCADA)

3) Number of measured voltage samples fulfilling the ± 10% voltage limits condition according to EN 50160 standard (with smart grid solutions)

4) Power quality measurements (from MEg38 devices through DAM or downloaded directly; or from DMS/SCADA)

3.3. EV charging stations load curtailment in emergency situations

Strategic objective of this KPI is to monitor decrease of EV charging power in case of emergency situations in distribution grid (monitoring of flexibility).

This KPI will measure the decrease of EV charging power of smart EV charging station in case of under voltage or under frequency in the grid and also in case of DSO command (send through narrow band simple PLC communication). Standard EV charging stations are not flexible and are not able to reduce charging power in case of emergency situations autonomously.

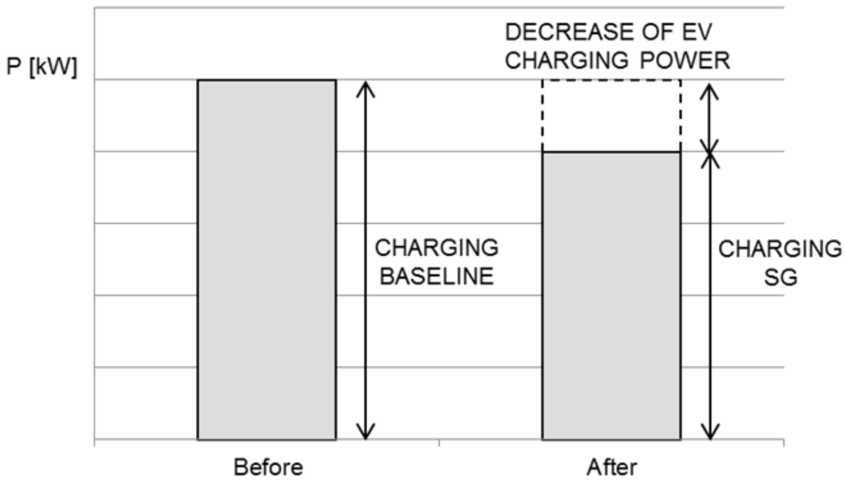


Figure 33 - Example of EV charging station charging power decrease.

This KPI will apply on WP6_3 use case.

$$\text{CHARGING}_{\%} = \frac{\text{CHARGING}_{\text{SG}} - \text{CHARGING}_{\text{Baseline}}}{\text{CHARGING}_{\text{Baseline}}} \times 100$$

$\text{CHARGING}_{\text{SG}}$ Charging power with Smart Grid solutions (kW).

$CHARGING_{Baseline}$	Charging power in Baseline situation (kW) – without any curtailment.

Note:
Positive value: charging power increase
Negative value: charging power decrease

Expectations:
Decrease of EV charging power in case of emergency situations in distribution:
WP6_3: -40%

Methodology:
Evaluation of nominal EV charging station power will be checked from the device specification (manufactures datasheet).

After smart solution implementation - evaluation of EV charging station charging power curtailment in case of under frequency or in case of under voltage or in case of DSO command will be evaluated by field tests.

Data collection:
For KPI evaluation, following data will be used:

1) Nominal charging power of EV charging station

2) Manufacturer of EV charging station

3) Charging power of EV charging station in emergency situation (or during field test)

4) Meg38 power quality device

5) Baseline EV charging stations charging power values will be checked from manufactures datasheets

3.4. PV feed-in peak shaving

Strategic objective of this KPI is to monitor decrease of PV feed-in peak thanks to the installation of home energy storage systems/batteries (monitoring of flexibility).

This KPI will measure the decrease of PV feed-in peak which overflow to the distribution grid thanks to the installation of PV together with home energy storage systems. PV + home energy storage systems will secure lower surplus of solar power to the distribution grid thanks to the smart control.

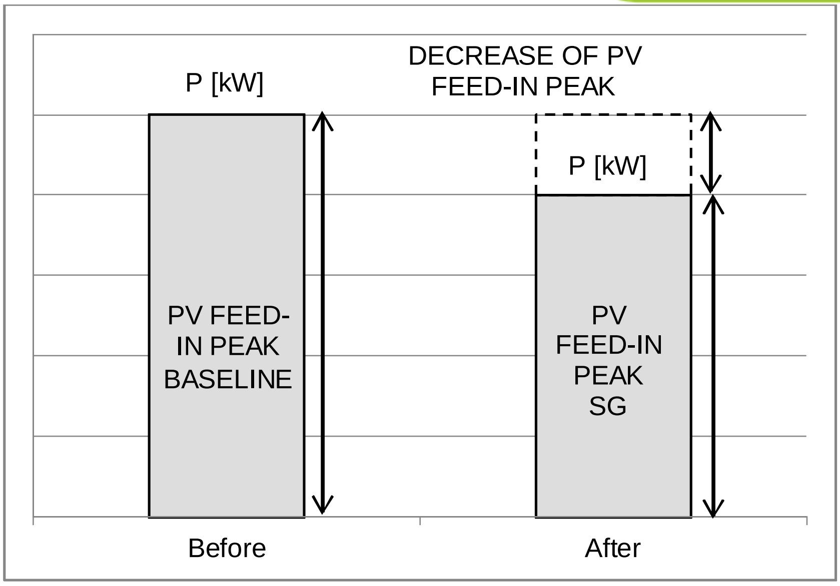


Figure 34 - Example of PV feed-in peak shaving.

This KPI will apply on WP6_4 use case.

$$\text{PV PEAK}_{\%} = \frac{\text{PV PEAK}_{\text{SG}} - \text{PV PEAK}_{\text{Baseline}}}{\text{PV PEAK}_{\text{Baseline}}} \times 100$$

$PV\ PEAK_{SG}$	PV feed-in peak with Smart Grid solutions (kW).
$\text{PV PEAK}_{\text{Baseline}}$	PV feed-in peak in Baseline situation (kW) – without any smart charging of home energy storage systems.

<u>Note:</u>
Positive value: PV feed-in peak increase
Negative value: PV feed-in peak decrease

<u>Expectations:</u>
Decrease of PV feed-in peak:
WP6_4: -20%

<u>Methodology:</u>
Evaluation of PV feed-in peak will be checked from the PV systems specifications (sum of PV modules power under Standard Test Conditions).

After smart solution implementation (smart charging of home energy storage) - evaluation of PV feed-in peak will be secured by field measurements for PV systems.

<u>Data collection:</u>
For KPI evaluation, following data will be used:

1) PV feed-in peak determined as a sum of installed PV power

2) Manufacturer of PV modules

3) PV feed-in peak after smart charging of home energy storage is implemented

4) Meg38 power quality device

5) Baseline PV module power values under Standard Test Conditions will be checked from manufactures datasheets

4. CUSTOMERS RECRUITMENT

For demonstration of WP6 solutions, specific customers are needed in order to prove use cases under real operation conditions. In use case WP6_1, residential customers with PV are needed for testing of smart PV inverters. In use case WP6_2, owners of large DER installations are needed for testing volt-var control on MV. In use case WP6_4, residential customers with PV and home energy storage systems are needed in order to test smart energy storage functions. CEZ Solarní company as a project partner is responsible for recruitment of customers for WP6_1, WP6_4 and partially for WP6_2 (recruitment of large PV system owner). Customers recruitment is key part of the project, otherwise demonstration of WP6 solution under real distribution grid conditions is not possible.

Customers who are recruited and listed in following chapters cooperate on voluntary basis. Equipment for demonstration of use cases WP6_1, WP6_4 and partially WP6_2 is delivered by CEZ Solarni as a project partner. PV systems and batteries under use case WP6_1 and WP6_4 are not cofinanced by InterFlex H2020 project.

4.1. Use case WP6_1 smart PV inverters

For use case WP6_1, CEZ Solarni recruited customers in 2 selected areas – Divisov and Teptin. The installation of PV systems with smart PV inverters will be finished in 2018 (as it is foreseen according to DoW). CEZ Solarni contacted all customers in selected areas and submitted them offers for purchase and installation of PV systems with smart PV inverters which are needed for demonstration. In order to secure customers participation, CEZ Solarni offered great discounts on equipment for customers. In return, customers must comply with project requirements. Details on baseline DER hosting capacity calculations compared with DERs connected thanks to smart PV inverters and smart energy storage are in scope for D6_2 Implementation of solution.

Divisov a)	4.94 kWp
Divisov b)	4.94 kWp
Divisov c)	4.94 kWp
Divisov d)	4.94 kWp

Figure 35 - Customers recruited in Divisov area

Figure 36 - Selected locations for PVinstallations in Divisov area

Teptin a)	9.81 kWp
Teptin b)	9.81 kWp
Teptin c)	3.12 kWp
Teptin d)	3.12 kWp

Figure 37 - Customers recruited in Divisov area

Figure 38 - Selected locations for PVinstallations in Teptin area

In case that during the installation process some of above listed selected customers will unexpectedly refuse the participation, CEZ Solarni is ready to submit offers for other customers in selected areas in order to secure installation of PV systems with sufficient installed capacity which is needed for the demonstration.

Above listed selected customers will provide enough 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.

4.2. Use case WP6_2 – volt var control of DER on MV

In order to test volt-var control on MV, 3 different types of DERs were selected in the beginning of the InterFlex project. The Criterias for selection of DERs was the ability to generate/consume reactive power by generators/inverters installed on DERs and willingness of DER owners for cooperation on this topic with CEZ Distribuce under InterFlex project. DER owners are not project partners, they cooperate on voluntary basis. CEZ Distribuce doesnt 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 3 different types of DERs with different technology (wind, PV and Biogas) in order to prove interoperability of designed solution.

PV Zamberk	1.1 MWp
Wind park Koprivna	4.6 MW
Biogas station Detenice	1.25 MW

Figure 39 - DER recruited for volt var control

Figure 40 - PV park Zamberk – 1.1 MWp of installed capacity

Figure 41 - Biogas station Detenice – 1.25 MW of installed capacity

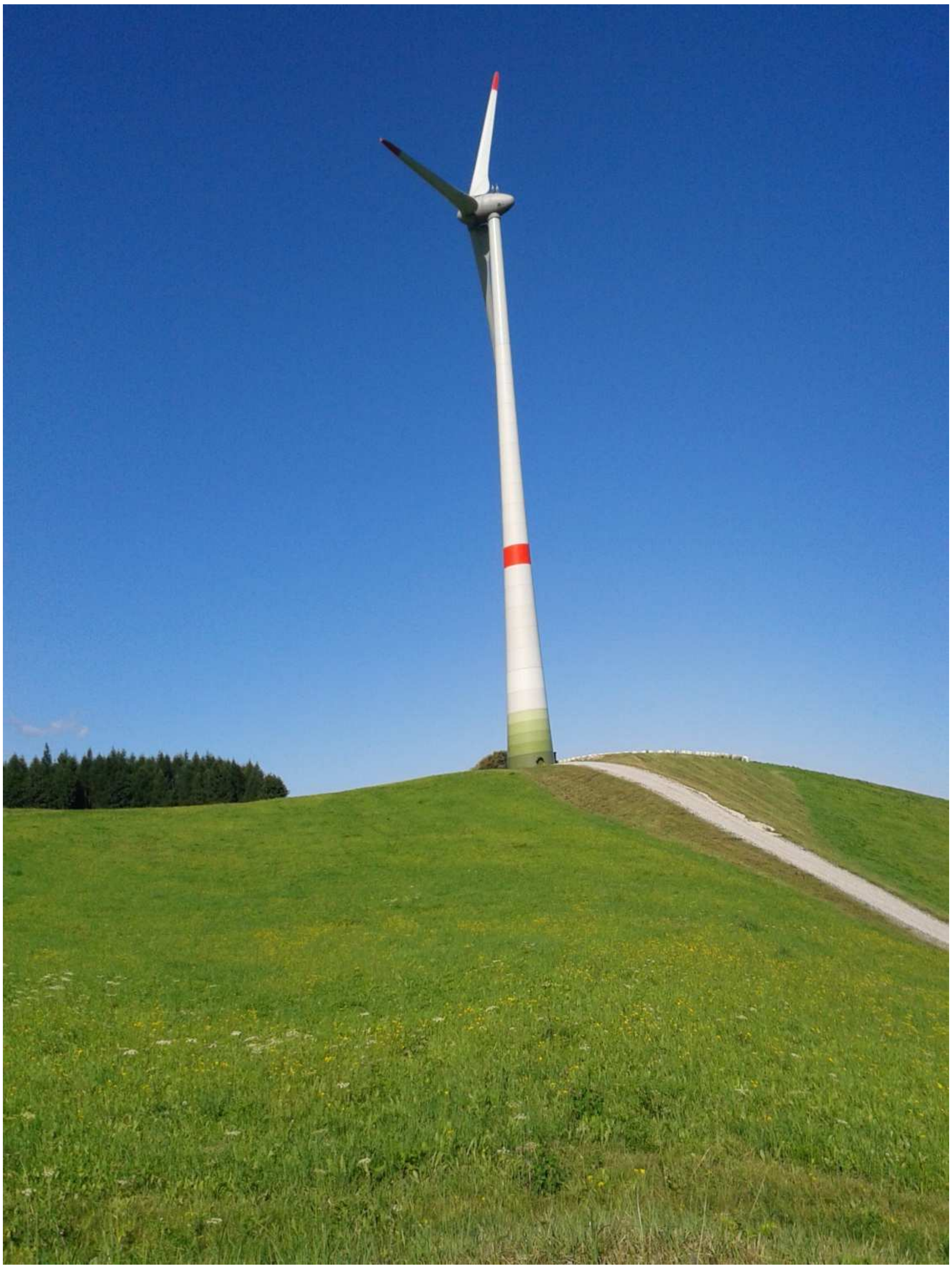


Figure 42 - Wind park Koprivna – 4.6MW of installed capacity

The installation and commissioning of volt-var control systems on above listed DER connected to MV grid will be finished in 2018 (as it is foreseen according to DoW).

4.3. Use case WP6_4 – smarsmart energy storage

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). CEZ Solarni contacted all customers in selected area and submitted them offers for purchase and installation of PV systems with smart PV inverters and batteries which are needed for demonstration. In order to secure customers participation, CEZ Solarni offered great discounts on equipment for customers. In return, customers must comply with project requirements. Details on baseline DER hosting capacity calculations compared with DERs connected thanks to smart PV inverters and smart energy storage are in scope for D6_2 Implementation of solution.

Luzany a)	5.2 kWp
Luzany b)	4.94 kWp
Luzany c)	4.94 kWp
Luzany d)	4.94 kWp
Luzany e)	4.94 kWp

Figure 43 - Customers recruited in Luzany area

Figure 44 - Selected locations for PV+energy storage installations in Luzany area

In case that during the installation process some of above listed selected customers will unexpectedly refuse the participation, CEZ Solarni is ready to submit offers for other customers in selected area in order to secure installation of PV systems and batteries with sufficient installed capacity which is needed for the demonstration.

Above listed selected customers will provide enough installed capacity of PV systems and batteries which is needed for demonstration of WP6 solution and KPIs fulfilment in 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.

5. 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 and solution for use cases WP6_1, WP6_3 and WP6_4 in order to prove proper function before the solutions are implemented in field. The other purpose of lab test is to confirm interoperability of selected solutions in order to 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 for WP6_1, WP6_3 and WP6_4 in 2018 is foreseen. However this additional testing in will not delay schedule for implementation of solution in 2018.

5.1. WP6_1: Increase the DER hosting capacity of LV distribution networks by combining smart PV inverter functions (demonstration of Q(U) and P(U))

5.1.1. Implemented functions and functions to be tested

WP6_1 is based on the following two local control functions, which can be used separately or in combination:

- Q(U): control of the reactive power exchange (injection or consumption) according to the voltage
- P(U): reduction of the injected active power in case of over-voltage

5.1.2. Scope of the lab tests / equipment under test

Since this use-case purely relies on local control functions, the communication infrastructure is not in the scope of the testing, as visible on the SGAM diagram below.

The devices used for the testing (Equipment Under Test - EUT) are shown below:

	Fronius	**Schneider Electric**
Model	Symo Hybrid 5.0-3-S[1]	Conext RL 3000 E[2] External hardware for P(U)
AC nominal output (kW)	5.0	3.0
AC nominal apparent power (kVA)	5.0	3.0
Grid connection	3~NPE 400 V	1~NPE 230 V
Power factor range	0.85	0.80

Figure 45 - EUT for WP6_1

[1] For WP6, the devices used in the field will be from the series *Fronius Symo (for use case WP6_1)* or Symo Hybrid *(for use cases WP6_1 and WP6_4)*. Both types of PV ivnerters are equipped with the same network support function.
[2] For the P(U) function, additional hardware is necessary (not shown on this figure)

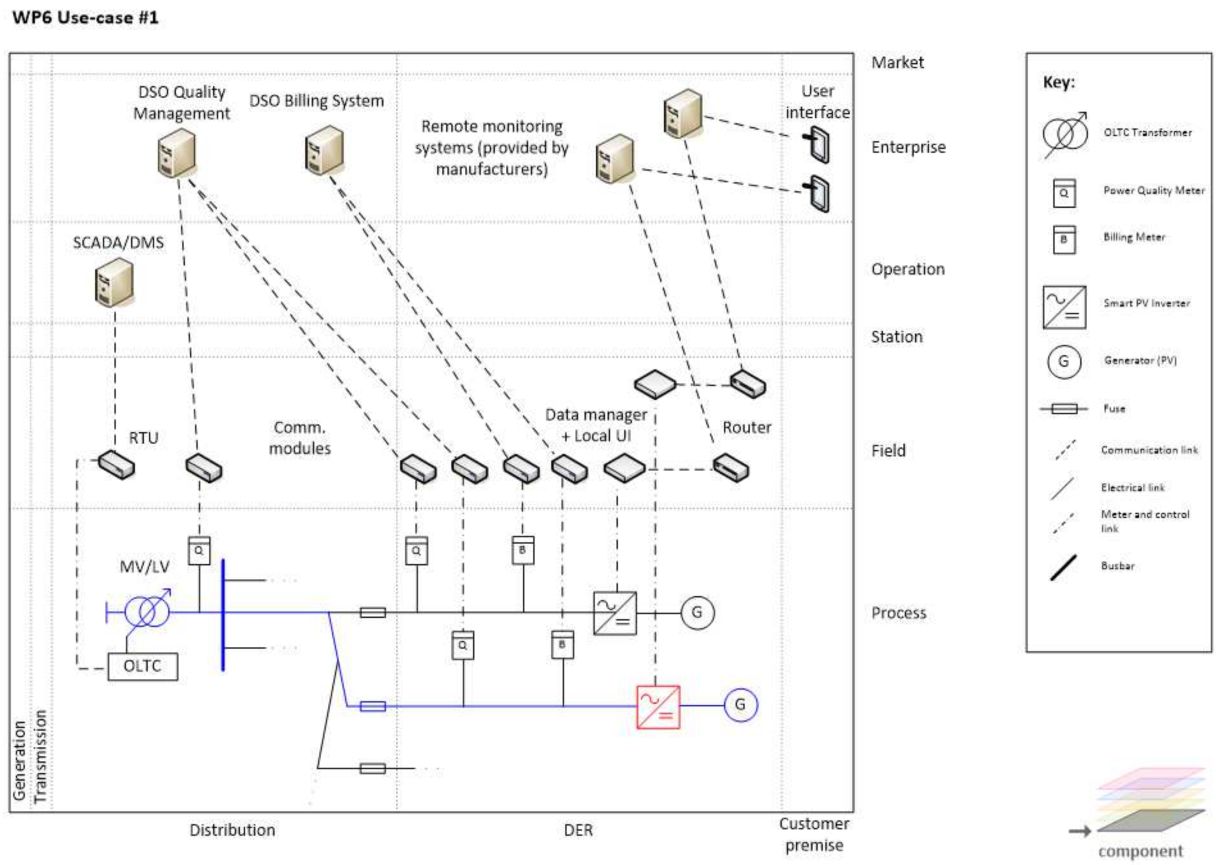


Figure 46 - Scope of lab tests shown on the SGAM description of WP6_1 (red: Equipment Under Test / blue: emulated part)

5.2. WP6_3: Smart EV charging

5.2.1. Implemented functions and functions to be tested

WP6_3 “Smart EV charging” consists in constraining the charging of e-vehicles in case of network constraints. The charging stations allow the reduction of the charging power (to 50 % of the maximal power for each phase) in case of:

- Under-frequency (function implemented locally – default threshold: 49.9 Hz). A reset/restart after f > 49.9Hz for 5 minutes is included according to CEZ Distribuce requirements.
- Under-voltage (function implemented locally – default threshold: 95 % of the nominal voltage = 380 V, reset when the voltage has remained for at least 5 minutes above the threshold)
- Request from the DSO (function requiring a communication interface (narrow band simple one way PLC communication))

5.2.2. Scope of the lab tests / equipment under test

Since this use-case relies on both local and centralized functions, the communication infrastructure is in the scope of the testing, as visible on the SGAM diagrams) for the two implementations of WP6_3 (Schneider Electric = 3a and Siemens = 3b).

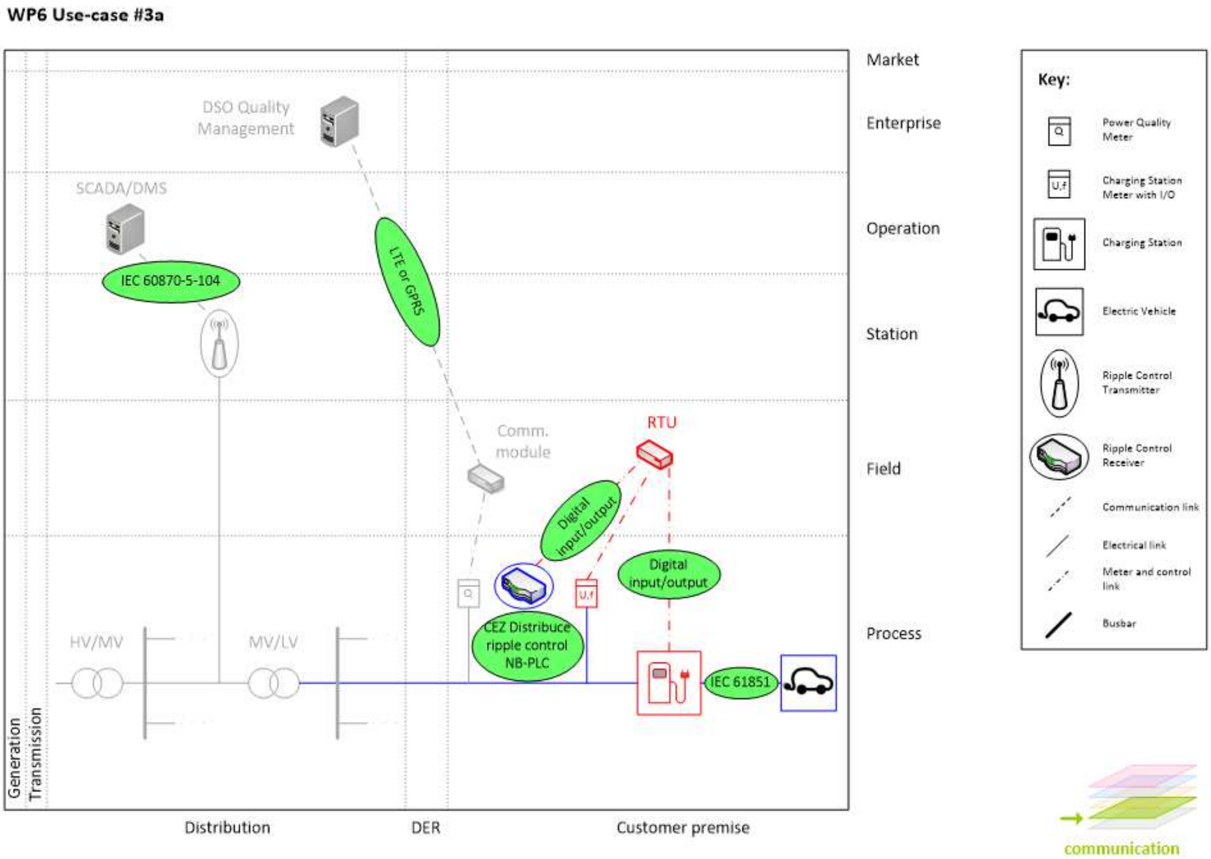


Figure 47- Scope of lab tests shown on the SGAM description of 3a (Schneider Electric) (red: Equipment Under Test / blue: emulated part)

The devices used for the testing (Equipment Under Test - EUT) are shown below:

	Schneider Electric		Siemens
Model	- EV Link Parking - measurement device (outside) the charging station	- EVlink Smart Wallbox - measurement device (outside)[3]	DUCATI energia
AC maximal power (kW)	22.1 kW and 2 kW	22.1 kW and 2 kW (only one at the same time)	22.1 x 2
Grid connection	3~NPE 400 V	3~NPE 400 V	3~NPE 400 V

Figure 48- EUT for WP6_1

[3] Only one power measurement device will be provided for the lab tests (for the - EV Link Parking and the EVlink Smart Wallbox)

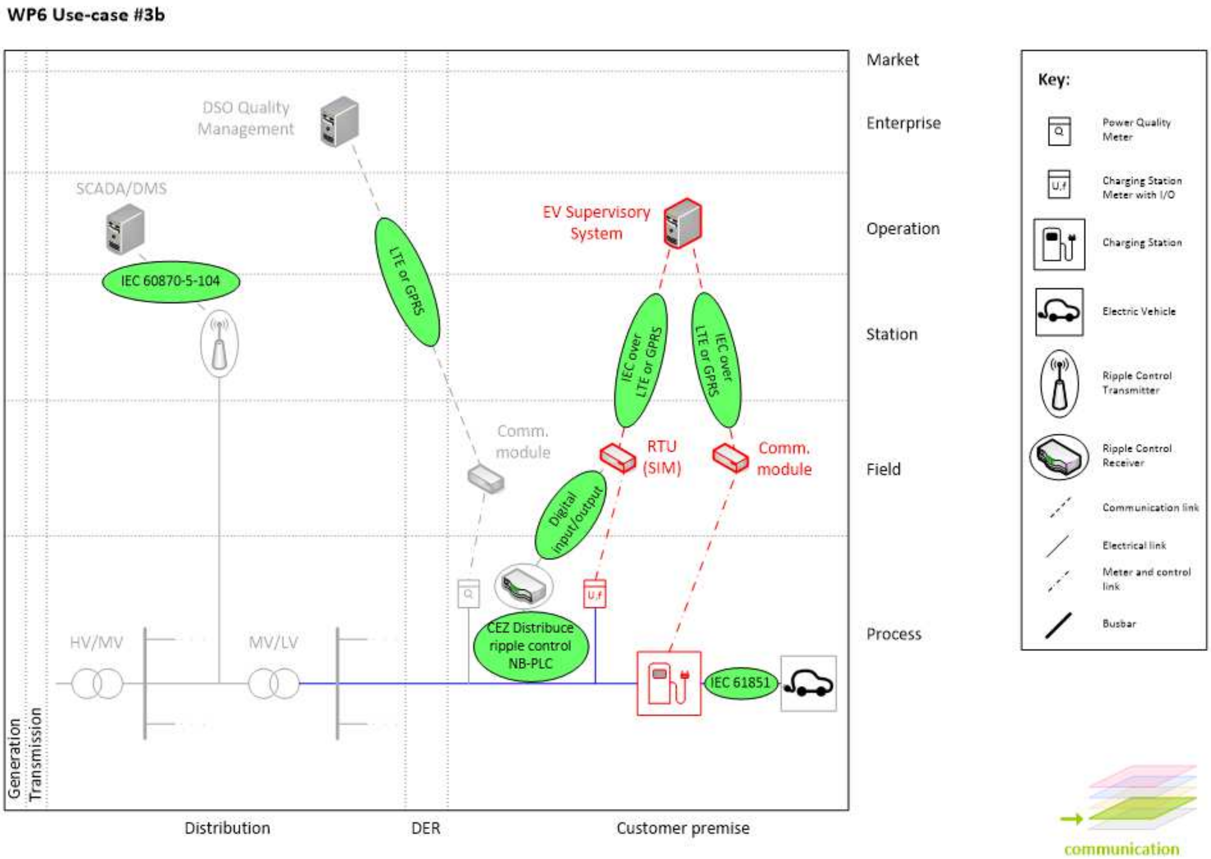


Figure 49 – Scope of lab tests shown on the SGAM description of 3b (Siemens) (red: Equipment Under Test / blue: emulated part)

In addition to the charging station, further following components which are necessary for the remote control will be used: RTU, Comm. module. Some of them are included in the charging station.

5.3. WP6_4: Smart energy storage

5.3.1. Implemented functions and functions to be tested

The hybrid PV storage systems will feature the control functions covered in WP6_1 (Q(U), P(U), see chapter 5.1) and will, in addition, offer the following functions (partly based on WP6_3):

Local functions:

- Permanent limitation of the power surplus injected into the network to 50 % of the nominal power of the installed PV power.
- Under-frequency stage 1 (function implemented locally – default threshold: 49.9 Hz): stop the charging of the battery. The charging can restart if the frequency is above 49.9 Hz for at least 5 minutes
- Under-frequency stage 2 (function implemented locally – default threshold: 49.85 Hz): discharge of the battery at 100 % of nominal power until the min. allowed SoC (70 %) of the battery is reached or the frequency exceeds 50.1 Hz

- Under-voltage stage 1 (function implemented locally – default threshold: 95 % of the nominal voltage = 380 V): stop the charging of the battery. The charging can restart if the frequency is above 380 V for at least 5 minutes
- Under-voltage stage 2 (function implemented locally – default threshold: 92.5 % of the nominal voltage = 370 V): discharge of the battery at 100 % of nominal power until the min. allowed SoC (70 %) of the battery is reached or the voltage exceeds 420 V

Remote functions:
As in WP6_3, a remote control is included: the PV + storage system must allow the discharge at 100 % of the nominal power of battery system after activation via narrow band simple one way PLC communication from DSO until the min. allowed SoC (70 %) of the battery is reached.

5.3.2. Scope of the lab tests / equipment under test

Since this use-case relies on both local and centralized functions, the communication infrastructure is in the scope of the testing, as visible on the SGAM diagram, Figure and Figure) for the two implementations of WP6_4 (Fronius = 4a and Schneider Electric = 4b).

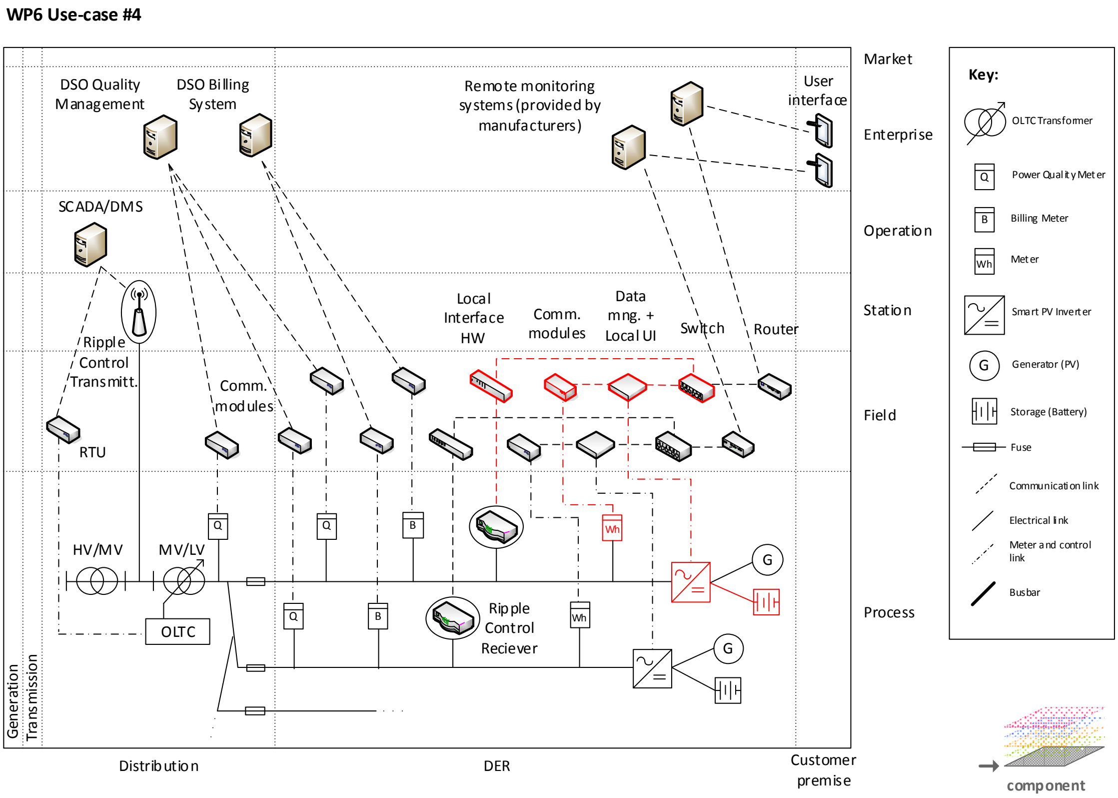


Figure 50 - Scope of lab tests shown on the SGAM description of WP6_4 (Fronius) (red: Equipment Under Test / blue: emulated part)

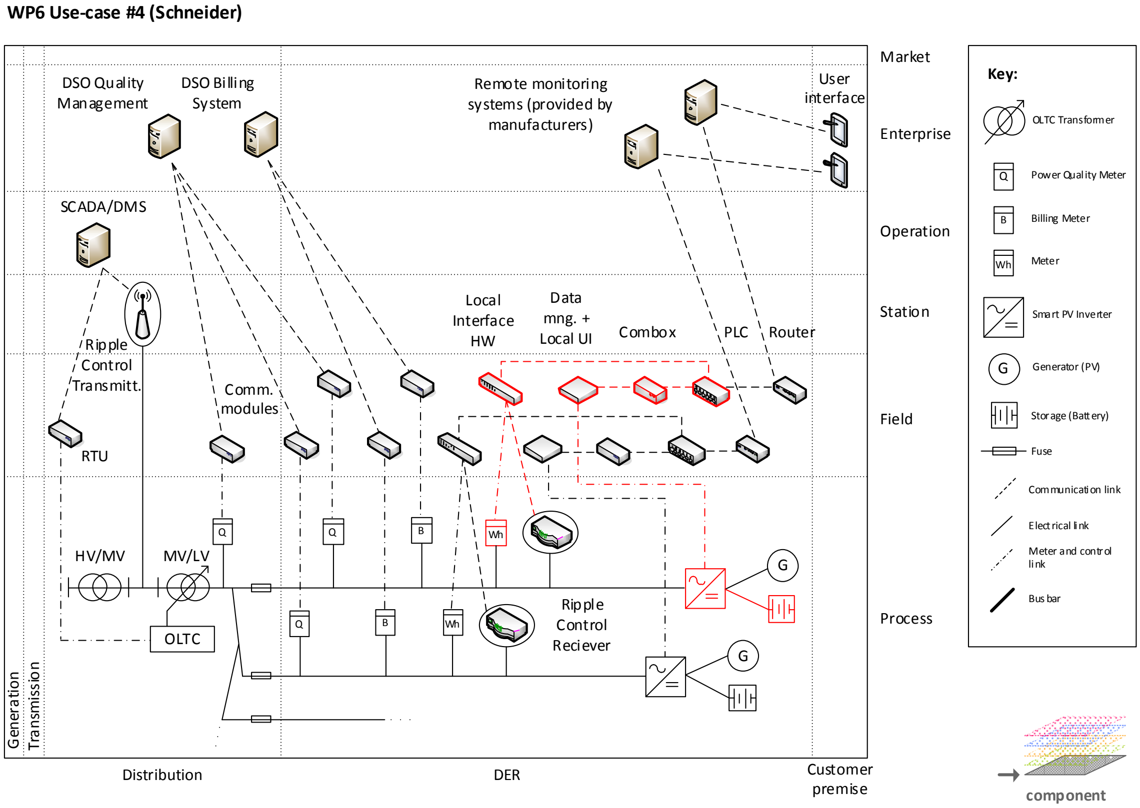


Figure 51 - Scope of lab tests shown on the SGAM description of WP6_4 (Schneider) (red: Equipment Under Test / blue: emulated part)

The devices used for the testing (Equipment Under Test - EUT) are shown below.

	Fronius
Model	- Symo Hybrid 5.0-3-S[4] - Solar Battery - Smart Meter - local interface
AC nominal output (kW)	5.0
AC nominal apparent power (kVA)	5.0
Grid connection	3~NPE 400 V
Power factor	0.85
Battery capacity (kWh)	9.6 kWh

Figure 52- EUT for WP6_4 Fronius

[4] For WP6_4, the devices used in the field will be *Fronius Symo Hybrid*.

	Schneider Electric
Model	- solar charger MPPT 60 150 - hybrid inverter Conext XW+ 7048 E (7.0 KW 230V 48V) - power measurement device PM - BMS - Combox - Battery (LiFeYPO4 3.2V/160Ah WIDE)
AC nominal output (kW) XW+	5,5
Grid sell current max (A) XW+	20
DC nominal output (kW) MPPT 100 % of the nominal power	2,8
Grid connection	1~NPE 230 V
Battery capacity (Ah)	160
Battery capacity (Wh)	7680

Figure 53 - EUT for WP6_4 Schneider Electric

For Schneider Electric in addition to PV, inverter and battery system, further following components which are necessary for the remote control will be used: RTU, Comm. module (Figure and Figure).

Complete report of lab test scenarios is included in annex 6.4.   WP6 AIT Lab tests scenarios definition. This report contains also all information about testing infrastructure, data acquisition and processing and detailed description of each test for use cases WP6_1, WP6_3 and WP6_4.

5.4. Lab tests – results

Dates for realization of lab test was discussed and proposed by AIT together with relevant project partners (Fronius, Schneider Electric and Siemens).

<u>Plan and realization of lab test:</u>
Equipment for WP6_1 use case (Fronius) -24th and 25th of October 2017
Equipment for WP6_1 use case (Schneider Electric) - 27th and 28th of November
Equipment for WP6_3 use case (Schneider Electric and Siemens) – from 11th to 15th December
Equipment for WP6_4 use case (Fronius and Schneider Electric) – from 18th to 20th of December

Lab test complete results for equipment for WP6_1 use case are included in Annex 6.5 “WP6 AIT Lab tests scenarios results.pdf”.

Lab test results of equipment for WP6_1 use case confirmed that Fronius and Schneider Electric smart PV inverters which will be implemented in later stage of WP6 are equipped with Q(U) and P(U) autonomous functions. If properly set, Q(U) and P(U) autonomous functions have a strong potential for increasing of DER hosting capacity in LV distribution grids.

Results of equipment lab tests for WP6_3 and WP6_4 use cases will be included in deliverable D6_1_Implementation of solution.

6. ANNEXES

Annex 6.1

Use Case Description

UC WP6_1 – Increase DER hosting capacity of LV distribution networks by smart PV inverters

Scope

This document describes the Use Case **UC WP6_1 – Increase DER hosting capacity of LV distribution networks by smart PV inverters**.

The Use Case description within is divided in to five areas:

1. Description of the Use Case
2. Diagrams of the Use Case
3. Technical data - Actors
4. Step by Step Analysis of Use Case (can be extended by detailed info on “information exchanged”)
5. Information exchanged

1. Description of the Use Case

1.1. Use Case Identification

ID	Domains/Zones[1]	Name of Use Case	Level of Use Case[2]
WP6_1	DER/PROCESS	Increase DER hosting capacity of LV distribution networks by smart PV inverters	Detailed Use case

1.2. Version Management

Version	Date	Name Author(s) or	Changes
V1.0	24.5.2017	Jan Švec	First version of the document

1.3. Scope and objectives

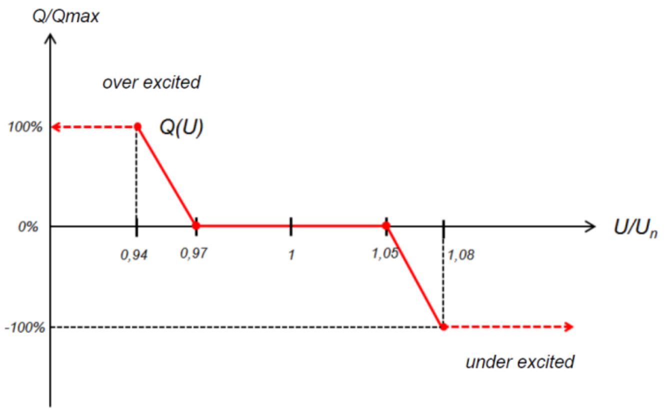
Scope and Objectives of the Use Case	
Scope	The aim of the use case is field demonstration of smart PV inverters functions which enables increasing of DER hosting capacity in two different areas with different LV grid topology.
Objective	Increase of DER hosting capacity in LV grids thanks to the installation of smart PV inverters and securing the power quality according to EN 50160 standard.
Related Business Case	*CEZ Distribuce could defer investments to grid reinforcement.*

1.4. Narrative of Use Case

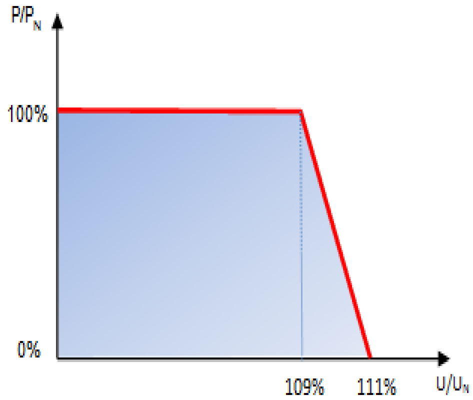
Short description – max 3 sentences
Increasing of DER hosting capacity in LV distribution grid case that smart PV inverters are used.

Complete description

ČEZ Distribuce and its partners aims at demonstrating how the combination of new smart PV inverter functions Q(U) and P(U) under real operating conditions within LV distribution networks can increase the DER hosting capacity. A successful demonstration requires appropriate conditions for testing roof PV systems using smart PV inverters (fulfilling the EN 50438 ed.2 standard) installed massively under preselected 2 MV/LV secondary substations. Two areas with different topologies but high penetration of PV systems are needed. Crucial tasks for this use case are the recruitment of customers within the selected areas, the installation of PV systems with smart PV inverters and the delivery of technical operational data and results from the PV inverter monitoring systems with the customer's consent. Descriptions and SGAMs are separated for option a) from Fronius and b) from Schneider.

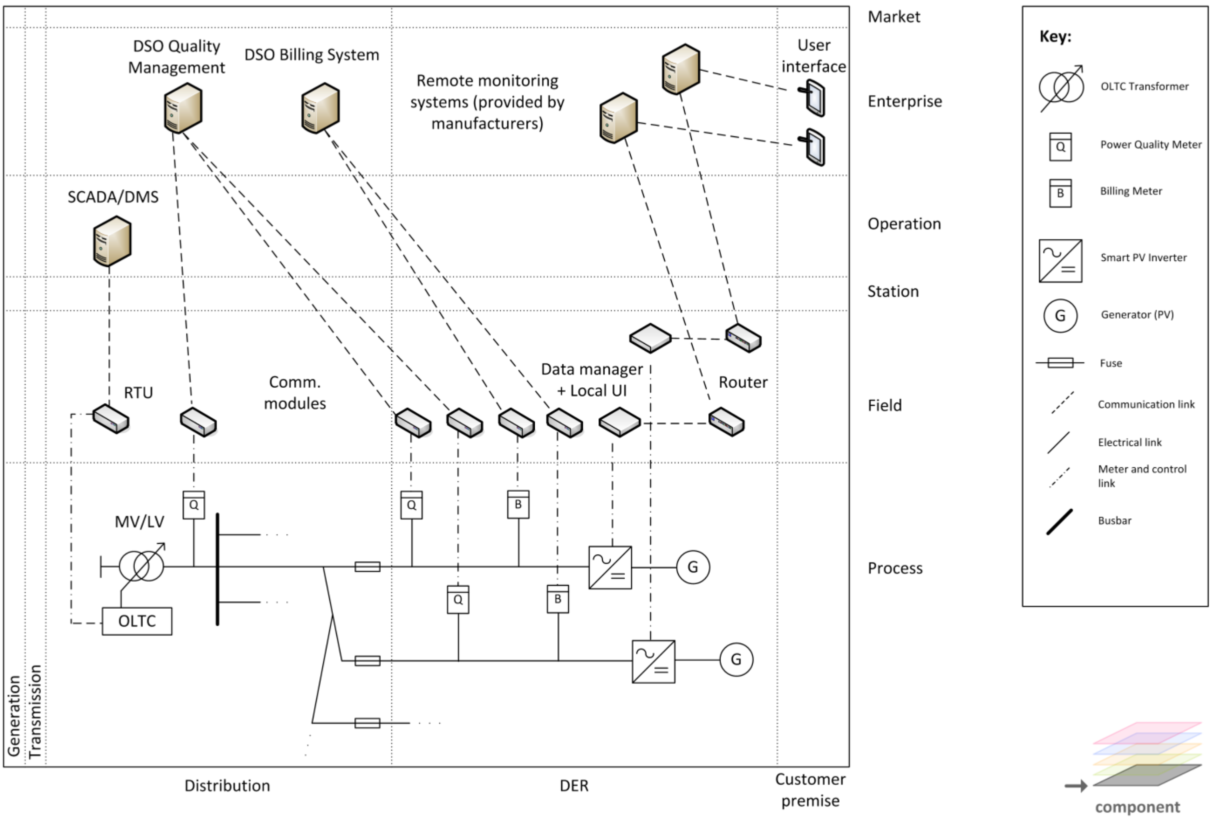


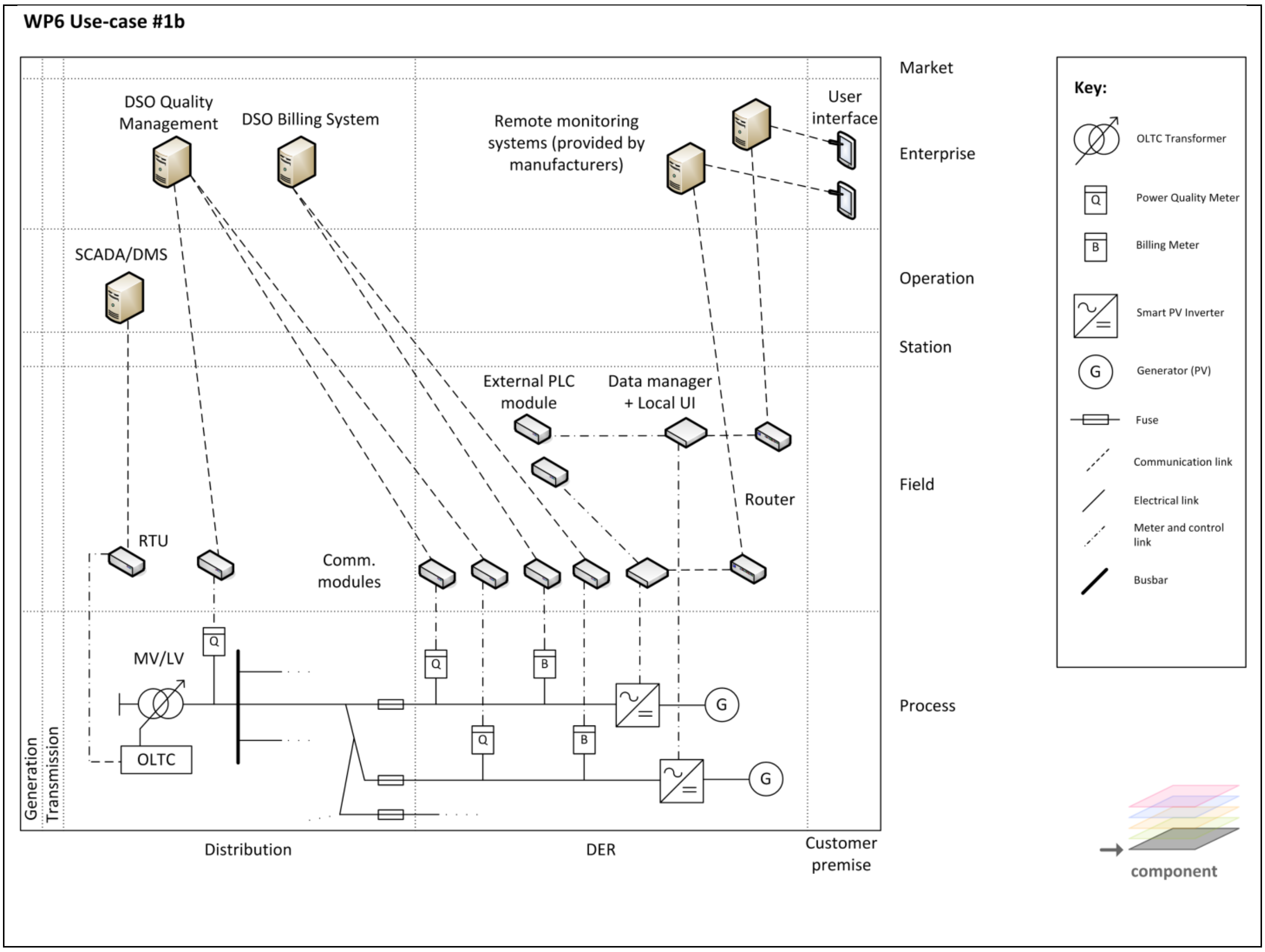
Q(U) function - example



P(U) function – example

WP6 Use-case #1a





1.5. KPIs

ID	Name	Description	Reference to mentioned Use Case objectives
KPI6_1	Increasing DER hosting capacity	in % compared with the baseline situation	WP6_1, WP6_2, WP6_4
KPI6_2	Power quality (according to EN 50160 standard)	Power quality will not be negatively affected by implementation of solutions	WP6_1, WP6_2, WP6_3, WP6_4

1.6. Use Case conditions

Actor	Triggering Event	Pre-conditions	Assumption
Voltage in the point of DER connection	In case voltage is higher than threshold, PV inverter starts to consume reactive power thanks to Q(U) function, in case the voltage rise even more, PV inverter starts to reduce active power production thanks to P(U) function. In case voltage is lower than threshold, PV inverter starts to generate reactive power thanks to Q(U) function.	PV inverters must be equipped with Q(U) and P(U) functions.	Q(U) and P(U) functions are set during the commissioning of PV inverter.

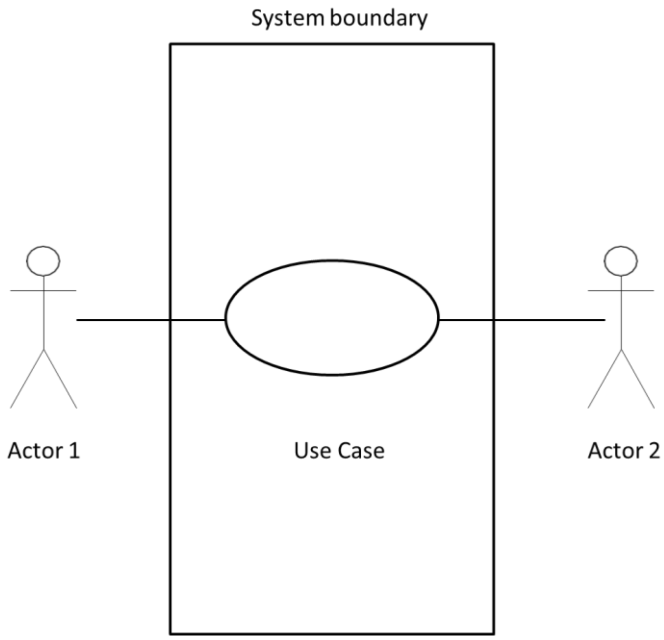
1.7. Classification information

Relation to Other Use Cases in the same project or area
Associate – use cases WP6_1, WP6_2, WP6_4 aim to increase DER hosting capacity of distribution grids.
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Prioritization
Very important
Generic, Regional or National Regional relation
Generic
Nature of the viewpoint- describes the viewpoint and field of attention
Technical point of view
Further Keywords for Classification
PV inverter, EN 50160, EN 50438:2013, hosting capacity, DER, LV grid, Q(U), P(U)
Maturity of Use Case
Realized in demonstration project

2. Diagrams of the Use Case

2.1. Diagram of the Use Case

actor 1 = voltage in the point of PV inverter connection before the Q(U) or P(U) functions are activated; voltage in the point of PV inverter connection after the Q(U) or P(U) functions are activated; system boundary – please see SGAM

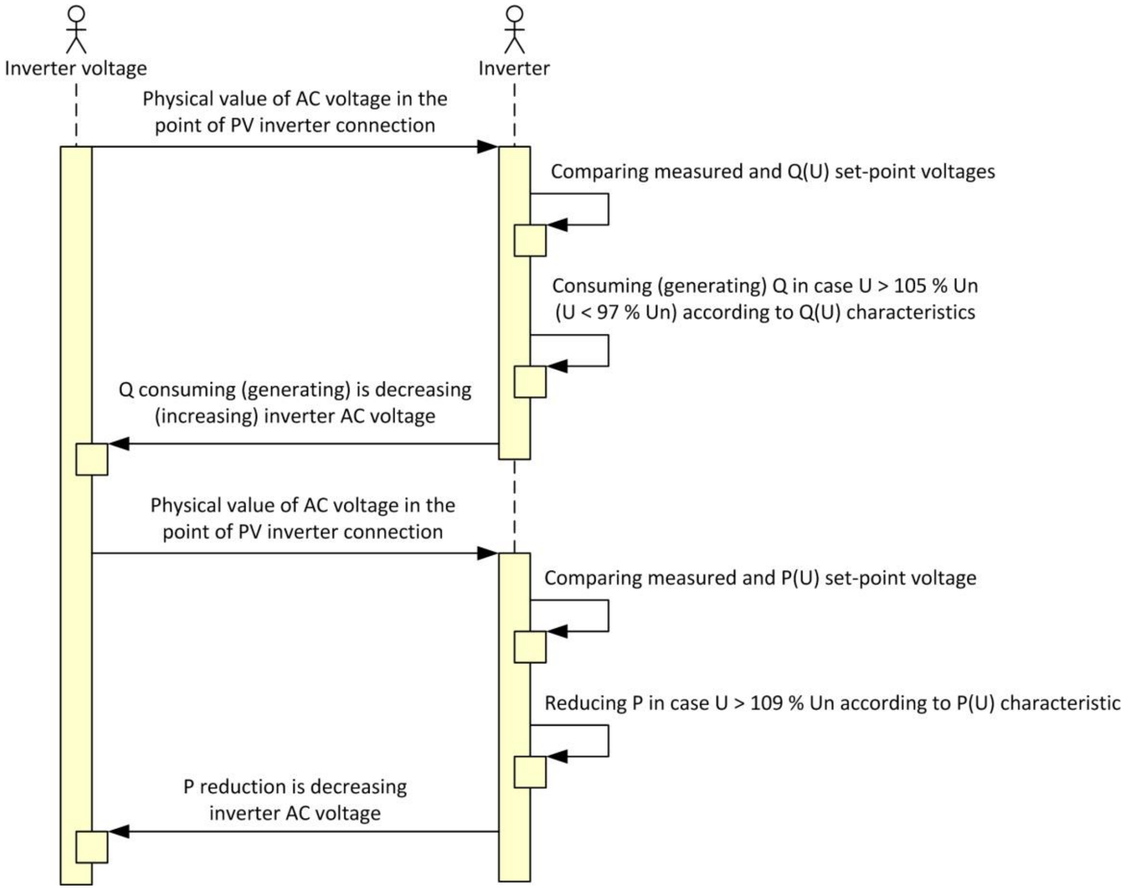


2.2. Sequence diagram of the Use Case

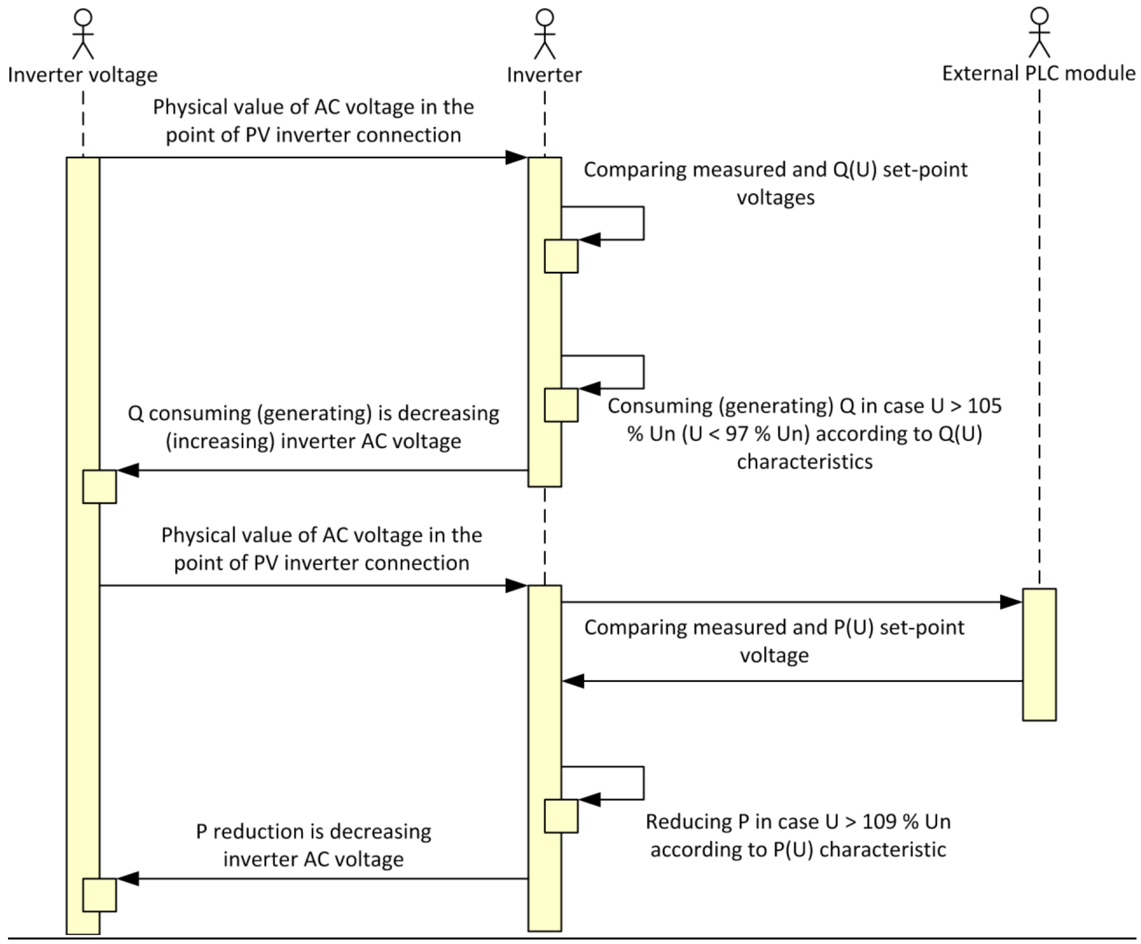
1 – voltage in the point of PV inverter connection is higher than Q(U) set-point (105 % Un) thus the PV inverter starts consuming reactive power according to the curve – this will reduce the voltage in the point of connection
2 – voltage in the point of PV inverter connection is higher than P(U) set-point (109 % Un) thus the PV inverter starts curtailing active power according to the curve – this will reduce the voltage in the point of connection
3 – voltage in the point of PV inverter connection is lower than Q(U) set-point (97 % Un) thus the PV inverter starts generating reactive power according to the curve - this will reduce the voltage in the point of connection

MV/LV OLTC transformer is used for simulation of different voltage levels in LV grid. Taps could be regulated through DMS. Power quality is monitored in the LV grid through DSO power quality management system. For use case evaluation also data from DSO billing system are used. Data from PV inverter are also used for use case evaluation.

Sequence diagram #1a



Sequence diagram #1b



3. Technical details of the Use Case – Actors

UC3a (Fronius)

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this UC	Equipment Manufacturer	Grid Connection Requirements	IEC Standards
SCADA/DMS	System	IS IT	Operator via SCADA/DMS sends control commands to action devices.	Sends commands to set OLTC tap changer.	Will not be specified because of security reason. Type of manufacturer doesn't affect use case function.	N/A	60870-5-104 over GPRS
OLTC tap changer (incl. RTU)	System	Network device	Sets OLTC tap to change voltage level in DS.	RTU receives commands from SCADA/DMS and send them to OLTC tap changer to set the tap and simulate voltage changes in DS.	Will be selected by procurement later.	N/A	60870-5-104 Over GPRS
DER control system (incl. Data manager, Local UI, Router)	System	DER installation	Sends data to supervisory systems and interfaces.	Sends monitoring data to user interfaces and remote monitoring/control systems.	Fronius	N/A	Ethernet TCP/IP internet
Generator/Inverter	System	DER installation	Supplies active power to DS. Exchanges reactive power in inductive or capacitive mode with DS.	Measures voltage and autonomously changes reactive power in inductive or capacitive mode with DS according to volt-var control requirements.	Fronius	EN 50438:2013	N/A

UC3b (Schneider)

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this UC	Equipment Manufacturer	Grid Connection Requirements	IEC Standards
SCADA/DMS	System	IS IT	Operator via SCADA/DMS sends control commands to action devices.	Sends commands to set OLTC tap changer.	Will not be specified because of security reason. Type of manufacturer doesn't affect use case function.	N/A	60870-5-104 over GPRS
OLTC tap changer (incl. RTU)	System	Network device	Sets OLTC tap to change voltage level in DS.	RTU receives commands from SCADA/DMS and send them to OLTC tap changer to set the tap and simulate voltage changes in DS.	Will be selected by procurement later.	N/A	60870-5-104 Over GPRS
DER control system (incl. Data manager, Local UI, Router)	System	DER installation	Sends data to supervisory systems and interfaces.	Sends monitoring data to user interfaces and remote monitoring/control systems.	Schneider	N/A	Ethernet TCP/IP internet
Generator/Inverter	System	DER installation	Supplies active power to DS. Exchanges reactive power in inductive or capacitive mode with DS.	Measures voltage and changes reactive power in inductive or capacitive mode with DS according to volt-var control requirements.	Schneider	EN 50438:2013	N/A
External PLC Module	System	DER installation	PLC module which substitutes autonomous function of inverter to compare measured voltage and set P(U) char.	Receives measured data from Inverter and compare it with preset limits within the characteristics. Sends P limit set points to inverter to change active power.	Schneider	N/A	Modbus

4. Step by Step Analysis of the Use Case

4.1. List of scenarios

Scenario No.	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
UC1_1	Voltage regulation	In case voltage is higher than threshold, PV inverter starts to consume reactive power thanks to Q(U) function, in case the voltage rise even more, PV inverter starts to reduce active power production thanks to P(U) function. In case voltage is lower than threshold, PV inverter starts to generate reactive power thanks to Q(U) function.	Generator/Inverter	Voltage in the point of DER connection is out of limits defined in Q(U) or P(U) characteristics.	DER inverter connected to LV grid is equipped with activated and properly set Q(U) or P(U) characteristics.	Voltage in the point of DER connection is in the limits of Q(U) or P(U) characteristics.

No other scenarios (alternative, error,…) are considered in this use case.

4.2. Steps – Primary Scenario

Scenario Name: Voltage regulation									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Set up tap on OLTC	Operator through SCADA sets tap on OLTC transformer to simulate different overvoltage/under voltage situations.	SCADA/DMS	OLTC (incl. RTU)	I-01	CREATE	N/A	IEC 60870-5-104	protocol
2	Voltage and power quality measurements	Meters at LV busbar and connection points measure voltage and quality of supply. This information is collected in DSO Quality mgmt. and Billing Systems.	LV meters + comm. modules	DSO Quality Management, DSO Billing System	I-02	REPORT	N/A	IEC 60870-5-104	protocol

Scenario Name: Voltage regulation									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
3	Voltage regulation	Inverter measures voltage in connection point and autonomously changes reactive or active power to stay in voltage limits defined by DSO.	Inverter (in UC1b incl. PLC module)	Inverter	I-03	EXECUTE	N/A	Measurement is internal part of inverter.	Internal protocol
4	PV monitoring	DER data manager and local UI sends monitoring data to remote monitoring system and user interface.	Data manager (incl. local UI, router)	Remote monitoring system, user interface	I-04	REPORT	N/A	Depends on inverter manufacturer.	protocol

4.3. Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: N/A									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

5. Information exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories[5]	Requirements
I-01	Tap on OLTC	Operator through SCADA sets tap on OLTC transformer to simulate different overvoltage/under voltage situations.	Information exchanged between IS or sent to device	N/A
I-02	Voltage and power quality measurements	Meters at LV busbar and connection points measure voltage and quality of supply. This information is collected in DSO Quality mgmt. and Billing Systems.	Electrical parameter	N/A

I-03	Reactive power control	Inverter measures voltage in connection point and autonomously changes reactive or active power (in UC1b incl. PLC module) to stay in voltage limits defined by DSO.	Algorithm, formula, rule, specific model	N/A
I-04	PV monitoring	DER data manager and local UI sends monitoring data to remote monitoring system and user interface.	Electrical parameter	N/A

Annex A – List of Actor Subcategories

Category	Type	Subcategory	Definition	Example
Actors	Role	DSO	Responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area	Avacon, CEZ, E.ON, Enexis, Enedis
Actors	Role	Industrial partner	All industrial partners involved in InterFlex project at a DEMO level	- GE - Siemens - Schneider …
Actors	Role	University and research partner	All university or research partners involved in InterFlex project at a DEMO level	- RWTH - AIT etc
Actors	Role	Retailer	Licensed supplier of electricity to an end-user	- EDF - Engie...
Actors	Role	Legal Client	A legal client of a DSO that is involved at Demo scale	- Company producer - Municipalities - Tertiary service providers
Actors	Role	Physical client	A physical client of a DSO that is involved at Demo scale	- Residential client
Actors	System	Charging facilities	Facilities to charge electrical vehicles	- Charging facilities
Actors	System	DER installation	Power plant that use renewable technology and are owned by a legal person	- Photovoltaics panels - Biomass farm - Wind power, …
Actors	System	In house device	All devices working on electricity that can be find in a customer's dwelling.	- Heater - Meter - Local display - Customer's battery
Actors	System	Communication infrastructure	All the infrastructure that are used for communication at all level (from customer's place to power command)	- Modem - Routers
Actors	System	Network device	All devices placed on MV/LV network for monitoring or gathering information on grid's situation or electrical parameters values. It also include the IS associated	- Secondary Substation control infrastructure - RTU : Remote terminal units - Circuits breakers - sensors
Actors	System	IS IT	All the hardware and software associated, used at power command to control and monitor the network	- SCADA - Central database - Control operation center
Actors	System	Interactive communication device	All device used to interact with customers in order to involved him in the Demo	- Web portal - Display used for communication

Annex B – List of Information Subcategories

Category	Type	Subcategory	Definition	Example
Data	Document	Internal document	All the documentation made by Demo to run operation, to monitor and conduct the project's good development	- Meeting minutes - Report on the cost's impact of selected flexibility plans
Data	Document	InterFlex deliverable	All the deliverables that Demo have to produce during the project's time as agreed in the DOW	- Risk analysis - Documentation on KPI - Detailed Use Case - Report on technical experimentation, market research, …
Data	Document	Communication material	All the documentation that describe the project to the public and can be put on the future website	- Purpose of the DEMO (leaflet) - Brief description of Use Case - Location of Use Case
Data	Financial data	Project financial data	All the financial data that are produced during the project and that are used to make financial report for European Commission and internal report	- Invoices - Cost and time imputation
Data	Financial data	Solution cost and selling price	All the financial data that can be made concerning estimation prices of solution for replication	- Unit product cost of hardware developed by Demo - Sell price of the solution develop (software,…)
Data	Parameter	Condition parameter	All the external parameters that may influence the success of the Use Case	- Weather - Time of day - Day of week …
Data	Parameter	Scenario assumption	All the stated parameters that are necessary to determinate a scenario for the Use Case	- Location of islanding - Experiment's location
Data	Parameter	Electrical parameter	All the electrical parameters that are used to supervise the network and its good state	- Intensity - Voltage - Frequency - Quality
Data	Parameter	Algorithm, formula, rule, specific model	All the intellectual data that are created during the project to made software's contents	- Algorithm to optimize flexibility plan - Simulation to determine location of circuit breaker - Voltage regulation algorithm
Data	Parameter	Optimized value	Values of parameters that optimized the Use Case or the demo's performance	- Optimization time of islanding
Data	Parameter	Forecast data	All the data used to forecast consumption or production of customer	- Forecast customer's consumption - Forecast photovoltaic panels' production
Data	Facility data	Network topology	All information on network devices and their location and interaction, mainly coming from GIS (Geographic Information System)	- Map of the network - Substations location - All the other data found in the GIS (Geographical Information System)
Data	Facility data	Network state	All information concerning the network's status (global or local) at a precise moment useful to monitor the network	- Feeding situation in a distribution area - State of network regarding Limit value violation - Location of constraint - Flexibility needs of DSO

Category	Type	Subcategory	Definition	Example
Data	Facility data	Customer's meter state and output	All the information concerning customer’s meter state and outputs information	- Customer’s consumption or production
Data	Facility data	Other device state and output	All the information concerning device's state and outputs information	- State of charge of batteries - Consumption data coming from meter - Production data coming from meter - State of charge of storage components
Data	Parameter	Information exchanged between IS or sent to device	All automated information sent between facilities in order to send information or order for monitoring	- Order sent to breaker devices (open, close,…) - Information on local network status coming from sensors - Order and roadmap sent to network devices (batteries, aggregator,…)
Data	Parameter	Detailed specification on devices	All detailed information (reference components, specification, process,…) useful to build the devices	- Detailed specification of the telecommunication infrastructure - Detailed specification of interactive sensor network
Data	Network data	Network topology	All information on network devices and their location and interaction, mainly coming from GIS (Geographic Information System)	- Map of the network - Substations location - All the other data found in the GIS (Geographical Information System)
Data	Network data	Network state	All information concerning the network's status (global or local) at a precise moment useful to monitor the network	- Feeding situation in a distribution area - State of network regarding Limit value violation - Location of constraint - Flexibility needs of DSO
Data	KPI	Data for KPI (input raw data)	All raw data that are used to calculate the final KPI	- Duration of experiment - Customer response to DSO's demand - Electrical parameter used for KPI
Data	KPI	KPI (KPI values)	All the KPI values and the way to calculate them	- Economic KPI - System Efficiency KPI
Data	Customer data	Customer contract’s data	All the data in customer's contact that are used for contact or make payment	- Address - Phone number - Bank account details
Data	Customer data	Information sent to /received from customer	All the information and data that are exchanged between the DEMO and the customer in order to involve customer in the experiment	- Customer's response to DSO's request to reduce consumption - Information and data available to customer in order to visualize its consumption - Advices and encouragement sent to encourage a smart consumption
Data	Customer data	Customer analysis (profile analysis, studies on client reactivity,…)	All the data that are produced in order to better understand the customer's behaviour regarding the possibility to adopt smarter habits in their electricity consumption	- Customer's typology and behaviour patterns - Analysis on customer's response to DSO's request

Use Case Description

UC WP6_2 – Increase DER hosting capacity in MV networks by volt-var control

Scope

This document describes the Use Case **UC WP6_2 – Increase DER hosting capacity in MV networks by volt-var control**.

The Use Case description within is divided in to five areas:

1. Description of the Use Case
2. Diagrams of the Use Case
3. Technical data - Actors
4. Step by Step Analysis of Use Case (can be extended by detailed info on "information exchanged")
5. Information exchanged

1. Description of the Use Case

1.1. Use Case Identification

ID	Domains/Zones[1]	Name of Use Case	Level of Use Case[2]
WP6_2	DER/PROCESS	Increase DER hosting capacity in MV networks by volt-var control	Detailed Use case

1.2. Version Management

Version	Date	Name Author(s) or	Changes
V1.0	24.5.2017	Jan Švec	First version of the document

1.3. Scope and objectives

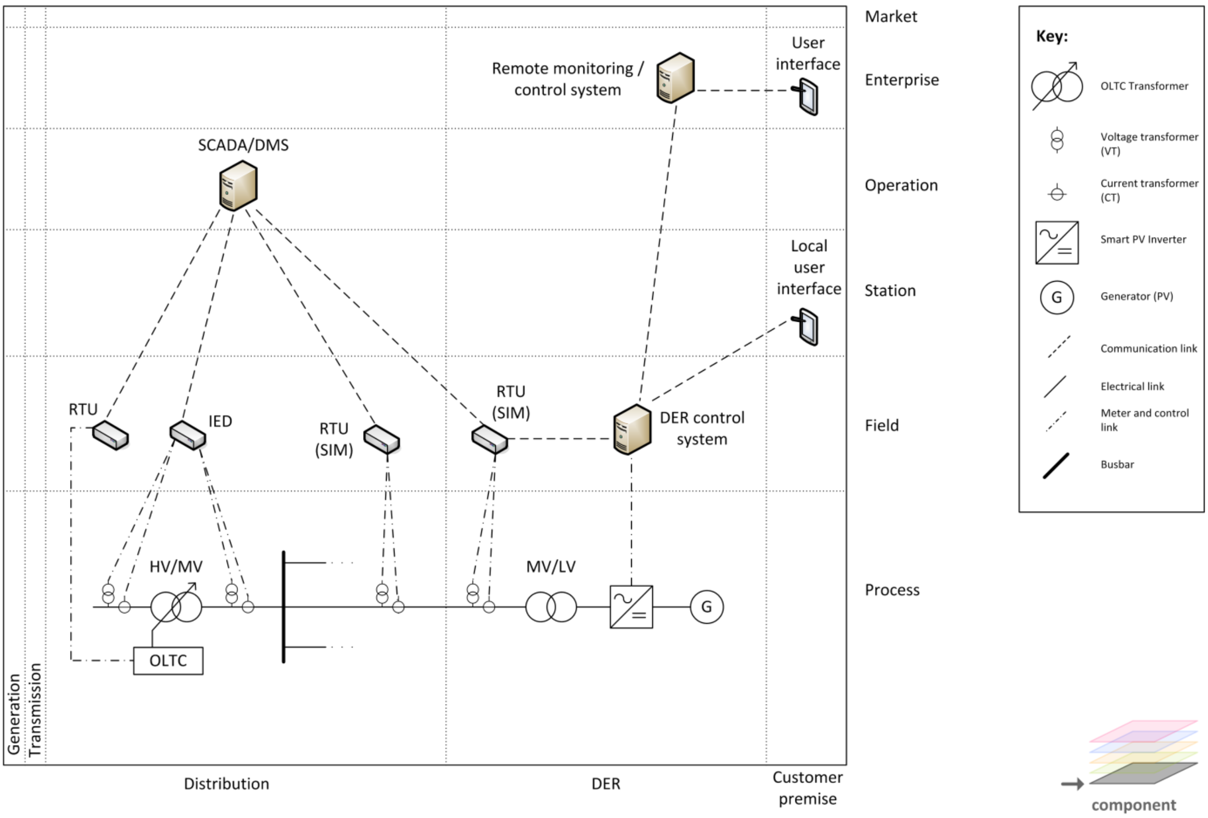
Scope and Objectives of the Use Case	
Scope	The aim of the use case is field demonstration of volt-var control system which enables increasing of DER hosting capacity in three different areas with three different DER (PV, Wind, Biogas) connected to the MV grid.
Objective	Increase of DER hosting capacity in MV grids thanks to the installation of smart PV inverters and securing the power quality according to EN 50160 standard.
Related Business Case	*CEZ Distribuce could defer investments to grid reinforcement.*

1.4. Narrative of Use Case

Short description – max 3 sentences
Increasing of DER hosting capacity in MV distribution grid in case that volt-var control system is used.

Complete description
ČEZ Distribuce integrates selected DER connected to MV networks into volt-var control system (PV: 1.1MW, biogas station: 1.25MW, wind: 4.6MW). The DSO can send required voltage set points from its SCADA to DER unit, which then react and regulate at the required voltage set points (thanks to reactive power generation/consumption. For this volt-var control strategy, ČEZ Distribuce leans on existing DER over 100kW with communication capabilities (usually GPRS) towards the DSO dispatching control system (SCADA).

WP6 Use-case #2



1.5. KPIs

ID	Name	Description	Reference to mentioned Use Case objectives
KPI6_1	Increasing DER hosting capacity	in % compared with the baseline situation	WP6_1, WP6_2, WP6_4
KPI6_2	Power quality (according to EN 50160 standard)	Power quality will not be negatively affected by implementation of solutions	WP6_1, WP6_2, WP6_3, WP6_4

1.6. Use Case conditions

Actor	Triggering Event	Pre-conditions	Assumption
Dispatcher	DSO dispatcher sends command for start of volt-var control of DER together with required voltage set point.	Dispatcher needs DER to regulate voltage in MV grid.	DER connected to MV grid is equipped with volt-var control system.

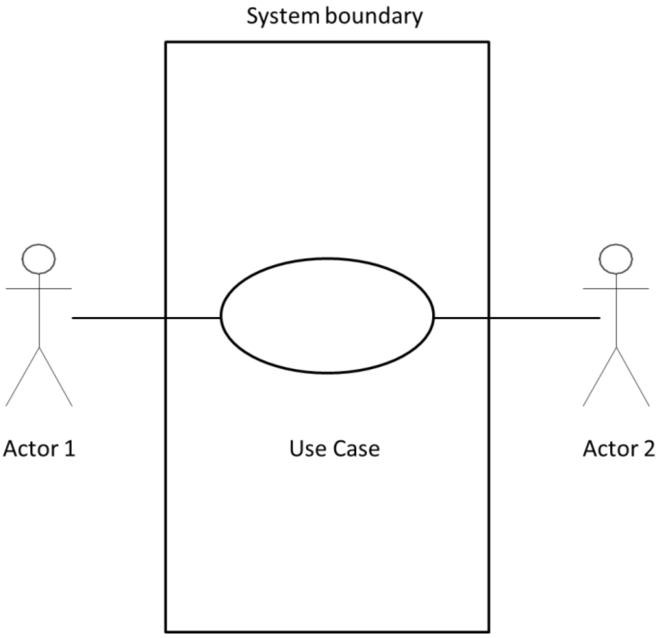
1.7. Classification information

Relation to Other Use Cases in the same project or area
Associate – use cases WP6_1, WP6_2, WP6_4 aim to increase DER hosting capacity of distribution grids.
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Prioritization
Very important
Generic, Regional or National Regional relation
Generic
Nature of the viewpoint- describes the viewpoint and field of attention
Technical point of view
Further Keywords for Classification
EN 50160, hosting capacity, DER, MV grid, volt-var control, reactive power
Maturity of Use Case
Realized in demonstration project

2. Diagrams of the Use Case

2.1. Diagram of the Use Case

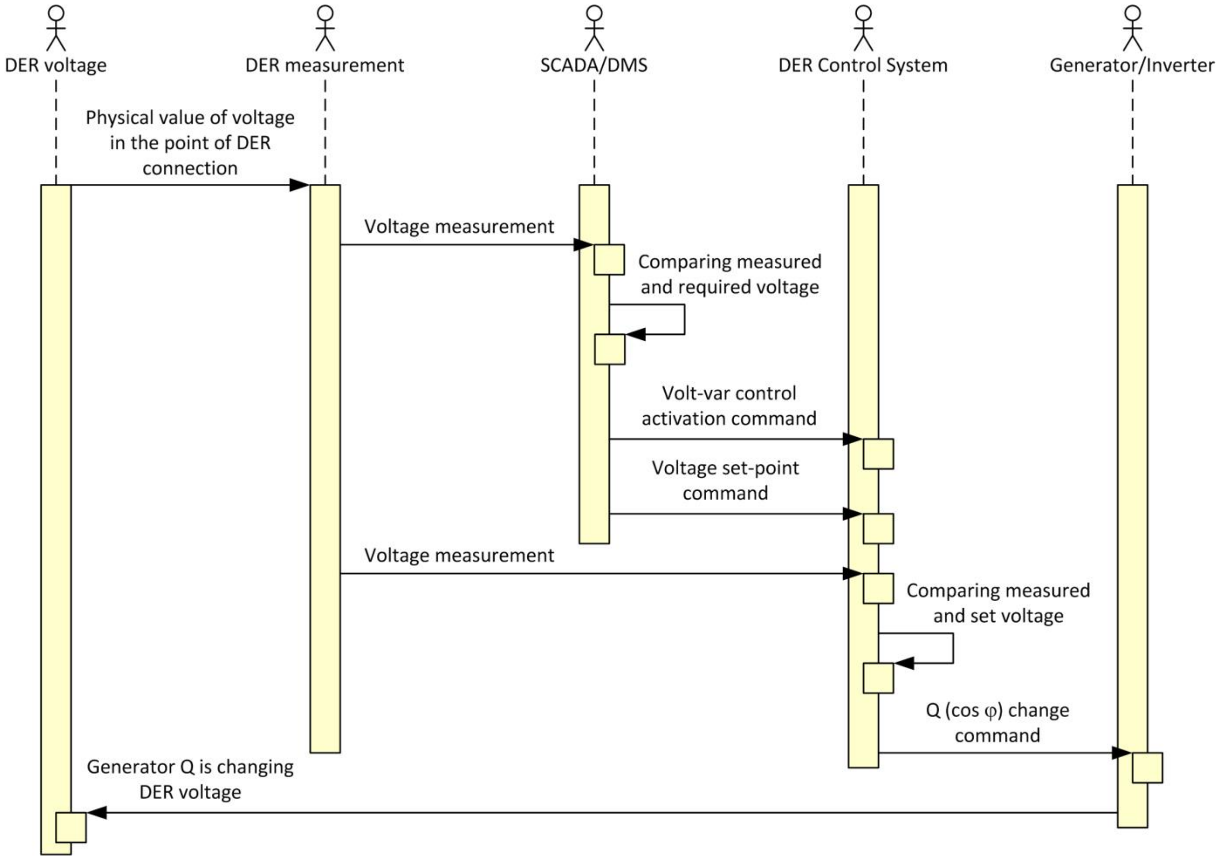
actor 1 = voltage in the point of DER connection before volt-var control system is activated; voltage in the point of DER connection after volt-var control is activated; system boundary – please see SGAM



2.2. Sequence diagram of the Use Case

1 – voltage in the point of DER connection is not according to the DSO dispatcher needs, thus the DSO dispatcher send command for the start of volt-var control together with the voltage set point. In case that voltage set point is higher than actual measured voltage value, the DER will start to generate reactive power in order to increase the voltage. In case that voltage set-point is lower than actual measured voltage value, DER will start to consume reactive power in order to decrease the voltage.

Voltage levels in different locations in MV and HV grid are monitored by DMS in order to provide relevant information for DSO dispatcher.



3. Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this UC	Equipment Manufacturer	Grid Connection Requirements	IEC Standards
HV/MV transformer measurement	System	Network device	Measures voltages and currents on HV and MV transformer busbars.	Measured data are used for setting HV/MV OLTC taps.	Type of manufacturer doesn't affect use case function.	N/A	N/A
MV busbar measurement	System	Network device	Measures voltage level on MV busbar in distribution system.	Measured voltage is used for setting HV/MV OLTC taps and/or for DER volt-var control.	Type of manufacturer doesn't affect use case function.	N/A	N/A
DER MV measurement	System	Network device	Measures voltage level on DER MV busbar.	Measured voltage is used for DER volt-var control.	Depends on DER owner. Type of manufacturer doesn't affect use case function.	PPDS – Czech grid code.	N/A
OLTC tap changer	System	Network device	Sets OLTC tap to change voltage level in DS.	Tap changing simulates voltage changes in DS.	Type of manufacturer doesn't affect use case function.	N/A	N/A
Generator/Inverter	System	DER installation	Supplies active power to DS. Exchanges reactive power in inductive or capacitive mode with DS.	Exchanges reactive power in inductive or capacitive mode with DS according to volt-var control requirements.	Type of manufacturer doesn't affect use case function.	PPDS – Czech grid code.	N/A
RTU_OLTC	System	Network device	Ensures commands sending from SCADA/DMS to OLTC tap changer.	Receives commands from SCADA/DMS and send them to OLTC tap changer to set the tap.	Type of manufacturer doesn't affect use case function.	N/A	60870-5-104 over fiber optic
IED_OLTC	System	Network device	Sends measured data to SCADA/DMS.	Measured data are used for setting HV/MV OLTC taps.	Type of manufacturer doesn't affect use case function.	N/A	60870-5-104 over fiber optic

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this UC	Equipment Manufacturer	Grid Connection Requirements	IEC Standards
RTU(SIM)_MV	System	Network device	Sends measured data to SCADA/DMS.	Measured voltage is used for setting HV/MV OLTC taps and/or for DER volt-var control.	Type of manufacturer doesn't affect use case function.	N/A	60870-5-104 over fiber optic
RTU(SIM)_DER	System	Network device	Communicates with SCADA/DMS and DER control system.	Sends measured data to SCADA/DMS and DER control system. Receives voltage set-point commands from SCADA/DMS and sends them to DER control system.	Type of manufacturer doesn't affect use case function.	PPDS – Czech grid code.	60870-5-104 over fiber optic and other
DER control system	System	DER installation	Controls DER reactive power and sends data to supervisory systems and interfaces	Receives measured data and voltage set-point commands from RTU. Sends reactive power or power factor set points to generator/inverter. Sends monitoring data to user interfaces and remote monitoring/control systems.	Type of manufacturer doesn't affect use case function.	PPDS – Czech grid code.	N/A
SCADA/DMS	System	IS IT	Receives measured data from DS and sends control commands to action devices.	Receives measured data from MV point in DS and from DER. Send commands to set OLTC tap and DER control system.	Will not be specified because of security reason. Type of manufacturer doesn't affect use case function.	N/A	60870-5-104 over fiber optic
Remote monitoring /control system	System	IS IT	Collects data about DS state and controls its operation.	Receives monitoring data from DER control system.	Type of manufacturer doesn't affect use case function.	N/A	N/A

4. Step by Step Analysis of the Use Case

4.1. List of scenarios

Scenario No.	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
UC2_1	Voltage control	Voltage in the point of DER connection is not according to the DSO dispatcher needs, thus the DSO dispatcher sends command for the start of volt-var control together with the voltage set point. In case that voltage set point is higher than actual measured voltage value, the DER will start to generate reactive power in order to increase the voltage. In case that voltage set point is lower than actual measured voltage value, DER will start to consume reactive power in order to decrease the voltage.	DER MV measurement	Voltage in the point of DER connection is far from the DSO dispatcher needs.	DER connected to MV grid is equipped with volt-var control system. This system is activated and connected to DSO dispatcher.	Voltage in the point of DER connection is equal or close to the DSO dispatcher needs.

No other scenarios (alternative, error,…) are considered in this use case.

4.2. Steps – Primary Scenario

Scenario Name: Voltage control									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Voltage measurement	DER MV measurement measures voltage in the point of DER connection. The measured data are sent to SCADA/DMS and to DER control system.	DER MV measurement	SCADA/DMS + DER control system	I-01	REPORT	N/A	IEC 60870-5-104	protocol

Scenario Name: Voltage control									
Step No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
2	Voltage set-point command	If the measured voltage is different from the required one, commands for volt-var control activation and for voltage set-point are sent from SCADA/DMS to DER control system.	SCADA/DMS	DER control system	I-02, I-03	CREATE	N/A	IEC 60870-5-104	protocol
3	DER control command	DER control system evaluates the voltage set point command and DER voltage measurement and sent adequately calculated command for changing reactive power or power factor to generator/inverter.	DER control system	Generator/ Inverter	I-04	CREATE	N/A	Depends on DER owner.	protocol
4	Reactive power change	Generator/inverter changes its reactive power according to DER control system commands until there are commands for Q changing from DER control system, i.e. until the measured voltage is close to the required one.	DER control system	Generator/ Inverter	I-04	EXECUTE	N/A	Depends on generator/inverter manufacturer.	protocol

4.3. Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: N/A									
Step No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

5. Information exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories[5]	Requirements
I-01	DER measured voltage	Measured values of voltage on MV level in the point of DER connection to the grid. Values are sent to SCADA/DMS and to DER control system.	Electrical parameter	N/A
I-02	Volt-var control activation	If the measured DER voltage is different from the desired one, SCADA/DMS send a command to DER control system to activate volt-var control.	Algorithm, formula, rule, specific model	N/A
I-03	Voltage set-point	When volt-var control is activated, the desired voltage value is sent from SCADA/DMS to DER control system.	Electrical parameter	N/A
I-04	Reactive power control	The value of required DER reactive power is continuously sent from DER control system to the generator/inverter to match the real voltage with the desired one as precisely as possible.	Algorithm, formula, rule, specific model	N/A

Annex A – List of Actor Subcategories

Category	Type	Subcategory	Definition	Example
Actors	Role	DSO	Responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area	Avacon, CEZ, E.ON, Enexis, Enedis
Actors	Role	Industrial partner	All industrial partners involved in InterFlex project at a DEMO level	- GE - Siemens - Schneider ...
Actors	Role	University and research partner	All university or research partners involved in InterFlex project at a DEMO level	- RWTH - AIT etc
Actors	Role	Retailer	Licensed supplier of electricity to an end-user	- EDF - Engie...
Actors	Role	Legal Client	A legal client of a DSO that is involved at Demo scale	- Company producer - Municipalities - Tertiary service providers
Actors	Role	Physical client	A physical client of a DSO that is involved at Demo scale	- Residential client
Actors	System	Charging facilities	Facilities to charge electrical vehicles	- Charging facilities
Actors	System	DER installation	Power plant that use renewable technology and are owned by a legal person	- Photovoltaics panels - Biomass farm - Wind power, ...
Actors	System	In house device	All devices working on electricity that can be find in a customer's dwelling.	- Heater - Meter - Local display - Customer's battery
Actors	System	Communication infrastructure	All the infrastructure that are used for communication at all level (from customer's place to power command)	- Modem - Routers
Actors	System	Network device	All devices placed on MV/LV network for monitoring or gathering information on grid's situation or electrical parameters values. It also include the IS associated	- Secondary Substation control infrastructure - RTU : Remote terminal units - Circuits breakers - sensors
Actors	System	IS IT	All the hardware and software associated, used at power command to control and monitor the network	- SCADA - Central database - Control operation center
Actors	System	Interactive communication device	All device used to interact with customers in order to involved him in the Demo	- Web portal - Display used for communication

Annex B – List of Information Subcategories

Category	Type	Subcategory	Definition	Example
Data	Document	Internal document	All the documentation made by Demo to run operation, to monitor and conduct the project's good development	- Meeting minutes - Report on the cost's impact of selected flexibility plans
Data	Document	InterFlex deliverable	All the deliverables that Demo have to produce during the project's time as agreed in the DOW	- Risk analysis - Documentation on KPI - Detailed Use Case - Report on technical experimentation, market research, …
Data	Document	Communication material	All the documentation that describe the project to the public and can be put on the future website	- Purpose of the DEMO (leaflet) - Brief description of Use Case - Location of Use Case
Data	Financial data	Project financial data	All the financial data that are produced during the project and that are used to make financial report for European Commission and internal report	- Invoices - Cost and time imputation
Data	Financial data	Solution cost and selling price	All the financial data that can be made concerning estimation prices of solution for replication	- Unit product cost of hardware developed by Demo - Sell price of the solution develop (software,…)
Data	Parameter	Condition parameter	All the external parameters that may influence the success of the Use Case	- Weather - Time of day - Day of week …
Data	Parameter	Scenario assumption	All the stated parameters that are necessary to determinate a scenario for the Use Case	- Location of islanding - Experiment's location
Data	Parameter	Electrical parameter	All the electrical parameters that are used to supervise the network and its good state	- Intensity - Voltage - Frequency - Quality
Data	Parameter	Algorithm, formula, rule, specific model	All the intellectual data that are created during the project to made software's contents	- Algorithm to optimize flexibility plan - Simulation to determine location of circuit breaker - Voltage regulation algorithm
Data	Parameter	Optimized value	Values of parameters that optimized the Use Case or the demo's performance	- Optimization time of islanding
Data	Parameter	Forecast data	All the data used to forecast consumption or production of customer	- Forecast customer's consumption - Forecast photovoltaic panels' production
Data	Facility data	Network topology	All information on network devices and their location and interaction, mainly coming from GIS (Geographic Information System)	- Map of the network - Substations location - All the other data found in the GIS (Geographical Information System)
Data	Facility data	Network state	All information concerning the network's status (global or local) at a precise moment useful to monitor the network	- Feeding situation in a distribution area - State of network regarding Limit value violation - Location of constraint - Flexibility needs of DSO

Category	Type	Subcategory	Definition	Example
Data	Facility data	Customer's meter state and output	All the information concerning customer's meter state and outputs information	- Customer's consumption or production
Data	Facility data	Other device state and output	All the information concerning device's state and outputs information	- State of charge of batteries - Consumption data coming from meter - Production data coming from meter - State of charge of storage components
Data	Parameter	Information exchanged between IS or sent to device	All automated information sent between facilities in order to send information or order for monitoring	- Order sent to breaker devices (open, close,...) - Information on local network status coming from sensors - Order and roadmap sent to network devices (batteries, aggregator,...)
Data	Parameter	Detailed specification on devices	All detailed information (reference components, specification, process,...) useful to build the devices	- Detailed specification of the telecommunication infrastructure - Detailed specification of interactive sensor network
Data	Network data	Network topology	All information on network devices and their location and interaction, mainly coming from GIS (Geographic Information System)	- Map of the network - Substations location - All the other data found in the GIS (Geographical Information System)
Data	Network data	Network state	All information concerning the network's status (global or local) at a precise moment useful to monitor the network	- Feeding situation in a distribution area - State of network regarding Limit value violation - Location of constraint - Flexibility needs of DSO
Data	KPI	Data for KPI (input raw data)	All raw data that are used to calculate the final KPI	- Duration of experiment - Customer response to DSO's demand - Electrical parameter used for KPI
Data	KPI	KPI (KPI values)	All the KPI values and the way to calculate them	- Economic KPI - System Efficiency KPI
Data	Customer data	Customer contract's data	All the data in customer's contact that are used for contact or make payment	- Address - Phone number - Bank account details
Data	Customer data	Information sent to /received from customer	All the information and data that are exchanged between the DEMO and the customer in order to involve customer in the experiment	- Customer's response to DSO's request to reduce consumption - Information and data available to customer in order to visualize its consumption - Advices and encouragement sent to encourage a smart consumption
Data	Customer data	Customer analysis (profile analysis, studies on client reactivity,...)	All the data that are produced in order to better understand the customer's behaviour regarding the possibility to adopt smarter habits in their electricity consumption	- Customer's typology and behaviour patterns - Analysis on customer's response to DSO's request

Use Case Description

UC WP6_3 – Smart EV charging

Scope

This document describes the Use Case **UC WP6_3 – Smart EV charging**.

The Use Case description within is divided in to five areas:

1. Description of the Use Case
2. Diagrams of the Use Case
3. Technical data - Actors
4. Step by Step Analysis of Use Case (can be extended by detailed info on “information exchanged”)
5. Information exchanged

1. Description of the Use Case

1.1. Use Case Identification

ID	Domains/Zones[1]	Name of Use Case	Level of Use Case[2]
WP6_3	CUSTOMER PREMISES/PROCESS	Smart EV charging	Detailed Use case

1.2. Version Management

Version	Date	Name Author(s) or	Changes
V1.0	24.5.2017	Jan Švec	First version of the document

1.3. Scope and objectives

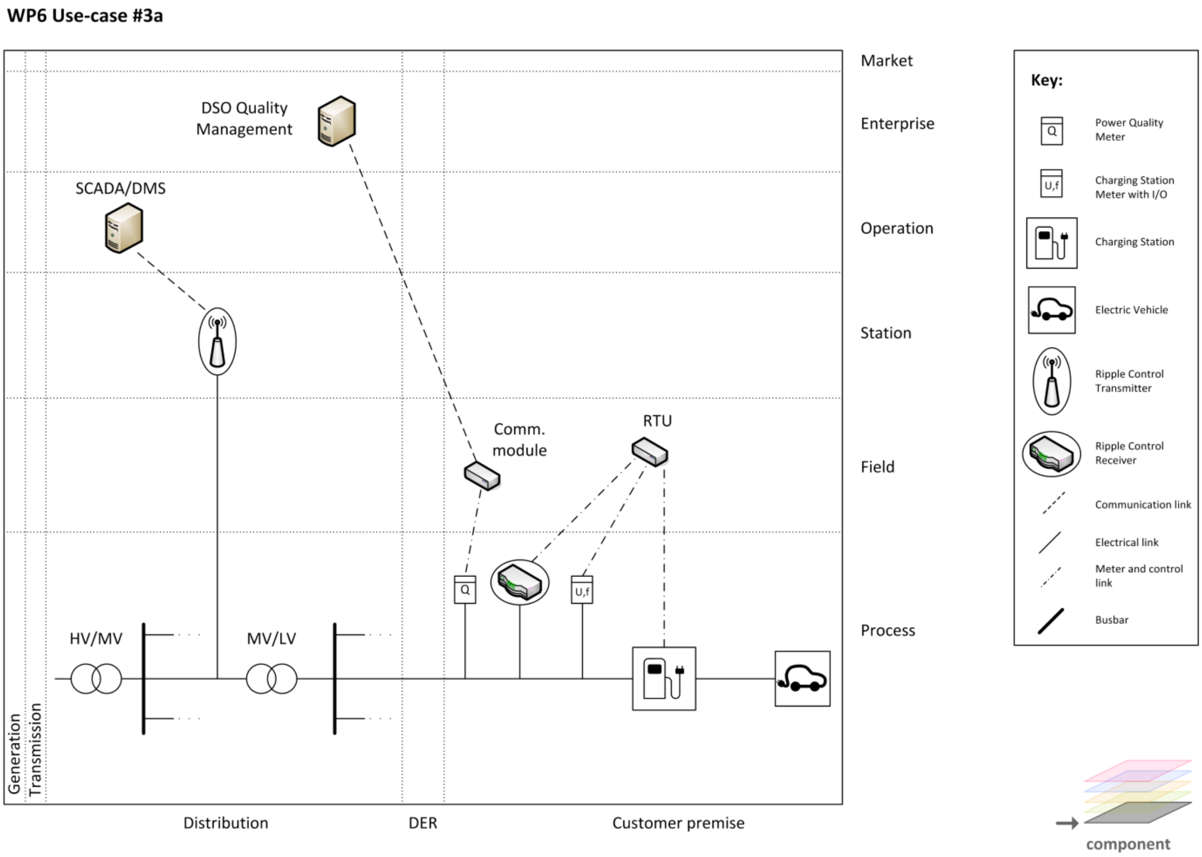
Scope and Objectives of the Use Case	
Scope	The aim is to quantify the impact of the Smart charging of EVs onto the distribution grid flexibility in case of emergency.
Objective	Reduce maximum charging power of smart charging station in case of underfrequency, undervoltage or in case of receiving signal from DSO through ripple control system (emergency functions) and power quality measurement during EV charging process (evaluated according to EN 50160).
Related Business Case	*CEZ Distribuce could defer investments to grid reinforcement.*

1.4. Narrative of Use Case

Short description – max 3 sentences
Curtailment of EV charging power in case of under voltage, under frequency or in case of DSO needs.

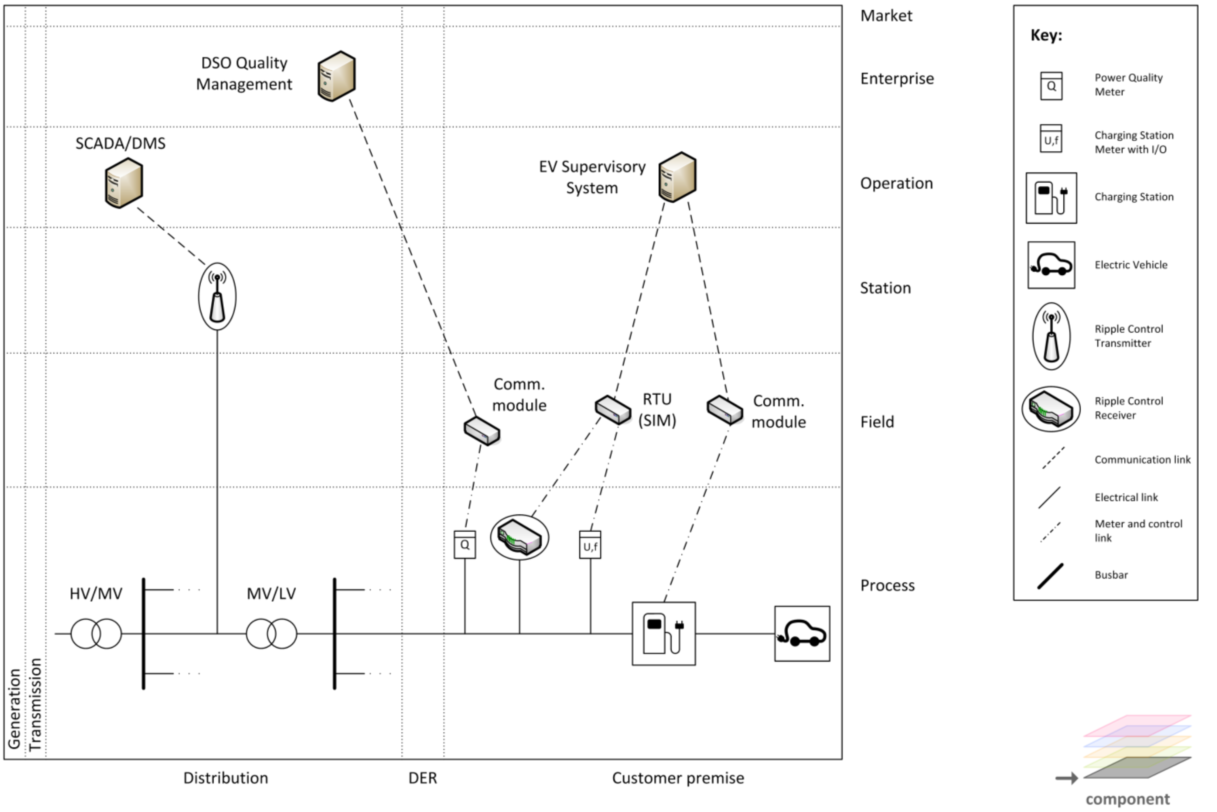
Complete description
ČEZ Distribuce together with partners aims at testing the influence of smart EV charging stations functions to show their potential for increasing the network flexibility through improved EV charging stations implementation into the distribution networks (services to the distribution network), and optimizing the future EV charging stations implementation to prevent from power quality issues and to contribute to the system stability and flexibility without reduction of customer comfort. The Smart functions to be tested (first in a laboratory then in the field) are partial active power curtailment of EV charging in case of under frequency or under voltage in the DS and partial remote active power curtailment from DSO SCADA in case of emergency.

Use Case 3a – Schneider Electric



Use Case 3b – Siemens

WP6 Use-case #3b



1.5. KPIs

ID	Name	Description	Reference to mentioned Use Case objectives
KPI6_2	Power quality (according to EN 50160 standard)	Power quality will not be negatively affected by implementation of solutions	WP6_1, WP6_2, WP6_3, WP6_4
KPI6_3	EV charging stations load curtailment in emergency situations	% of decrease of EV charging power	WP6_3

1.6. Use Case conditions

Actor	Triggering Event	Pre-conditions	Assumption
DSO dispatcher and voltage or frequency in the point of smart charging station connection	DSO dispatcher sends command for reduction of charging power. Smart charging station will also reduce charging power in case of under frequency or under voltage.	Emergency in distribution or transmission system and reaction of DSO dispatcher or under voltage or under frequency in the point of connection of smart charging station.	Smart charging station solution is able to react on DSO commands and on under voltage or under frequency in distribution system.

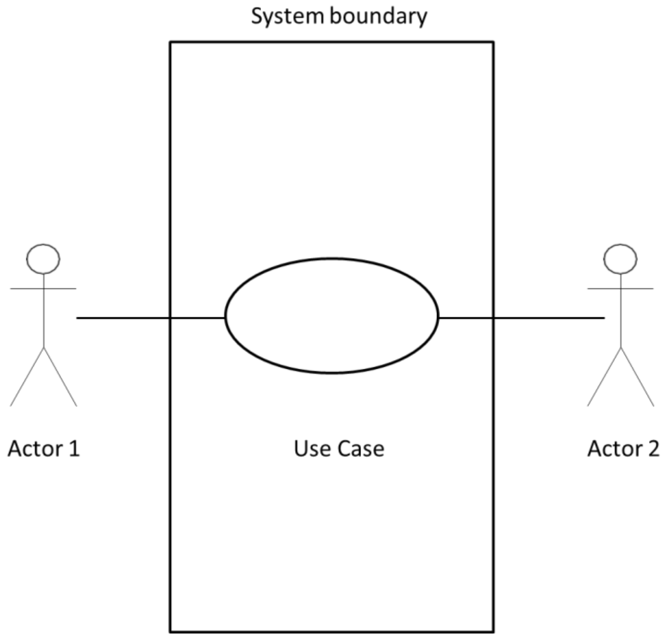
1.8. Classification information

Relation to Other Use Cases in the same project or area
N/A
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Prioritization
Very important
Generic, Regional or National Regional relation
Generic
Nature of the viewpoint- describes the viewpoint and field of attention
Technical point of view
Further Keywords for Classification
Charging station, EV, EN 60160, EN, ripple control system, voltage, frequency, emergency
Maturity of Use Case
Realized in demonstration project

2. Diagrams of the Use Case

2.1. Diagram of the Use Case

actor 1 = voltage or frequency in the point of smart charging station connection before reduction of charging power is activated (activation is based on voltage or frequency measurement or based on DSO dispatcher command); voltage or frequency in the point of smart charging station connection after reduction of charging power is activated (activation is based on voltage or frequency measurement or based on DSO dispatcher command – please see SGAM



2.2. Sequence diagram of the Use Case

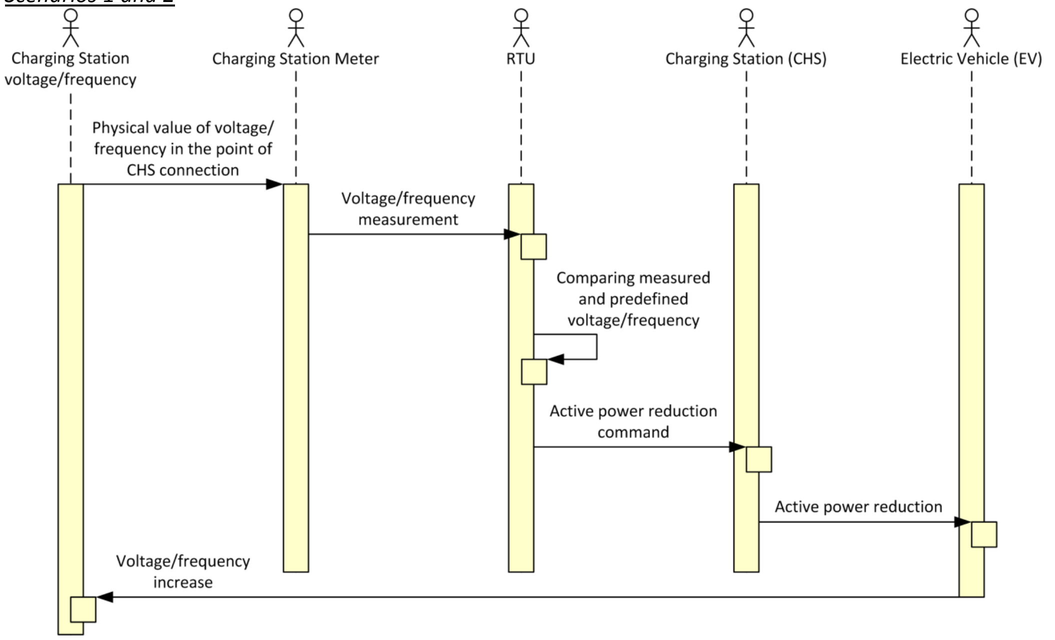
1 – voltage in the point of smart charging station connection is lower than predefined value, thus the smart charging station will reduce charging power – this will help to increase the voltage in the point of connection
2 – frequency in the point of smart charging station connection is lower than predefined value, thus the smart charging station will reduce charging power – this will help to increase the frequency in the point of connection
3 – in case of emergency, the DSO dispatcher will decide to reduce charging power and sends a command through PLC (power line communication), based on that signal, smart charging station will reduce charging power and this will help to reduce load in the selected area

Power quality during charging is monitored through DSO power quality management system.

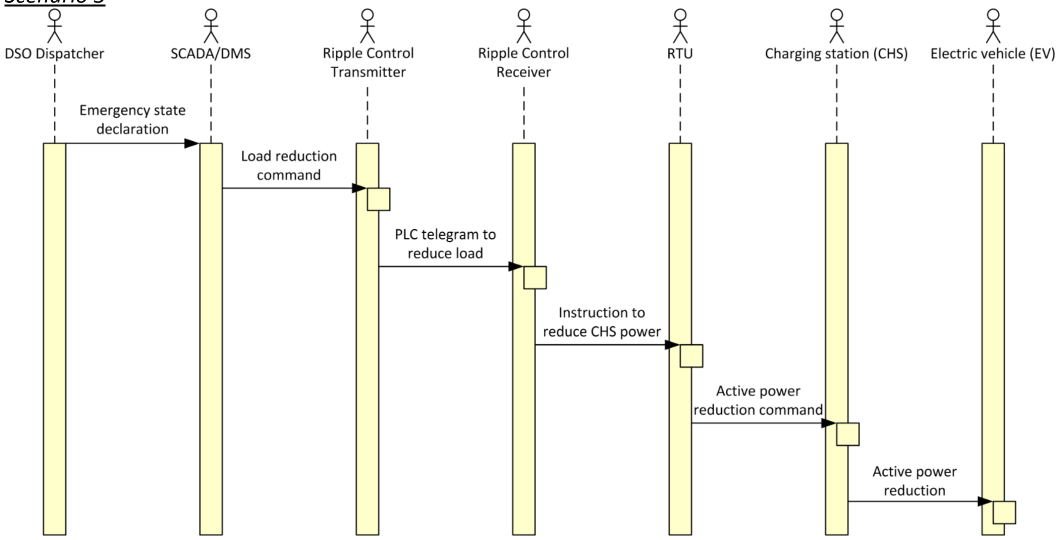
Use case 3 deals with autonomous functions triggered by voltage or frequency deviations, this means that voltage and frequency are also actors. Deviances in voltage or frequency trigger autonomous function of EV charging station (curtailment of charging power). Expected time of the sequence is no longer than 60s. If it takes more than 120s it could be ineffective in some cases. EV is considered as a load – this means that EV fits into "in house" actor subcategory.

Use Case 3a – Schneider Electric

Scenarios 1 and 2

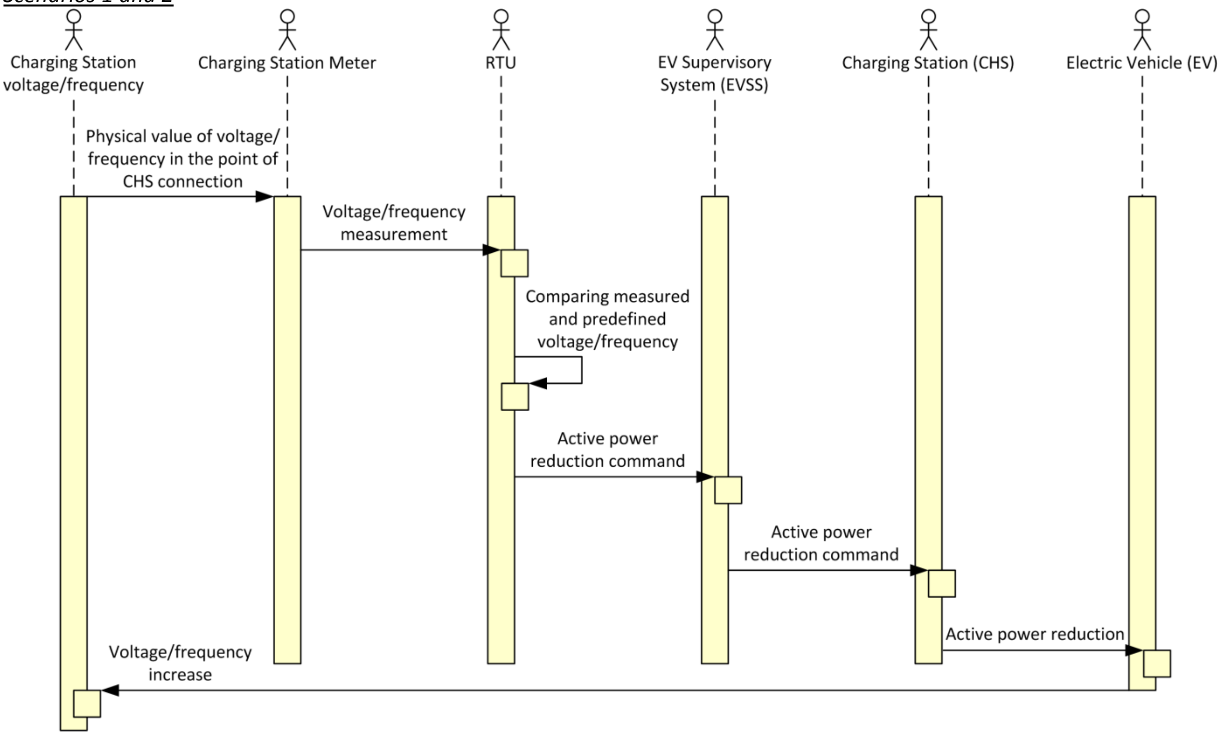


Scenario 3

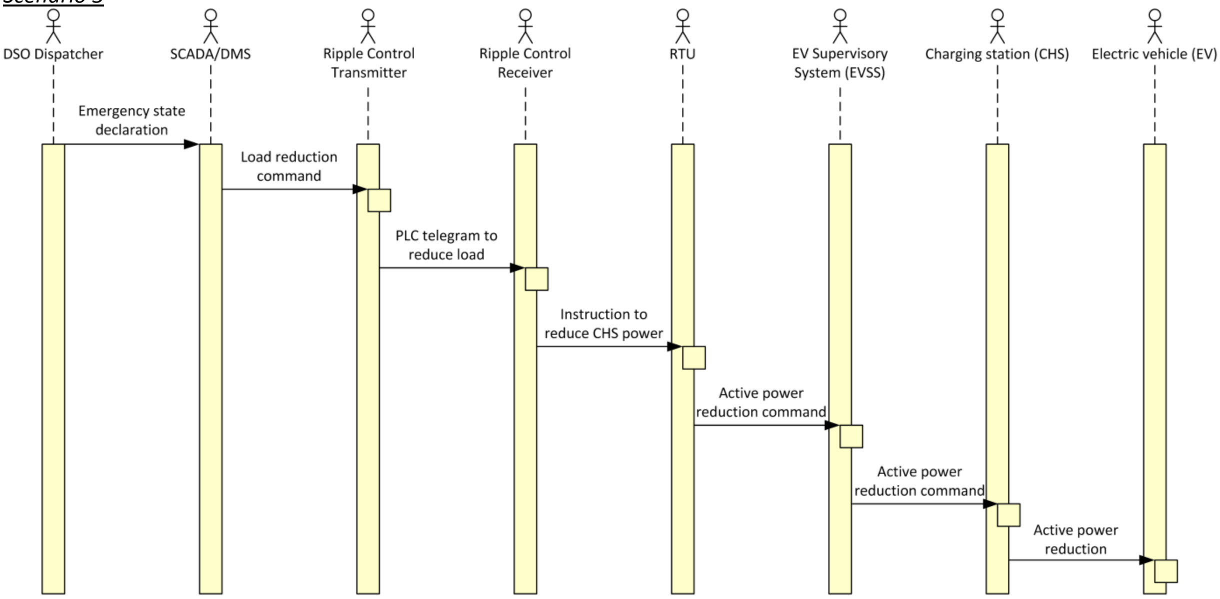


Use Case 3b – Siemens

Scenarios 1 and 2



Scenario 3



3. Technical details of the Use Case – Actors

UC3a

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this UC	Equipment Manufacturer	Grid Connection Requirements	IEC Standards
Charging Station	System	Charging facilities	Supplies electric vehicle with electric energy from the grid. It can be controlled from a supervisory system.	Supplies electric vehicle with electric energy from the grid. Its power can be reduced based on signals from RTU.	Schneider Electric	N/A	IEC 61851
Electric Vehicle	System	In house device	Consumes electricity from the charging station.	Consumes electricity from the charging station. Its consumption can be reduced based on the charging station control.	Different types of EV – the only requirement for testing is ability of EV to charge AC over 3x16A	N/A	IEC 61851
Quality Meter	System	Network device	Measures power quality data (voltages, currents, disturbances, fluctuations,…).	Measures power quality data and sends them to DSO quality management system.	MEgA	N/A	IEC 60870-5-104
Charging Station Meter	System	Network device	Measures basic electric quantities (voltage, frequency) to verify DS operational state.	Measures voltage and frequency and sends the data to RTU. If U or f is too low, the charging station should reduce its power.	Schneider Electric	N/A	N/A

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this UC	Equipment Manufacturer	Grid Connection Requirements	IEC Standards
RTU	System	Network device	Communicates with ripple control receiver, Charging Station Meter and charging station.	Receives data from ripple control receiver (signals – telegrams) and from Charging Station Meter (voltage, frequency). It sends commands to the charging station to change its power.	Type of manufacturer doesn't affect use case function.	N/A	N/A
Ripple Control Transmitter	System	Network device	Sends signals (telegrams) to DS to connect/disconnect specific groups of load in the grid.	Sends signals (telegrams) to the receiver at the charging station to reduce its consumed power in case of DS emergency.	Will not be specified because of security reason. Type of manufacturer doesn't affect use case function.	N/A	N/A
Ripple Control Receiver	System	Network device	Receives signals (telegrams) from the transmitter to connect/disconnect the load which it is connected to.	Receives signals (telegrams) from the transmitter to reduce charging station power.	Will not be specified because of security reason. Type of manufacturer doesn't affect use case function.	N/A	N/A
SCADA/DMS	System	IS IT	Receives measured data from DS and sends control commands to action devices.	Sends commands to ripple control transmitter to activate its signals to DS (telegrams).	Will not be specified because of security reason. Type of manufacturer doesn't affect use case function.	N/A	IEC 60870-5-104
DSO Quality Management	System	IS IT	Receives power quality data from different DS points.	Receives power quality data from quality meter at the charging station connection point.	Will not be specified because of security reason. Type of manufacturer doesn't affect use case function.	N/A	IEC 60870-5-104

UC3b

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this UC	Equipment Manufacturer	Grid Connection Requirements	IEC Standards
Charging Station	System	Charging facilities	Supplies electric vehicle with electric energy from the grid. It can be controlled from a supervisory system.	Supplies electric vehicle with electric energy from the grid. Its power can be reduced based on signals from EV supervisory system.	Siemens	N/A	IEC 61851
Electric Vehicle	System	In house device	Consumes electricity from the charging station.	Consumes electricity from the charging station. Its consumption can be reduced based on the charging station control.	Different types of EV – the only requirement for testing is ability of EV to charge AC over 3x16A	N/A	IEC 61851
Quality Meter	System	Network device	Measures power quality data (voltages, currents, disturbances, fluctuations,…).	Measures power quality data and send them to DSO quality management system.	MEgA	N/A	IEC 60870-5-104
Charging Station Meter	System	Network device	Measures basic electric quantities (voltage, frequency) to verify DS operational state.	Measures voltage and frequency and sends the data to RTU. If U or f is too low, the charging station should reduce its power.	Siemens	N/A	N/A
RTU	System	Network device	Communicates with ripple control receiver, Charging Station Meter and EV supervisory system.	Receives data from ripple control receiver (signals – telegrams) and from Charging Station Meter (voltage, frequency). It sends data to EV supervisory system so that influence charging power.	Type of manufacturer doesn’t affect use case function.	N/A	N/A

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this UC	Equipment Manufacturer	Grid Connection Requirements	IEC Standards
EV supervisory system	System	IS IT	Controls EV charging based on commands from other system units.	Receives data from ripple control receiver or Charging Station Meter to change EV charging power and sends adequate commands to the charging station.	Siemens	N/A	N/A
Ripple Control Transmitter	System	Network device	Sends signals (telegrams) to DS to connect/disconnect specific groups of load in the grid.	Sends signals (telegrams) to the receiver at the charging station to reduce its consumed power in case of DS emergency.	Will not be specified because of security reason. Type of manufacturer doesn't affect use case function.	N/A	N/A
Ripple Control Receiver	System	Network device	Receives signals (telegrams) from the transmitter to connect/disconnect the load which it is connected to.	Receives signals (telegrams) from the transmitter to reduce charging station power.	Will not be specified because of security reason. Type of manufacturer doesn't affect use case function.	N/A	N/A
SCADA/DMS	System	IS IT	Receives measured data from DS and sends control commands to action devices.	Sends commands to ripple control transmitter to activate its signals to DS (telegrams).	Will not be specified because of security reason. Type of manufacturer doesn't affect use case function.	N/A	IEC 60870-5-104
DSO Quality Management	System	IS IT	Receives power quality data from different DS points.	Receives power quality data from quality meter at the charging station connection point.	Will not be specified because of security reason. Type of manufacturer doesn't affect use case function.	N/A	IEC 60870-5-104

4. Step by Step Analysis of the Use Case

4.1. List of scenarios

Scenario No.	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
UC3_1	Voltage based reduction	Voltage in the point of smart charging station connection is lower than predefined value, thus the smart charging station will reduce charging power – this will help to increase the voltage in the point of connection.	Charging Station Meter	Voltage in the point of charging station connection is lower than predefined value.	Smart charging station is capable to reduce its consumption power based on RTU (or EV supervisory system) signals.	Due to charging power reduction, voltage in the point of charging station connection is increased in comparison with the state when no action is realized.
UC3_2	Frequency based reduction	Frequency in the point of smart charging station connection is lower than predefined value, thus the smart charging station will reduce charging power – this will help to increase the frequency in the point of connection.	Charging Station Meter	Frequency in the point of charging station connection is lower than predefined value.	Smart charging station is capable to reduce its consumption power based on RTU (or EV supervisory system) signals.	Due to charging power reduction, frequency in the point of charging station connection is increased in comparison with the state when no action is realized.
UC3_3	Emergency based reduction	In case of emergency, the DSO dispatcher will decide to reduce charging power and sends a ripple control command (telegram) through PLC (power line communication). Based on that signal, smart charging station will reduce charging power and this will help to reduce load in the selected area.	SCADA/DMS	DSO dispatcher declares an emergency state in the specific part of the grid.	Smart charging station is capable to reduce its consumption power based on RTU (or EV supervisory system) signals.	Charging power reduction results in selected area load reduction and hence possible cancelling the emergency state.

4.2. Steps – Primary Scenario

UC3a

Scenario Name: Voltage based reduction									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Voltage measurement	Charging Station Meter measures voltage in the point of charging station connection. The measured data are sent to RTU.	Charging Station Meter	RTU	I-01	REPORT	N/A	Charging station Meter is a physical part of RTU.	Internal protocol
2	Charging reduction command	If the measured voltage is lower than predefined value, RTU sends a command to the charging station to reduce its consumption power.	RTU	Charging Station	I-02	CREATE	N/A	Digital Input/Output	Protocol
3	Charging reduction	Charging station supplies electric vehicle with lower active power.	Charging Station	Electric Vehicle	I-03	EXECUTE	N/A	IEC 61851	Protocol

Scenario Name: Frequency based reduction									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Frequency measurement	Charging Station Meter measures frequency in the point of charging station connection. The measured data are sent to RTU.	Charging Station Meter	RTU	I-01	REPORT	N/A	Charging station Meter is a physical part of RTU.	Internal protocol
2	Charging reduction command	If the measured frequency is lower than predefined value, RTU sends a command to the charging station to reduce its consumption power.	RTU	Charging Station	I-02	CREATE	N/A	Digital Input/Output	Protocol

Scenario Name: Frequency based reduction									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
3	Charging reduction	Charging station supplies electric vehicle with lower active power.	Charging Station	Electric Vehicle	I-03	EXECUTE	N/A	IEC 61851	Protocol

Scenario Name: Emergency based reduction									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Emergency state command	If DSO dispatcher declares an emergency state in a selected grid area, SCADA/DMS sends a command to ripple control transmitter to activate load change.	SCADA/DMS	Ripple Control Transmitter	I-04	CREATE	N/A	IEC 60870-5-104	Protocol
2	Ripple control command	Ripple control transmitter sends signals (telegrams) via PLC to ripple control receiver in the selected area to activate load change.	Ripple Control Transmitter	Ripple Control Receiver	I-05	CREATE	N/A	CEZ Distribuce ripple control NB-PLC	Protocol
3	Charging reduction command - ripple	Based on the telegram, ripple control receiver sends a command to RTU to reduce charging station consumption power.	Ripple Control Receiver	RTU	I-06	CREATE	N/A	Digital Input/Output	Protocol
4	Charging reduction command - RTU	Based on the ripple control receiver signal, RTU sends a command to the charging station to reduce its consumption power.	RTU	Charging Station	I-02	CREATE	N/A	Digital Input/Output	Protocol
5	Charging reduction	Charging station supplies electric vehicle with lower active power.	Charging Station	Electric Vehicle	I-03	EXECUTE	N/A	IEC 61851	Protocol

UC3b

Scenario Name: Voltage based reduction									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Voltage measurement	Charging Station Meter measures voltage in the point of charging station connection. The measured data are sent to RTU.	Charging Station Meter	RTU	I-01	REPORT	N/A	Charging station Meter is a physical part of RTU.	Internal protocol
2	Charging reduction command - RTU	If the measured voltage is lower than predefined value, RTU sends a command to EV supervisory system to reduce charging station consumption power.	RTU	EV supervisory system	I-02	REPORT	N/A	IEC over LTE or GPRS	Protocol
3	Charging reduction command - EVSS	EV supervisory system resends the command from RTU further to the charging station via its communication module to reduce its consumption power.	EV supervisory system	Charging Station	I-03	CREATE	N/A	IEC over LTE or GPRS	Protocol
4	Charging reduction	Charging station supplies electric vehicle with lower active power.	Charging Station	Electric Vehicle	I-04	EXECUTE	N/A	IEC 61851	Protocol

Scenario Name: Frequency based reduction									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Frequency measurement	Charging Station Meter measures frequency in the point of charging station connection. The measured data are sent to RTU.	Charging Station Meter	RTU	I-01	REPORT	N/A	Charging station Meter is a physical part of RTU.	Internal protocol

Scenario Name: Frequency based reduction									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
2	Charging reduction command - RTU	If the measured frequency is lower than predefined value, RTU sends a command to EV supervisory system to reduce charging station consumption power.	RTU	EV supervisory system	I-02	REPORT	N/A	IEC over LTE or GPRS	Protocol
3	Charging reduction command - EVSS	EV supervisory system resends the command from RTU further to the charging station via its communication module to reduce its consumption power.	EV supervisory system	Charging Station	I-03	CREATE	N/A	IEC over LTE or GPRS	Protocol
4	Charging reduction	Charging station supplies electric vehicle with lower active power.	Charging Station	Electric Vehicle	I-04	EXECUTE	N/A	IEC 61851	Protocol

Scenario Name: Emergency based reduction									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Emergency state command	If DSO dispatcher declares an emergency state in a selected grid area, SCADA/DMS sends a command to ripple control transmitter to activate load change.	SCADA/DMS	Ripple Control Transmitter	I-05	CREATE	N/A	IEC 60870-5-104	Protocol
2	Ripple control command	Ripple control transmitter sends signals (telegrams) via PLC to ripple control receiver in the selected area to activate load change.	Ripple Control Transmitter	Ripple Control Receiver	I-06	CREATE	N/A	CEZ Distribuce ripple control NB-PLC	Protocol

Scenario Name: Emergency based reduction									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
3	Charging reduction command - ripple	Based on the telegram, ripple control receiver sends a command to RTU to reduce charging station consumption power.	Ripple Control Receiver	RTU	I-07	CREATE	N/A	Digital Input/Output	Protocol
4	Charging reduction command - RTU	RTU evaluates a command from ripple control receiver and sends a command to EV supervisory system to reduce charging station consumption power.	RTU	EV supervisory system	I-02	REPORT	N/A	IEC over LTE or GPRS	Protocol
5	Charging reduction command - EVSS	EV supervisory system resends the command from RTU further to the charging station via its communication module to reduce its consumption power.	EV supervisory system	Charging Station	I-03	CREATE	N/A	IEC over LTE or GPRS	Protocol
6	Charging reduction	Charging station supplies electric vehicle with lower active power.	Charging Station	Electric Vehicle	I-04	EXECUTE	N/A	IEC 61851	Protocol

No other scenarios (alternative, error,…) are considered in this use case.

4.3. Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: N/A									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

5. Information exchanged

UC3a

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories[5]	Requirements
I-01	DS state quantities	Measured voltage and frequency in the point of charging station connection to the grid. Values are sent from Charging Station Meter to RTU.	Electrical parameter	N/A
I-02	RTU charging command	If RTU evaluates low voltage or frequency or receives a command from ripple control receiver, it sends a command to the charging station to reduce its power.	Information exchanged between IS or sent to device	N/A
I-03	EV instruction	If charging station is controlled to reduce its power, it exchanges information with electric vehicle about the proper charging.	Information exchanged between IS or sent to device	N/A
I-04	Emergency command	If DSO dispatcher declares an emergency state in a selected grid area, SCADA/DMS sends an emergency command to ripple control transmitter to activate load change.	Information exchanged between IS or sent to device	N/A
I-05	Ripple control signal	Ripple control transmitter sends signals (telegrams) via PLC to ripple control receiver in the selected area to activate load change.	Information exchanged between IS or sent to device	N/A
I-06	Ripple control charging command	Based on the telegram, ripple control receiver sends a command to RTU to reduce charging station consumption power.	Information exchanged between IS or sent to device	N/A

UC3b

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories[5]	Requirements
I-01	DS state quantities	Measured voltage and frequency in the point of charging station connection to the grid. Values are sent from Charging Station Meter to RTU.	Electrical parameter	N/A
I-02	RTU command	Voltage or frequency measurement or ripple control command resent from RTU to EV supervisory system for their evaluation.	Information exchanged between IS or sent to device	N/A
I-03	EVSS charging command	If EV supervisory system evaluates low voltage or frequency or receives a command from ripple control receiver, it sends a command to the charging station to reduce its power.	Information exchanged between IS or sent to device	N/A
I-04	EV instruction	If charging station is controlled to reduce its power, it exchanges information with electric vehicle about the proper charging.	Information exchanged between IS or sent to device	N/A
I-05	Emergency command	If DSO dispatcher declares an emergency state in a selected grid area, SCADA/DMS sends an emergency command to ripple control transmitter to activate load change.	Information exchanged between IS or sent to device	N/A
I-06	Ripple control signal	Ripple control transmitter sends signals (telegrams) via PLC to ripple control receiver in the selected area to activate load change.	Information exchanged between IS or sent to device	N/A
I-07	Ripple control charging command	Based on the telegram, ripple control receiver sends a command to RTU to reduce charging station consumption power.	Information exchanged between IS or sent to device	N/A

Annex A – List of Actor Subcategories

Category	Type	Subcategory	Definition	Example
Actors	Role	DSO	Responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area	Avacon, CEZ, E.ON, Enexis, Enedis
Actors	Role	Industrial partner	All industrial partners involved in InterFlex project at a DEMO level	- GE - Siemens - Schneider …
Actors	Role	University and research partner	All university or research partners involved in InterFlex project at a DEMO level	- RWTH - AIT etc
Actors	Role	Retailer	Licensed supplier of electricity to an end-user	- EDF - Engie...
Actors	Role	Legal Client	A legal client of a DSO that is involved at Demo scale	- Company producer - Municipalities - Tertiary service providers
Actors	Role	Physical client	A physical client of a DSO that is involved at Demo scale	- Residential client
Actors	System	Charging facilities	Facilities to charge electrical vehicles	- Charging facilities
Actors	System	DER installation	Power plant that use renewable technology and are owned by a legal person	- Photovoltaics panels - Biomass farm - Wind power, …
Actors	System	In house device	All devices working on electricity that can be find in a customer's dwelling.	- Heater - Meter - Local display - Customer's battery
Actors	System	Communication infrastructure	All the infrastructure that are used for communication at all level (from customer's place to power command)	- Modem - Routers
Actors	System	Network device	All devices placed on MV/LV network for monitoring or gathering information on grid's situation or electrical parameters values. It also include the IS associated	- Secondary Substation control infrastructure - RTU : Remote terminal units - Circuits breakers - sensors
Actors	System	IS IT	All the hardware and software associated, used at power command to control and monitor the network	- SCADA - Central database - Control operation center
Actors	System	Interactive communication device	All device used to interact with customers in order to involved him in the Demo	- Web portal - Display used for communication

Annex B – List of Information Subcategories

Category	Type	Subcategory	Definition	Example
Data	Document	Internal document	All the documentation made by Demo to run operation, to monitor and conduct the project's good development	- Meeting minutes - Report on the cost's impact of selected flexibility plans
Data	Document	InterFlex deliverable	All the deliverables that Demo have to produce during the project's time as agreed in the DOW	- Risk analysis - Documentation on KPI - Detailed Use Case - Report on technical experimentation, market research, …
Data	Document	Communication material	All the documentation that describe the project to the public and can be put on the future website	- Purpose of the DEMO (leaflet) - Brief description of Use Case - Location of Use Case
Data	Financial data	Project financial data	All the financial data that are produced during the project and that are used to make financial report for European Commission and internal report	- Invoices - Cost and time imputation
Data	Financial data	Solution cost and selling price	All the financial data that can be made concerning estimation prices of solution for replication	- Unit product cost of hardware developed by Demo - Sell price of the solution develop (software,…)
Data	Parameter	Condition parameter	All the external parameters that may influence the success of the Use Case	- Weather - Time of day - Day of week …
Data	Parameter	Scenario assumption	All the stated parameters that are necessary to determinate a scenario for the Use Case	- Location of islanding - Experiment's location
Data	Parameter	Electrical parameter	All the electrical parameters that are used to supervise the network and its good state	- Intensity - Voltage - Frequency - Quality
Data	Parameter	Algorithm, formula, rule, specific model	All the intellectual data that are created during the project to made software's contents	- Algorithm to optimize flexibility plan - Simulation to determine location of circuit breaker - Voltage regulation algorithm
Data	Parameter	Optimized value	Values of parameters that optimized the Use Case or the demo's performance	- Optimization time of islanding
Data	Parameter	Forecast data	All the data used to forecast consumption or production of customer	- Forecast customer's consumption - Forecast photovoltaic panels' production
Data	Facility data	Network topology	All information on network devices and their location and interaction, mainly coming from GIS (Geographic Information System)	- Map of the network - Substations location - All the other data found in the GIS (Geographical Information System)
Data	Facility data	Network state	All information concerning the network's status (global or local) at a precise moment useful to monitor the network	- Feeding situation in a distribution area - State of network regarding Limit value violation - Location of constraint - Flexibility needs of DSO

Category	Type	Subcategory	Definition	Example
Data	Facility data	Customer's meter state and output	All the information concerning customer's meter state and outputs information	- Customer's consumption or production
Data	Facility data	Other device state and output	All the information concerning device's state and outputs information	- State of charge of batteries - Consumption data coming from meter - Production data coming from meter - State of charge of storage components
Data	Parameter	Information exchanged between IS or sent to device	All automated information sent between facilities in order to send information or order for monitoring	- Order sent to breaker devices (open, close,...) - Information on local network status coming from sensors - Order and roadmap sent to network devices (batteries, aggregator,...)
Data	Parameter	Detailed specification on devices	All detailed information (reference components, specification, process,...) useful to build the devices	- Detailed specification of the telecommunication infrastructure - Detailed specification of interactive sensor network
Data	Network data	Network topology	All information on network devices and their location and interaction, mainly coming from GIS (Geographic Information System)	- Map of the network - Substations location - All the other data found in the GIS (Geographical Information System)
Data	Network data	Network state	All information concerning the network's status (global or local) at a precise moment useful to monitor the network	- Feeding situation in a distribution area - State of network regarding Limit value violation - Location of constraint - Flexibility needs of DSO
Data	KPI	Data for KPI (input raw data)	All raw data that are used to calculate the final KPI	- Duration of experiment - Customer response to DSO's demand - Electrical parameter used for KPI
Data	KPI	KPI (KPI values)	All the KPI values and the way to calculate them	- Economic KPI - System Efficiency KPI
Data	Customer data	Customer contract's data	All the data in customer's contact that are used for contact or make payment	- Address - Phone number - Bank account details
Data	Customer data	Information sent to /received from customer	All the information and data that are exchanged between the DEMO and the customer in order to involve customer in the experiment	- Customer's response to DSO's request to reduce consumption - Information and data available to customer in order to visualize its consumption - Advices and encouragement sent to encourage a smart consumption
Data	Customer data	Customer analysis (profile analysis, studies on client reactivity,...)	All the data that are produced in order to better understand the customer's behaviour regarding the possibility to adopt smarter habits in their electricity consumption	- Customer's typology and behaviour patterns - Analysis on customer's response to DSO's request

Use Case Description

UC WP6_4 – Smart energy storage

Scope

This document describes the Use Case **UC WP6_4 – Smart energy storage**.

The Use Case description within is divided in to five areas:

1. Description of the Use Case
2. Diagrams of the Use Case
3. Technical data - Actors
4. Step by Step Analysis of Use Case (can be extended by detailed info on “information exchanged”)
5. Information exchanged

1. Description of the Use Case

1.1. Use Case Identification

ID	Domains/Zones[1]	Name of Use Case	Level of Use Case[2]
WP6_4	DER/PROCESS	Smart energy storage	Detailed Use case

1.2. Version Management

Version	Date	Name Author(s) or	Changes
V1.0	24.5.2017	Jan Švec	First version of the document
V1.1	26.5.2017	Jan Kůla	Added chapters 3,4,5

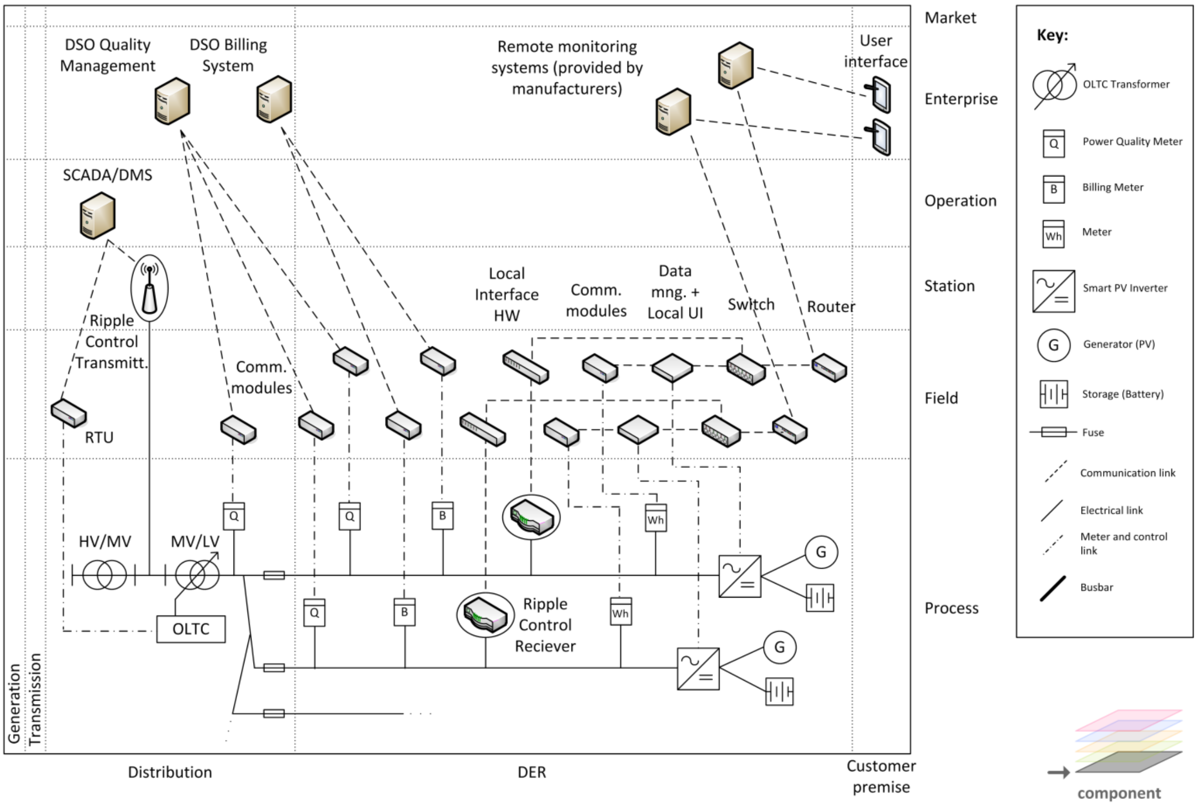
1.3. Scope and objectives

Scope and Objectives of the Use Case	
Scope	The aim of the use case is field demonstration of smart PV inverters with batteries which enables increasing of DER hosting capacity in one area thanks to the peak shaving of PV production. Provision of flexibility to DSO in case of emergency.
Objective	Increase of DER hosting capacity in LV grids thanks to the installation of smart PV inverters with batteries which allow peak shaving of PV production and securing the power quality according to EN 50160 standard. Delivery of active power from batteries in case of underfrequency, undervoltage or in case of receiving signal from DSO through ripple control system (emergency functions).
Related Business Case	*CEZ Distribuce could defer investments to grid reinforcement.*

1.4. Narrative of Use Case

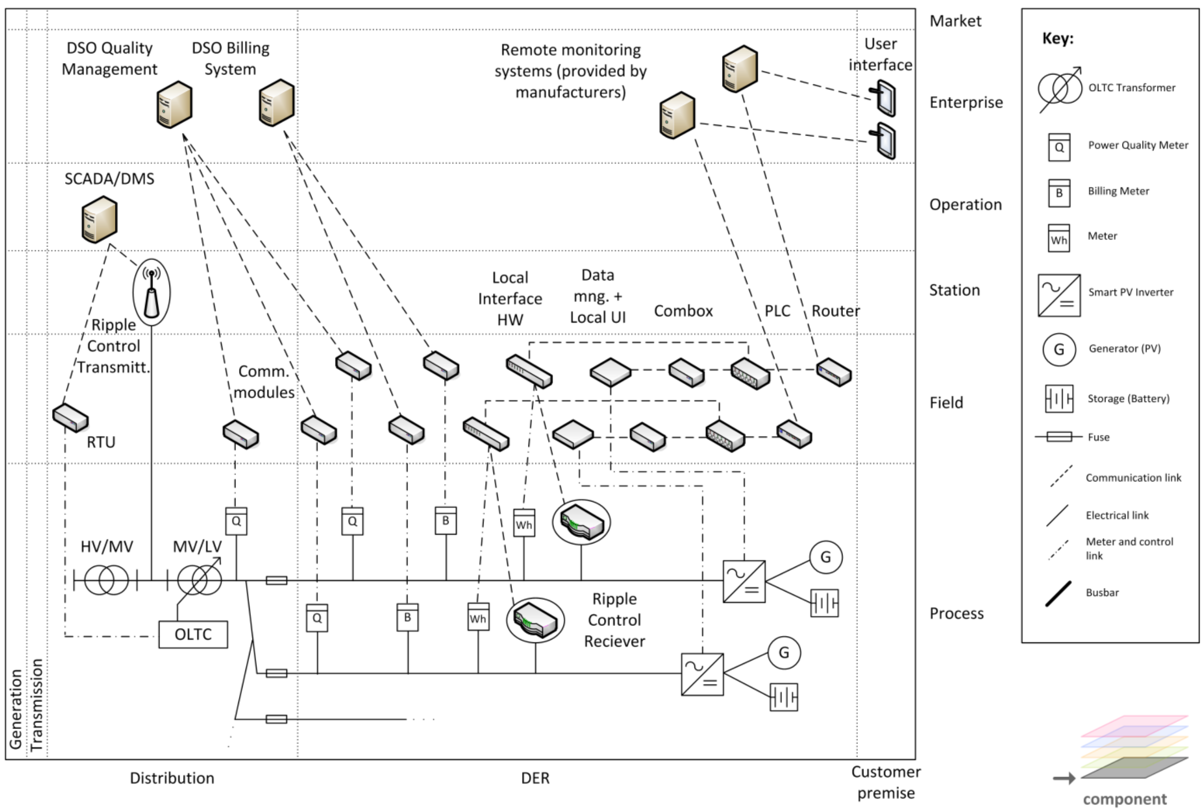
Short description – max 3 sentences
Increasing of DER hosting capacity and reduction of PV production peak in case that smart PV inverters with energy storage are used.

Complete description
ČEZ Distribuce tests the influence of using the residential energy storage systems (PV + battery) on the PV peak shaving in LV distribution network and assesses the potential of grid-connected energy storage systems (for increasing the flexibility by providing grid services). The smart energy storage functions which are going to be tested are: active power injection in case of DSO request and active power injection in case of under frequency or under voltage in the distribution network. Customer participation is essential. Testing the influence of residential energy storage systems on solar peak shaving helps determining how these systems affect the power quality and how they contribute to avoiding congestions in the distribution network. Use Case 4a – Fronius **WP6 Use-case #4**



Use Case 4b – Schneider Electric

WP6 Use-case #4 (Schneider)



1.5. KPIs

ID	Name	Description	Reference to mentioned Use Case objectives
KPI6_1	Increasing DER hosting capacity	in % compared with the baseline situation	WP6_1, WP6_2, WP6_4
KPI6_2	Power quality (according to EN 50160 standard)	Power quality will not be negatively affected by implementation of solutions	WP6_1, WP6_2, WP6_3, WP6_4
KPI6_4	PV production peak shaving	% of decrease of PV production peak	WP6_4

1.6. Use Case conditions

Actor	Triggering Event	Pre-conditions	Assumption
DSO dispatcher and voltage or frequency in the point of PV + battery connection	DSO dispatcher sends command for discharging of the battery. Battery will also discharge in case of under frequency or under voltage.	Emergency in distribution or transmission system and reaction of DSO dispatcher or under voltage or under frequency in the point of connection of PV + battery.	PV + battery solution is able to react on DSO commands and on under voltage or under frequency in distribution system.

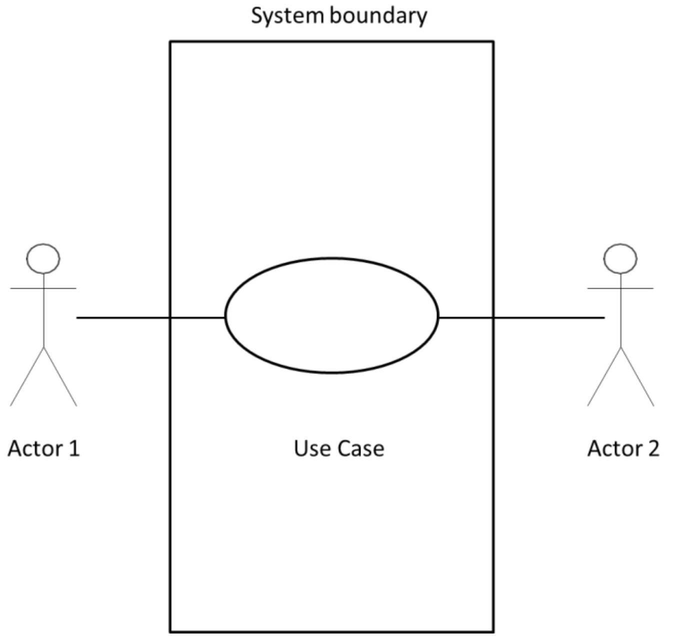
1.7. Classification information

Relation to Other Use Cases in the same project or area
Associate – use cases WP6_1, WP6_2, WP6_4 aim to increase DER hosting capacity of distribution grids.
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Prioritization
Very important
Generic, Regional or National Regional relation
Generic
Nature of the viewpoint- describes the viewpoint and field of attention
Technical point of view
Further Keywords for Classification
PV inverter, EN 50160, hosting capacity, DER, energy storage, peak shaving, ripple control system, LV grid, Q(U), P(U), voltage, frequency, emergency
Maturity of Use Case
Realized in demonstration project

2. Diagrams of the Use Case

2.1. Diagram of the Use Case

actor 1 = voltage or frequency in the point of PV + battery connection before discharging is activated (activation is based on voltage or frequency measurement or based on DSO dispatcher command); voltage or frequency in the point of PV + battery connection after discharging is activated (activation is based on voltage or frequency measurement or based on DSO dispatcher command – please see SGAM

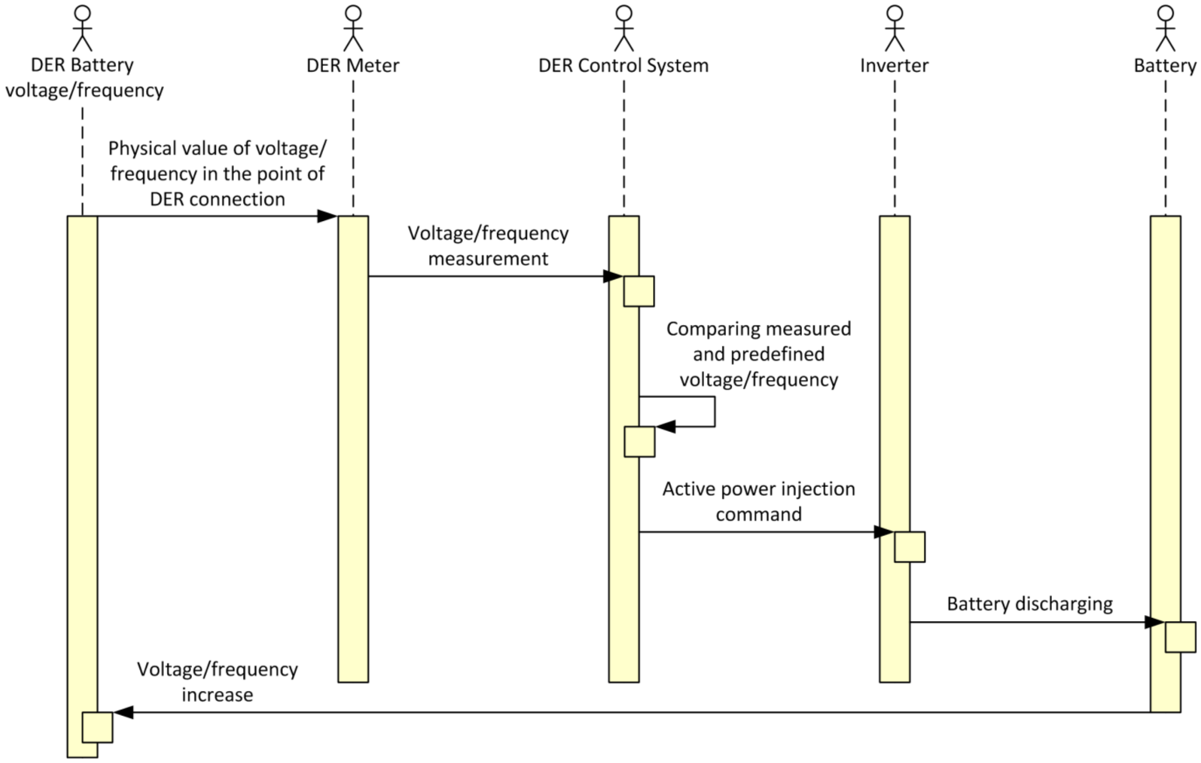


2.2. Sequence diagram of the Use Case

1 – voltage in the point of PV inverter + battery connection is lower than predefined value, thus the s PV inverter + battery will discharge – this will help to increase the voltage in the point of connection
2 – frequency in the point of PV inverter + battery connection is lower than predefined value, thus the PV inverter + battery will discharge – this will help to increase the frequency in the point of connection
3 – in case of emergency, the DSO dispatcher will decide to discharge the battery and sends a command through PLC (power line communication), based on that signal, PV inverter + battery will discharge and this will help to reduce load in the selected area

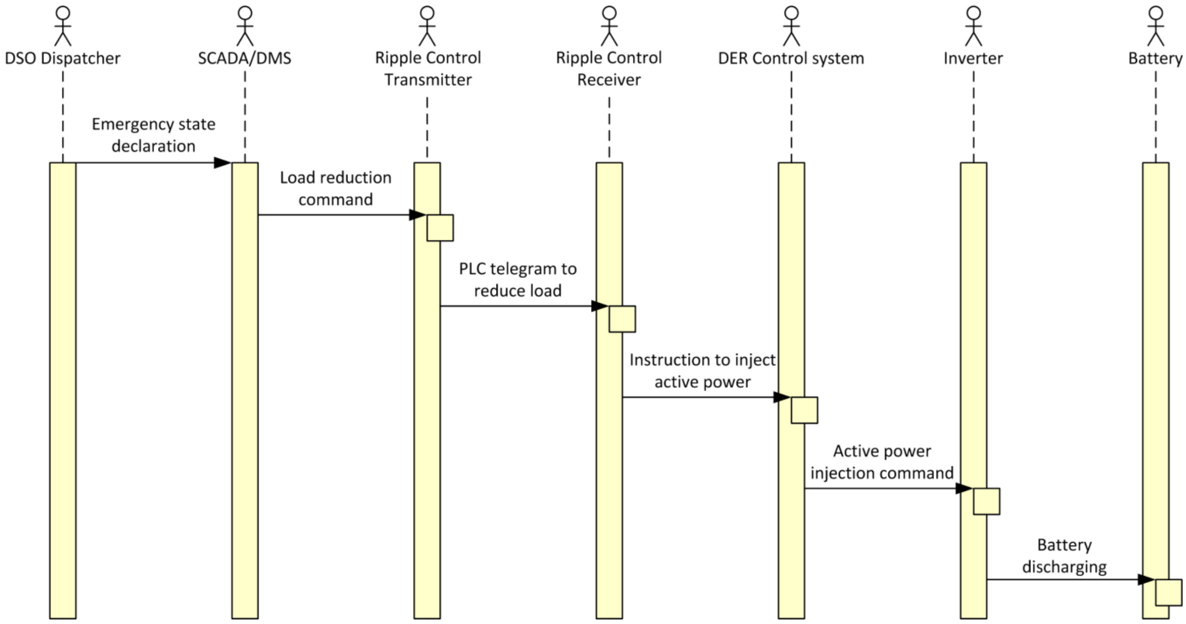
Maximum feed in power of the system (PV + battery) back to the distribution grid is limited to 50 % of the PV installed capacity. This is secured by Wh meter and communication towards the PV inverter.
MV/LV OLTC transformer is used for simulation of different voltage levels in LV grid. Taps could be regulated through DMS.
Power quality is monitored in the LV grid through DSO power quality management system. For use case evaluation also data from DSO billing system are used. Data from PV inverter are also used for use case evaluation.

<u>**Use Case 4 (both Fronius and Schneider)**</u>
<u>Scenarios 1 and 2</u>



Use Case 4 (both Fronius and Schneider)

Scenario 3



3. Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this UC	Equipment Manufacturer	Grid Connection Requirements	IEC Standards
SCADA/DMS (Dispatcher command)	System	IS IT	Receives measured data from DS and sends control commands to action devices.	Sends commands to ripple control transmitter to activate its signals to DS (telegrams).	Will not be specified because of security reason. Type of manufacturer doesn't affect use case function.	N/A	IEC 60870-5-104
OLTC tap changer (incl. RTU)	System	Network device	Sets OLTC tap to change voltage level in DS.	RTU receives commands from SCADA/DMS and send them to OLTC tap changer to set the tap and simulate voltage changes in DS.	Will be selected by procurement later.	N/A	60870-5-104 Over GPRS
DER control system (incl. Data manager, Local UI, Router, Local Interface HW)	System	DER installation	Receives signals from Ripple Control Receiver. Sends data to supervisory systems and interfaces.	Sends monitoring data to user interfaces and remote monitoring/control systems. Send command to battery whether battery discharge is needed.	Fronius, Schneider	N/A	Ethernet TCP/IP internet
Generator + Inverter + Battery storage	System	DER installation	Battery discharge in case of DSO request or under frequency or under voltage in the distribution network.	Measures voltage and receives signals from ripple control transmitter. Local UI determines whether battery could be used for power injection.	Fronius, Schneider	EN 50438:2013	N/A
Ripple Control Transmitter	System	Network device	Sends signals (telegrams) to DS to connect/disconnect specific groups of load in the grid.	Sends signals (telegrams) to the receiver to reduce its consumed power in case of DS emergency.	Will not be specified because of security reason. Type of manufacturer doesn't affect use case function.	N/A	N/A
Ripple Control Receiver	System	Network device	Receives signals (telegrams) from the transmitter to connect/disconnect the load which it is connected to.	Receives signals (telegrams) from the transmitter to reduce injected power.	Will not be specified because of security reason. Type of manufacturer doesn't affect use case function.	N/A	N/A

4. Step by Step Analysis of the Use Case

4.1. List of scenarios

Scenario No.	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
UC4_1	Voltage based discharge	Voltage in the point of DER + battery connection is lower than predefined value, thus the Battery will discharge – this will help to increase the voltage in the point of connection	DER control system (incl. Data manager, Local UI, Router, Local Interface HW)	Voltage in the point of DER connection is lower than predefined value.	DER with storage is capable to charge/discharger based on received signal signals.	Due to battery discharging, voltage in the point of DER connection is increased in comparison with the state when no action is realized.
UC4_2	Frequency based discharge	Frequency in the point DER connection is lower than predefined value, thus the PV inverter + battery will discharge – this will help to increase the frequency in the point of connection	DER control system (incl. Data manager, Local UI, Router, Local Interface HW)	Frequency in the point of DER connection is lower than predefined value.	DER with storage is capable to charge/discharger based on received signal signals.	Due to battery discharging, frequency in the point of DER connection is increased in comparison with the state when no action is realized.
UC4_3	Emergency based discharge	In case of emergency, the DSO dispatcher will decide to discharge the battery and sends a command through PLC (power line communication), based on that signal, PV inverter + battery will discharge and this will help to reduce load in the selected area	SCADA/DMS (Dispatcher command)	DSO dispatcher declares an emergency state in the specific part of the grid.	DER with storage is capable to discharger based on received signal signals.	Due to battery discharging in selected area load reduction is realized and hence it is possible cancelling the emergency state.

4.2. Steps – Primary Scenario

Scenario Name: Voltage based discharge									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Voltage measurement	DER Meter measures voltage in the point of connection. The measured data are sent to Local interface HW of DER.	DER meter	Local UI of DER	I-01	REPORT	N/A	Meter is a physical part of Local interface HW of DER.	Internal protocol
2	Discharging command	DER system decides if the battery is charged and sends command to the inverter connected to battery via its communication module to discharge.	Local UI	Inverter	I-02	CREATE	N/A	Ethernet Modbus TCP (Sunspec)	Protocol
3	Battery Discharging	Battery produces active power injection to the grid. This will help to increase the voltage in the point of connection	Inverter	Battery	I-03	EXECUTE	N/A	Ethernet Modbus TCP (Sunspec)	Protocol

Scenario Name: Frequency based discharge									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Frequency measurement	DER Meter measures frequency in the point of connection. The measured data are sent to Local interface HW of DER.	DER meter	Local UI of DER	I-01	REPORT	N/A	Meter is a physical part of Local interface HW of DER.	Internal protocol
2	Discharging command	DER system decides if the battery is charged and sends command to the inverter connected to battery via its communication module to discharge.	Local UI	Inverter	I-02	CREATE	N/A	Ethernet Modbus TCP (Sunspec)	Protocol
3	Battery Discharging	Battery produces active power injection to the grid. This will help to increase the frequency in the point of connection	Inverter	Battery	I-03	EXECUTE	N/A	Ethernet Modbus TCP (Sunspec)	Protocol

Scenario Name: Emergency based discharge									
Step No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Emergency state command	If DSO dispatcher declares an emergency state in a selected grid area, SCADA/DMS sends a command to ripple control transmitter to activate load change.	SCADA/DMS	Ripple Control Transmitter	I-04	CREATE	N/A	IEC 60870-5-104	Protocol
2	Ripple control command	Ripple control transmitter sends signals (telegrams) via PLC to ripple control receiver in the selected area to activate load change.	Ripple Control Transmitter	Ripple Control Receiver	I-05	CREATE	N/A	CEZ Distribuce ripple control NB-PLC	Protocol
3	DER command	Based on the telegram, ripple control receiver sends a command to DER Control system to inject active power from battery.	Ripple Control Receiver	DR Control System	I-06	CREATE	N/A	Digital Input/Output	Protocol
4	Discharging command	DER system decides if the battery is charged and sends command to the inverter connected to battery via its communication module to discharge.	Local UI	Inverter	I-02	CREATE	N/A	Ethernet Modbus TCP (Sunspec)	Protocol
5	Battery Discharging	Battery produces active power injection to the grid. This will help to increase the frequency in the point of connection	Inverter	Battery	I-03	EXECUTE	N/A	Ethernet Modbus TCP (Sunspec)	Protocol

No other scenarios (alternative, error,…) are considered in this use case.

4.3. Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: N/A									
Step No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

5. Information exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories[5]	Requirements
I-01	DS state quantities	Measured voltage or frequency in the point of DER connection to the grid. Values are sent from DER Meter to DER Control system.	Electrical parameter	N/A
I-02	Discharging command	If DER Control system evaluates low voltage or frequency or receives a command from ripple control receiver, it sends a command to Inverter to inject active power.	Information exchanged between IS or sent to device	N/A
I-03	Battery Discharging	If inverter is controlled to inject active power, it exchanges information with battery and execute.	Information exchanged between IS or sent to device	N/A
I-04	Emergency command	If DSO dispatcher declares an emergency state in a selected grid area, SCADA/DMS sends an emergency command to ripple control transmitter to activate load change.	Information exchanged between IS or sent to device	N/A
I-05	Ripple control signal	Ripple control transmitter sends signals (telegrams) via PLC to ripple control receiver in the selected area to activate load change.	Information exchanged between IS or sent to device	N/A
I-06	Ripple control discharging command	Based on the telegram, ripple control receiver sends a command to DER control system to inject active power from battery.	Information exchanged between IS or sent to device	N/A

Annex A – List of Actor Subcategories

Category	Type	Subcategory	Definition	Example
Actors	Role	DSO	Responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area	Avacon, CEZ, E.ON, Enexis, Enedis
Actors	Role	Industrial partner	All industrial partners involved in InterFlex project at a DEMO level	- GE - Siemens - Schneider …
Actors	Role	University and research partner	All university or research partners involved in InterFlex project at a DEMO level	- RWTH - AIT etc
Actors	Role	Retailer	Licensed supplier of electricity to an end-user	- EDF - Engie...
Actors	Role	Legal Client	A legal client of a DSO that is involved at Demo scale	- Company producer - Municipalities - Tertiary service providers
Actors	Role	Physical client	A physical client of a DSO that is involved at Demo scale	- Residential client
Actors	System	Charging facilities	Facilities to charge electrical vehicles	- Charging facilities
Actors	System	DER installation	Power plant that use renewable technology and are owned by a legal person	- Photovoltaics panels - Biomass farm - Wind power, …
Actors	System	In house device	All devices working on electricity that can be find in a customer's dwelling.	- Heater - Meter - Local display - Customer's battery
Actors	System	Communication infrastructure	All the infrastructure that are used for communication at all level (from customer's place to power command)	- Modem - Routers
Actors	System	Network device	All devices placed on MV/LV network for monitoring or gathering information on grid's situation or electrical parameters values. It also include the IS associated	- Secondary Substation control infrastructure - RTU : Remote terminal units - Circuits breakers - sensors
Actors	System	IS IT	All the hardware and software associated, used at power command to control and monitor the network	- SCADA - Central database - Control operation center
Actors	System	Interactive communication device	All device used to interact with customers in order to involved him in the Demo	- Web portal - Display used for communication

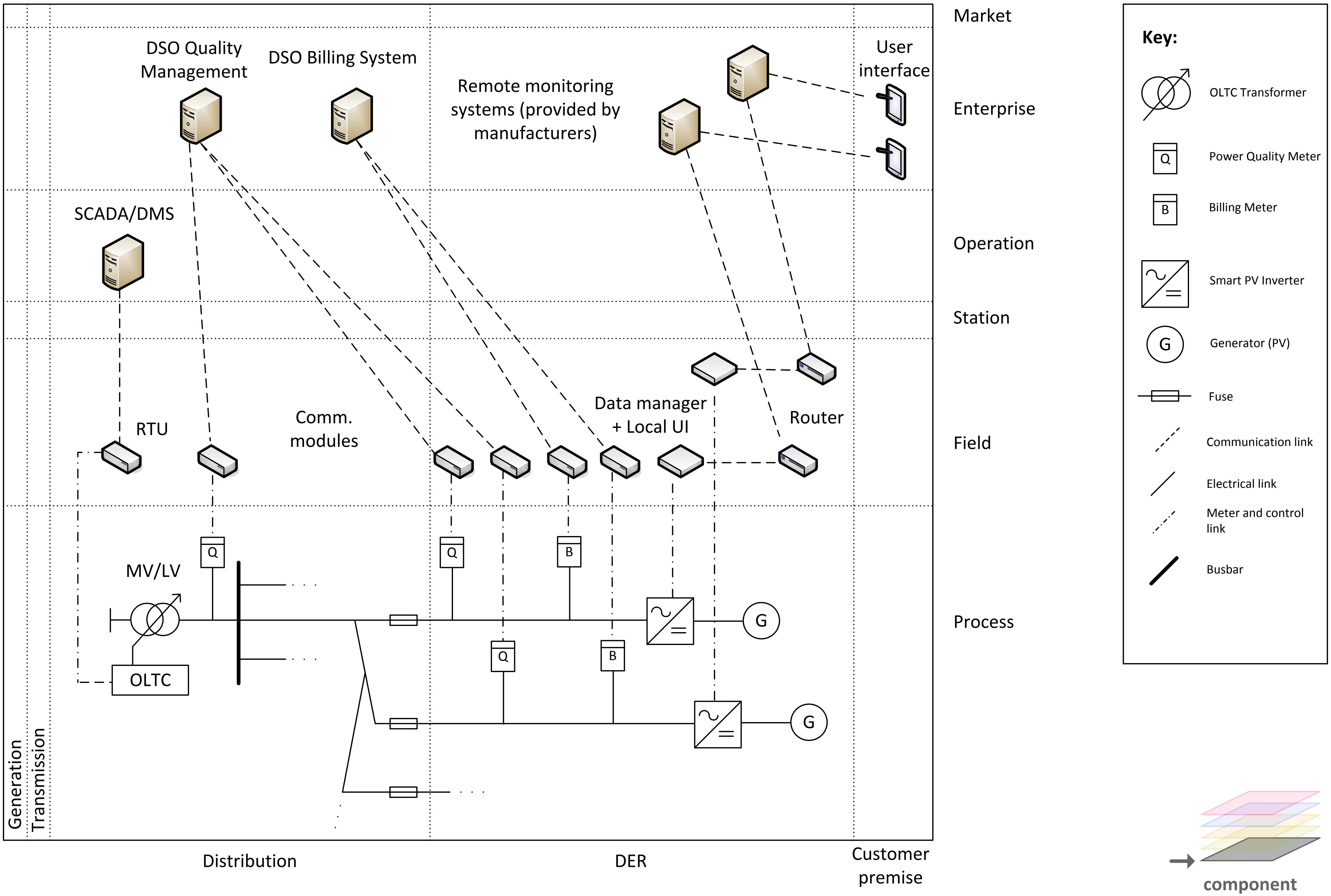
Annex B – List of Information Subcategories

Category	Type	Subcategory	Definition	Example
Data	Document	Internal document	All the documentation made by Demo to run operation, to monitor and conduct the project's good development	- Meeting minutes - Report on the cost's impact of selected flexibility plans
Data	Document	InterFlex deliverable	All the deliverables that Demo have to produce during the project's time as agreed in the DOW	- Risk analysis - Documentation on KPI - Detailed Use Case - Report on technical experimentation, market research, …
Data	Document	Communication material	All the documentation that describe the project to the public and can be put on the future website	- Purpose of the DEMO (leaflet) - Brief description of Use Case - Location of Use Case
Data	Financial data	Project financial data	All the financial data that are produced during the project and that are used to make financial report for European Commission and internal report	- Invoices - Cost and time imputation
Data	Financial data	Solution cost and selling price	All the financial data that can be made concerning estimation prices of solution for replication	- Unit product cost of hardware developed by Demo - Sell price of the solution develop (software,…)
Data	Parameter	Condition parameter	All the external parameters that may influence the success of the Use Case	- Weather - Time of day - Day of week …
Data	Parameter	Scenario assumption	All the stated parameters that are necessary to determinate a scenario for the Use Case	- Location of islanding - Experiment's location
Data	Parameter	Electrical parameter	All the electrical parameters that are used to supervise the network and its good state	- Intensity - Voltage - Frequency - Quality
Data	Parameter	Algorithm, formula, rule, specific model	All the intellectual data that are created during the project to made software's contents	- Algorithm to optimize flexibility plan - Simulation to determine location of circuit breaker - Voltage regulation algorithm
Data	Parameter	Optimized value	Values of parameters that optimized the Use Case or the demo's performance	- Optimization time of islanding
Data	Parameter	Forecast data	All the data used to forecast consumption or production of customer	- Forecast customer's consumption - Forecast photovoltaic panels' production
Data	Facility data	Network topology	All information on network devices and their location and interaction, mainly coming from GIS (Geographic Information System)	- Map of the network - Substations location - All the other data found in the GIS (Geographical Information System)
Data	Facility data	Network state	All information concerning the network's status (global or local) at a precise moment useful to monitor the network	- Feeding situation in a distribution area - State of network regarding Limit value violation - Location of constraint - Flexibility needs of DSO

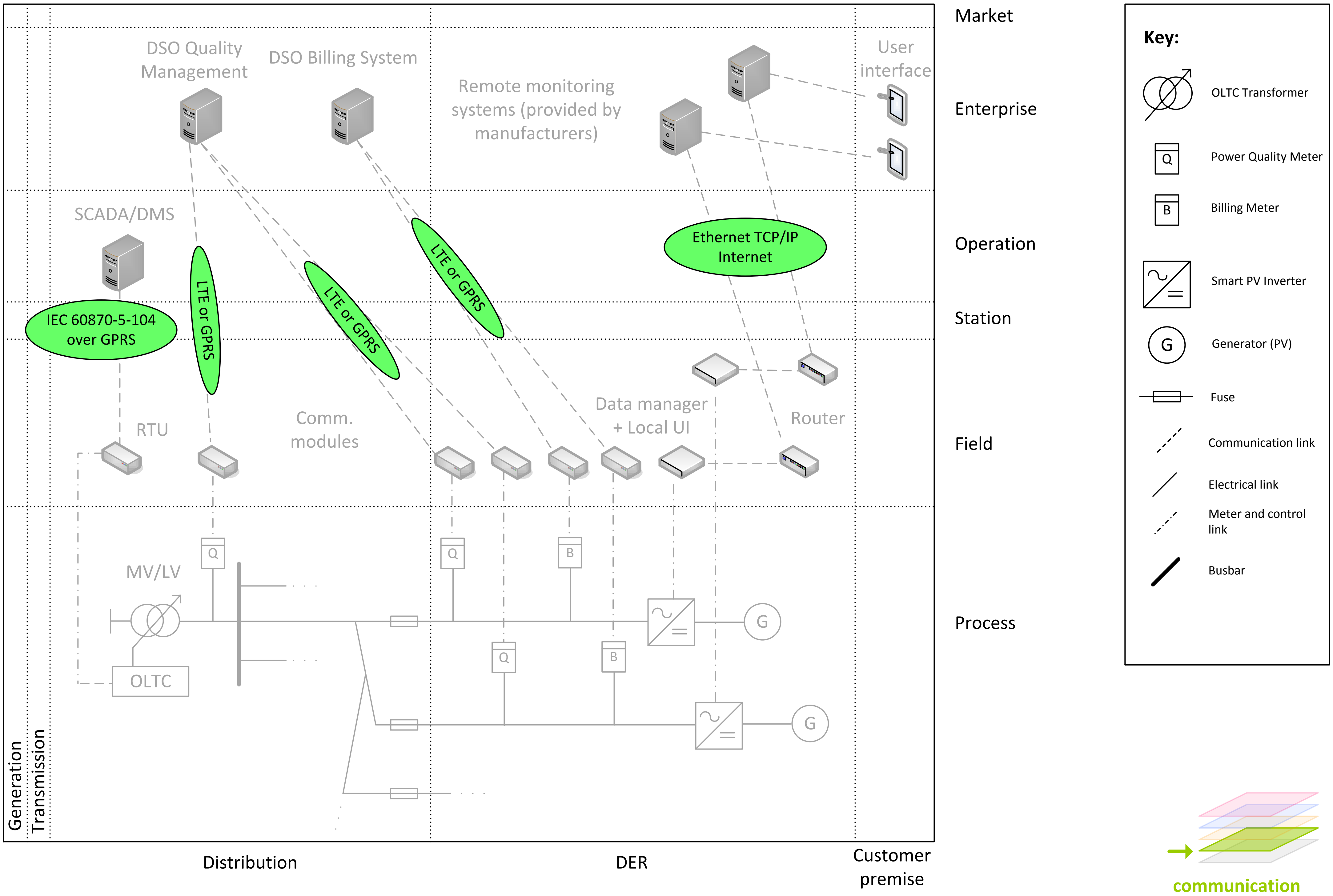
Category	Type	Subcategory	Definition	Example
Data	Facility data	Customer's meter state and output	All the information concerning customer's meter state and outputs information	- Customer's consumption or production
Data	Facility data	Other device state and output	All the information concerning device's state and outputs information	- State of charge of batteries - Consumption data coming from meter - Production data coming from meter - State of charge of storage components
Data	Parameter	Information exchanged between IS or sent to device	All automated information sent between facilities in order to send information or order for monitoring	- Order sent to breaker devices (open, close,…) - Information on local network status coming from sensors - Order and roadmap sent to network devices (batteries, aggregator,…)
Data	Parameter	Detailed specification on devices	All detailed information (reference components, specification, process,…) useful to build the devices	- Detailed specification of the telecommunication infrastructure - Detailed specification of interactive sensor network
Data	Network data	Network topology	All information on network devices and their location and interaction, mainly coming from GIS (Geographic Information System)	- Map of the network - Substations location - All the other data found in the GIS (Geographical Information System)
Data	Network data	Network state	All information concerning the network's status (global or local) at a precise moment useful to monitor the network	- Feeding situation in a distribution area - State of network regarding Limit value violation - Location of constraint - Flexibility needs of DSO
Data	KPI	Data for KPI (input raw data)	All raw data that are used to calculate the final KPI	- Duration of experiment - Customer response to DSO's demand - Electrical parameter used for KPI
Data	KPI	KPI (KPI values)	All the KPI values and the way to calculate them	- Economic KPI - System Efficiency KPI
Data	Customer data	Customer contract's data	All the data in customer's contact that are used for contact or make payment	- Address - Phone number - Bank account details
Data	Customer data	Information sent to /received from customer	All the information and data that are exchanged between the DEMO and the customer in order to involve customer in the experiment	- Customer's response to DSO's request to reduce consumption - Information and data available to customer in order to visualize its consumption - Advices and encouragement sent to encourage a smart consumption
Data	Customer data	Customer analysis (profile analysis, studies on client reactivity,…)	All the data that are produced in order to better understand the customer's behaviour regarding the possibility to adopt smarter habits in their electricity consumption	- Customer's typology and behaviour patterns - Analysis on customer's response to DSO's request

Annex 6.2

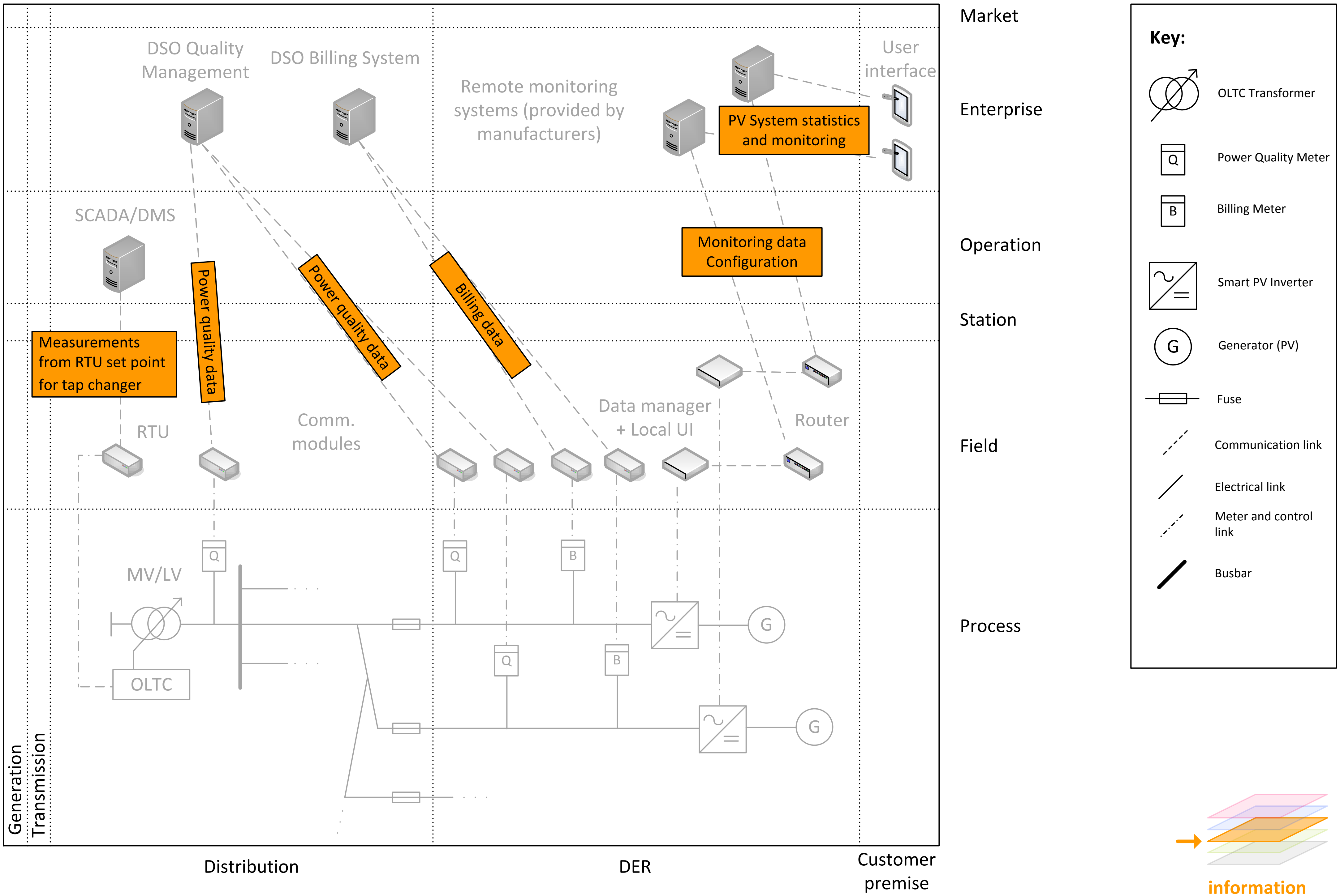
WP6 Use-case #1a



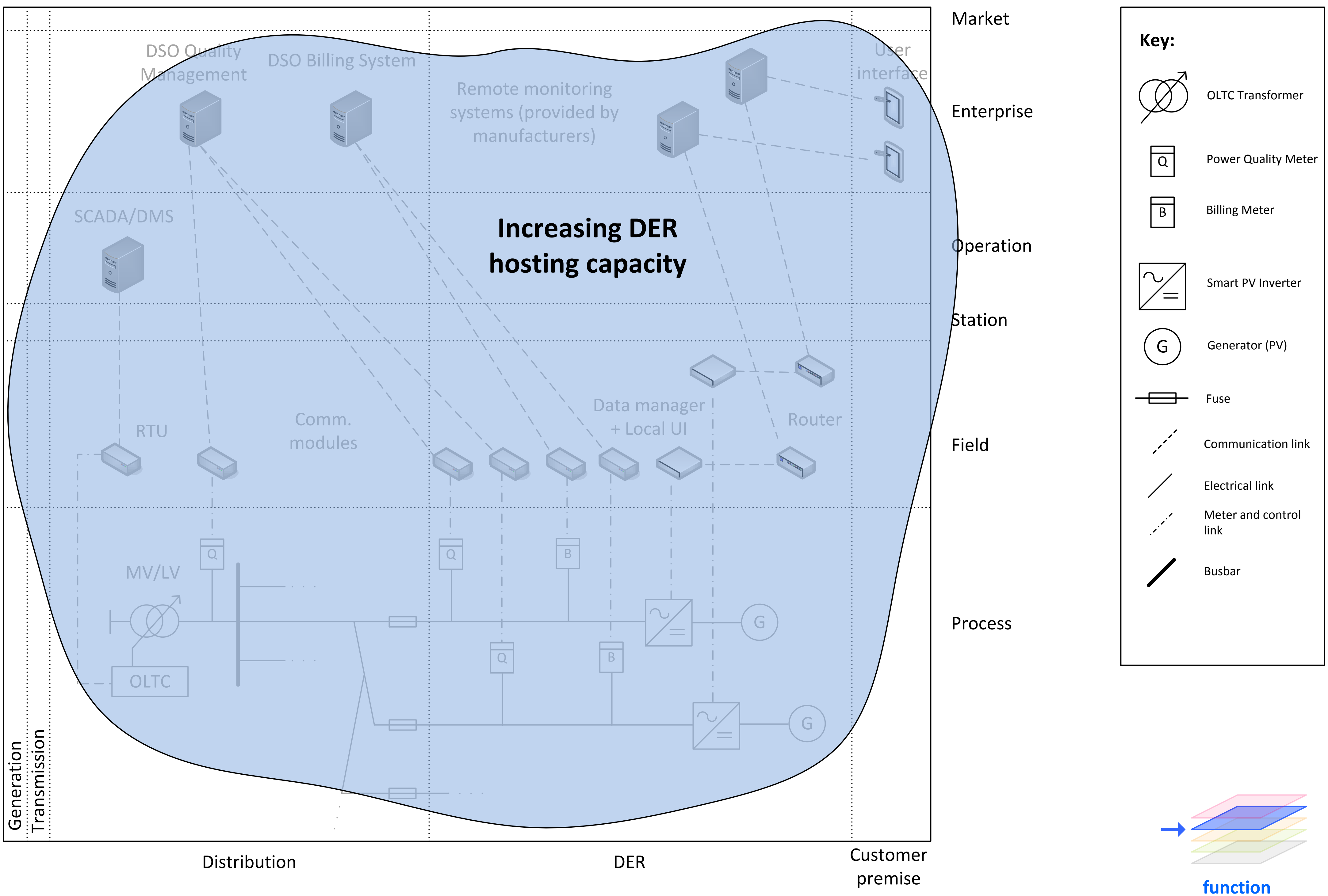
WP6 Use-case #1a



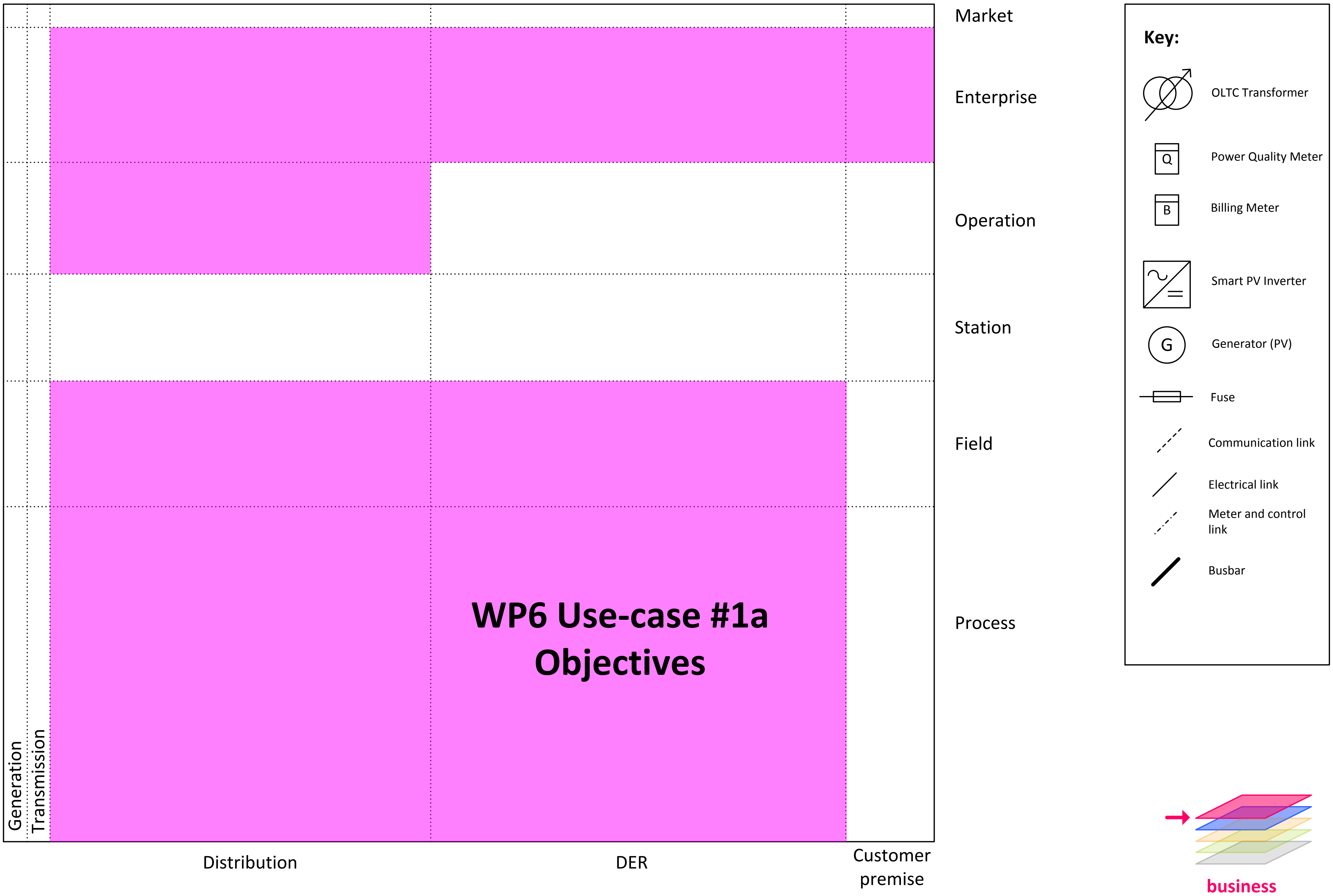
WP6 Use-case #1a



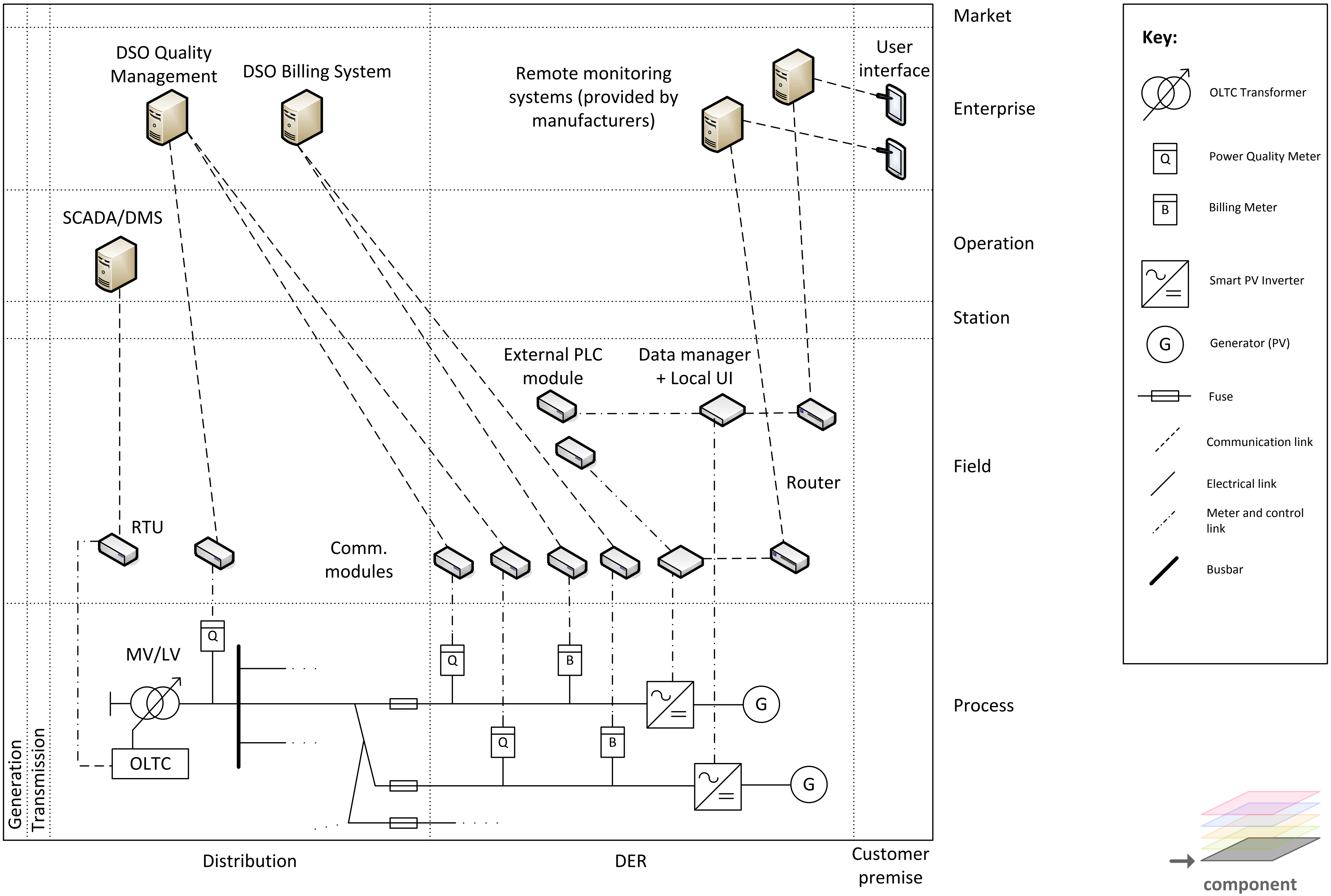
WP6 Use-case #1a



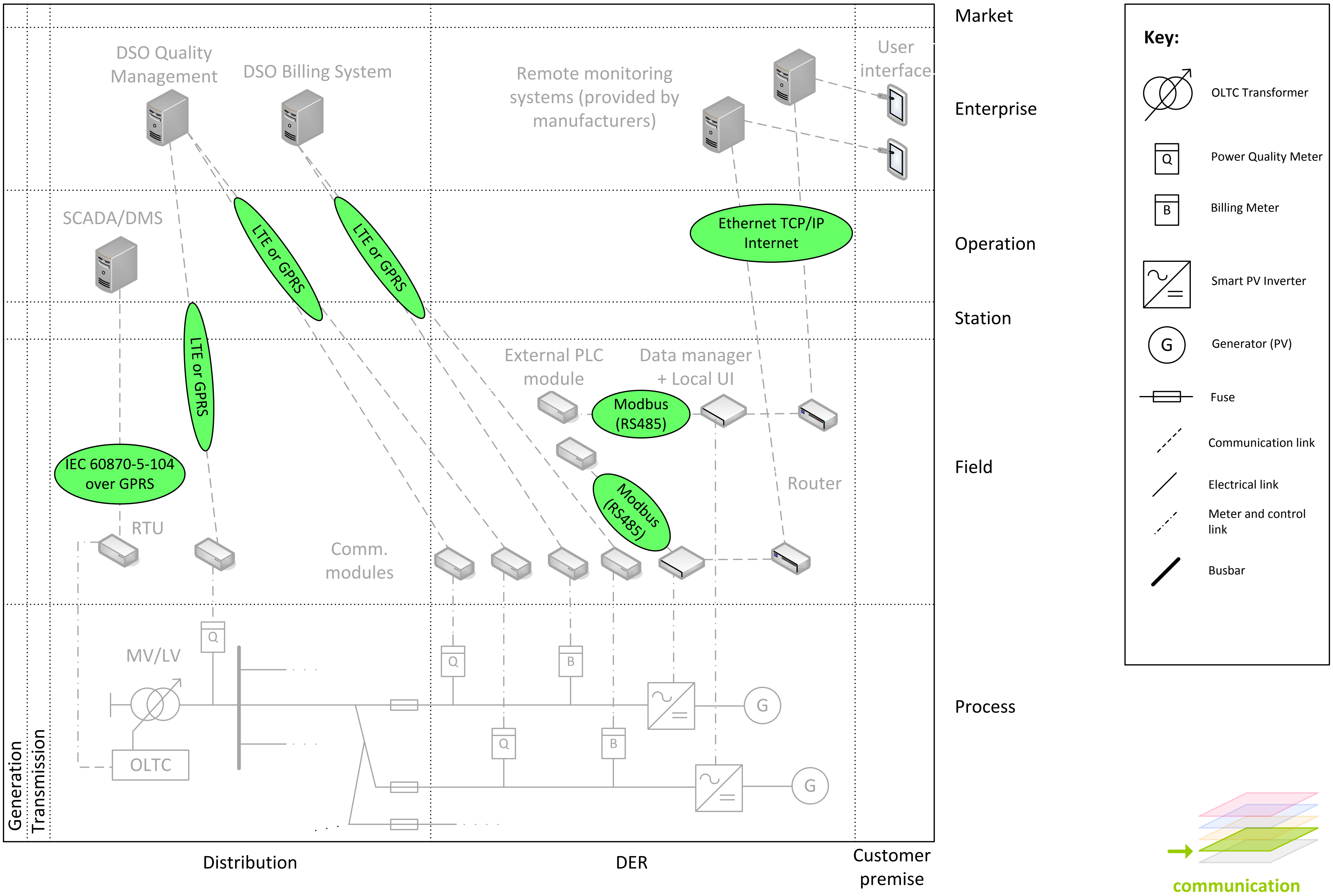
WP6 Use-case #1a



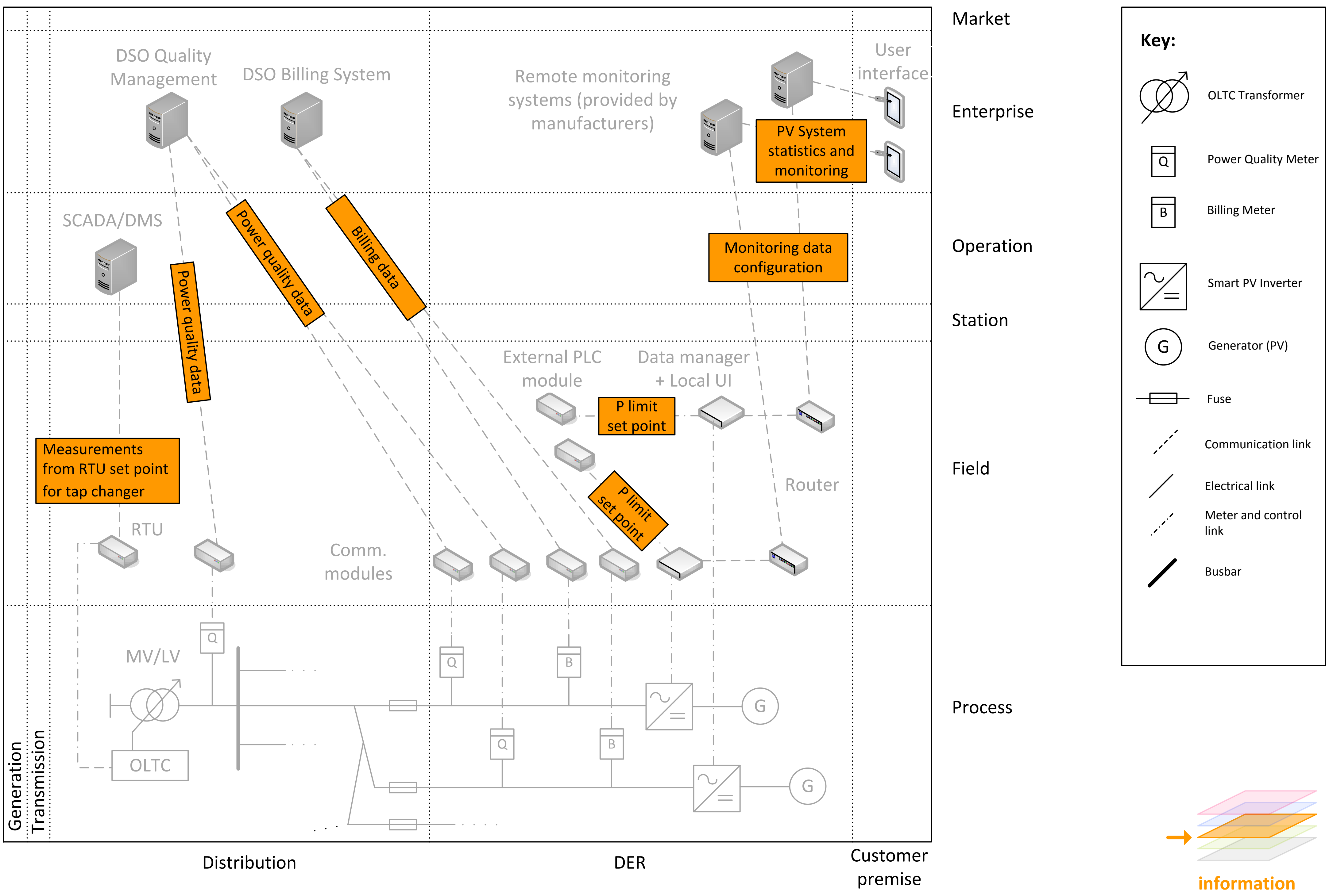
WP6 Use-case #1b



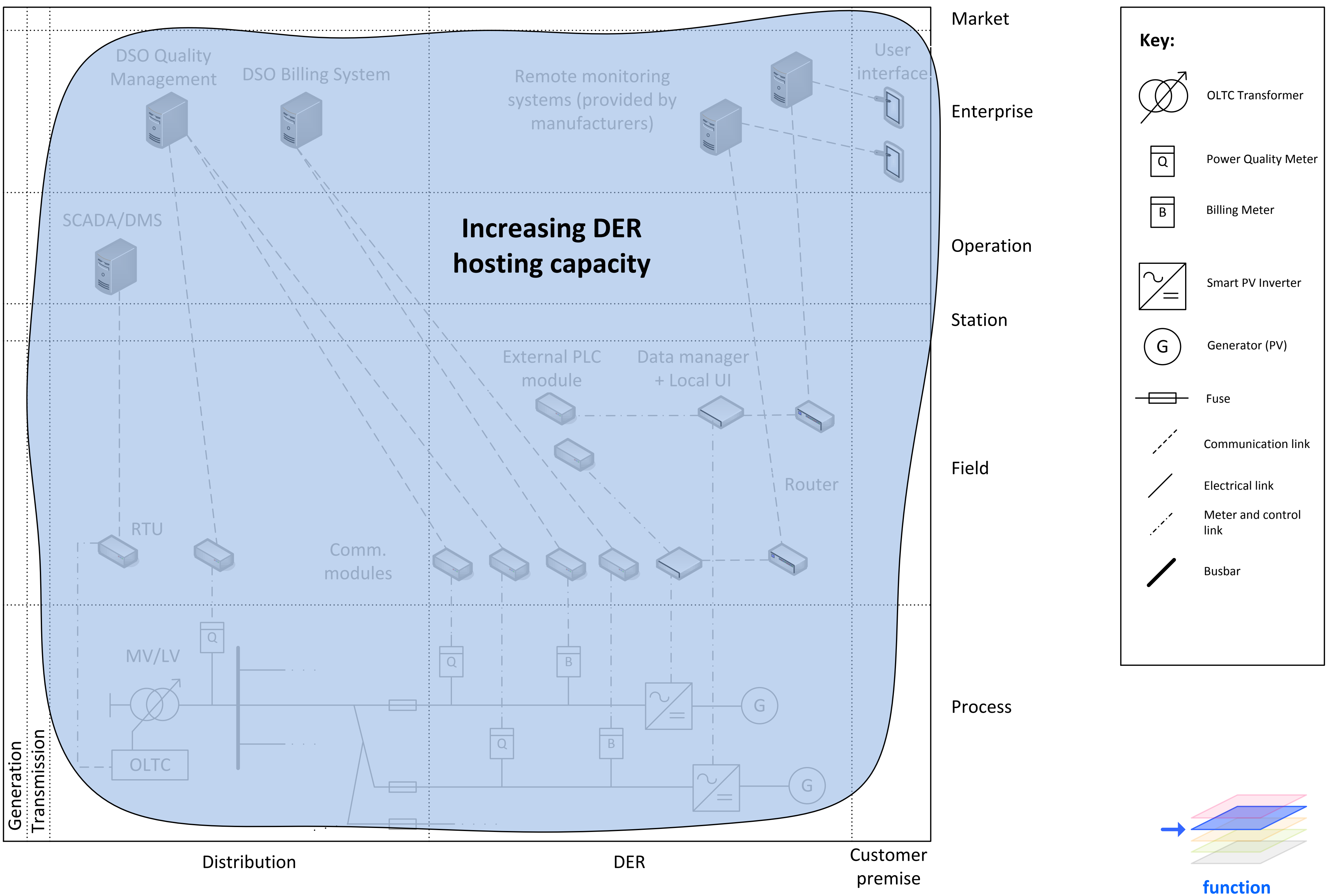
WP6 Use-case #1b



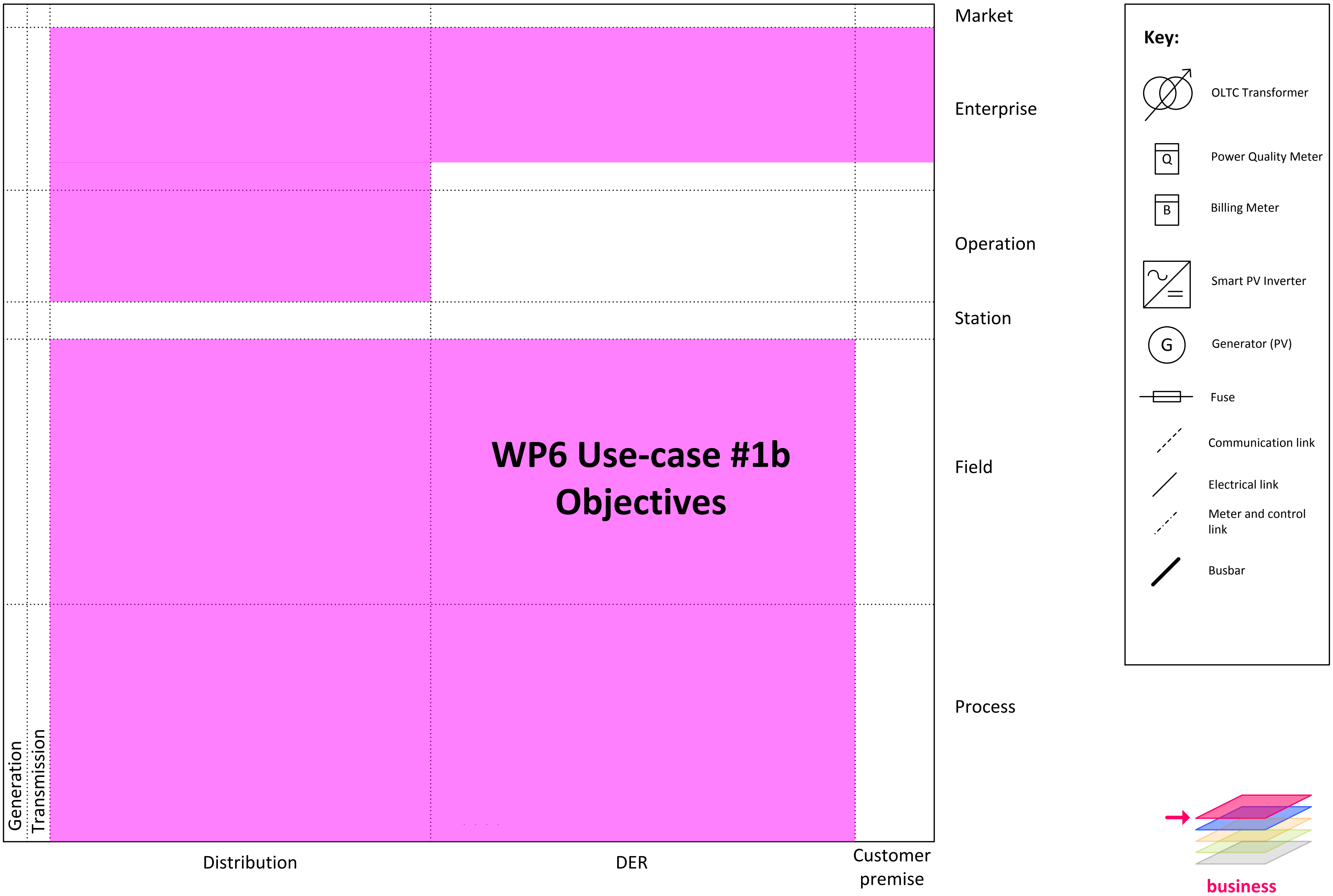
WP6 Use-case #1b



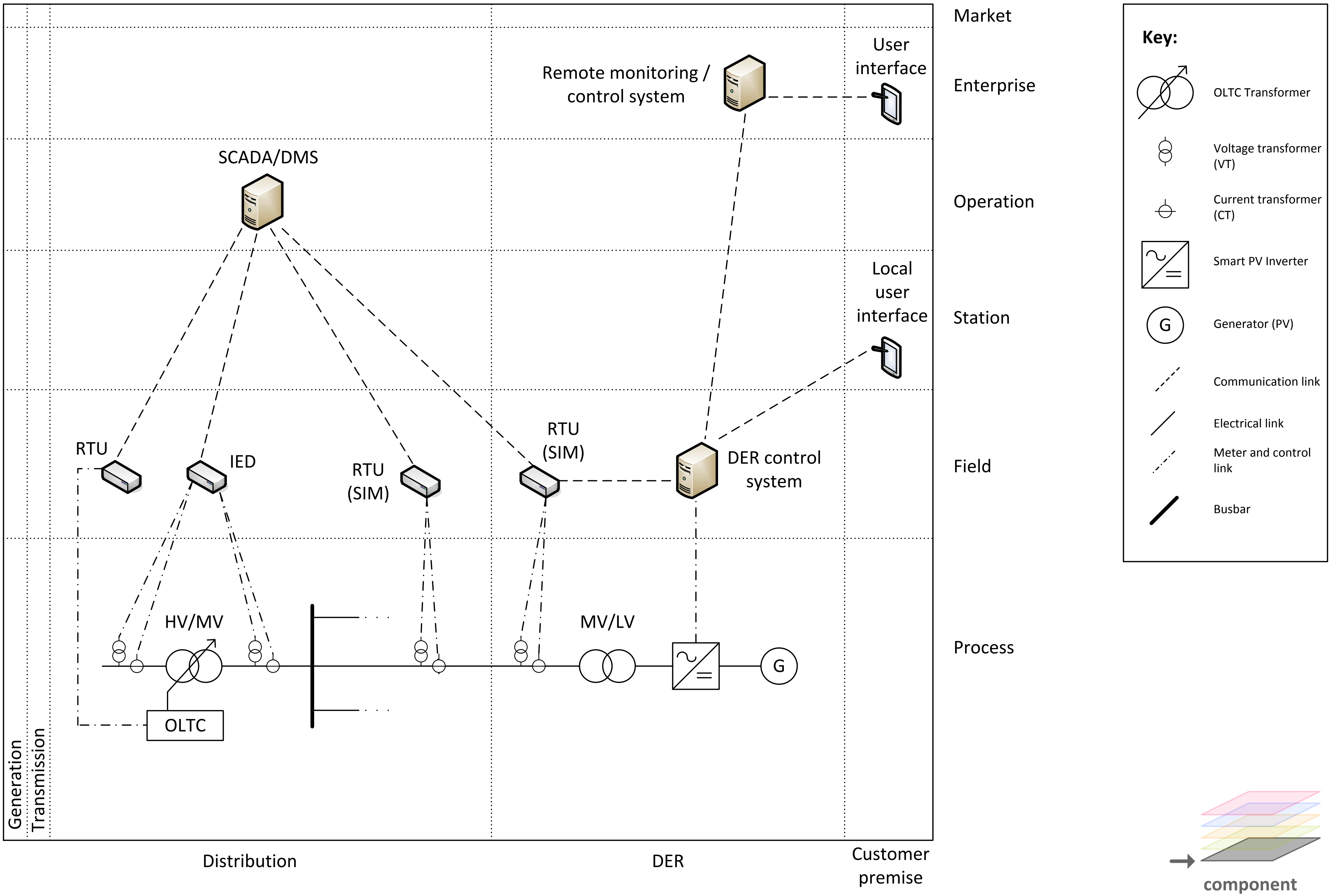
WP6 Use-case #1b



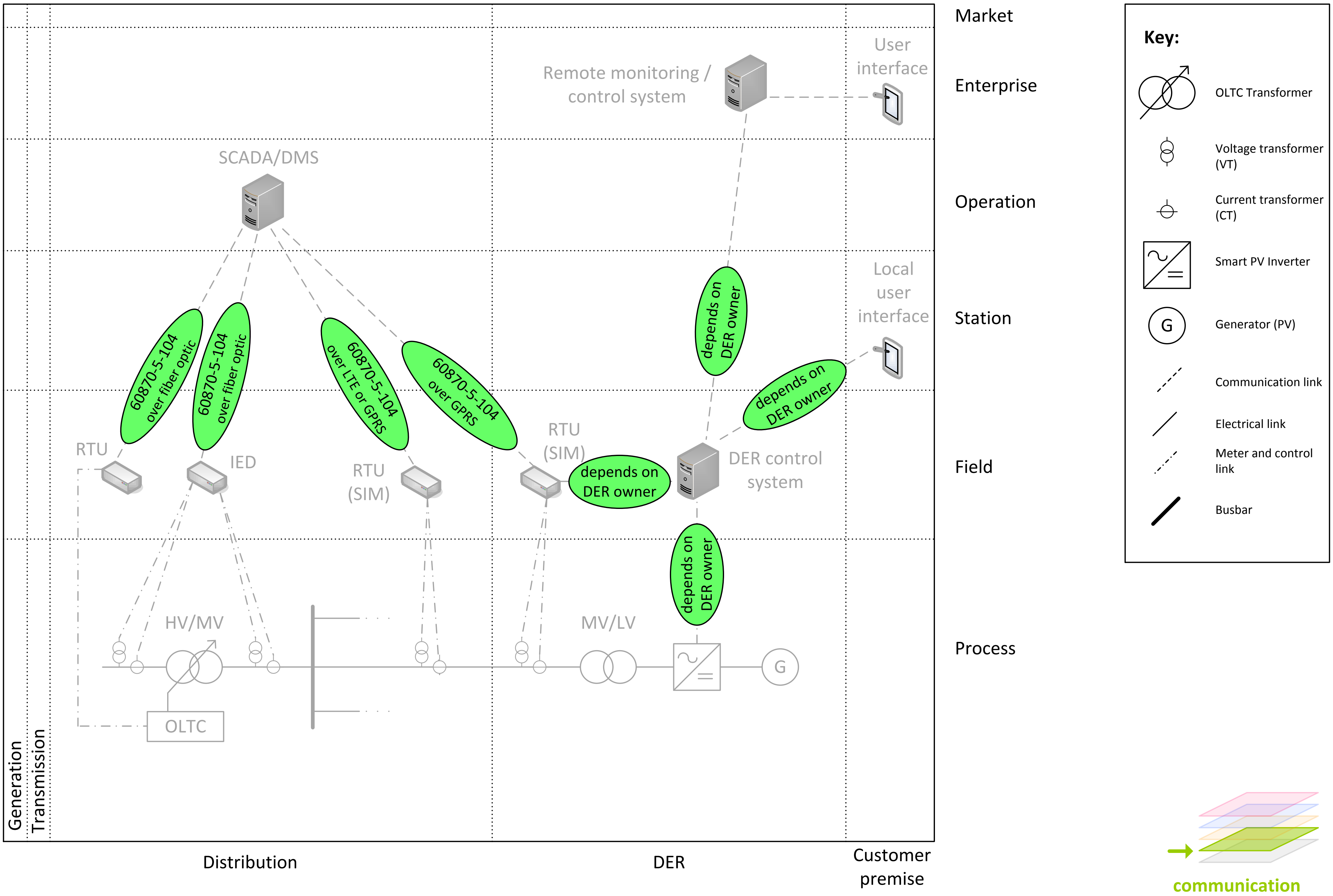
WP6 Use-case #1b



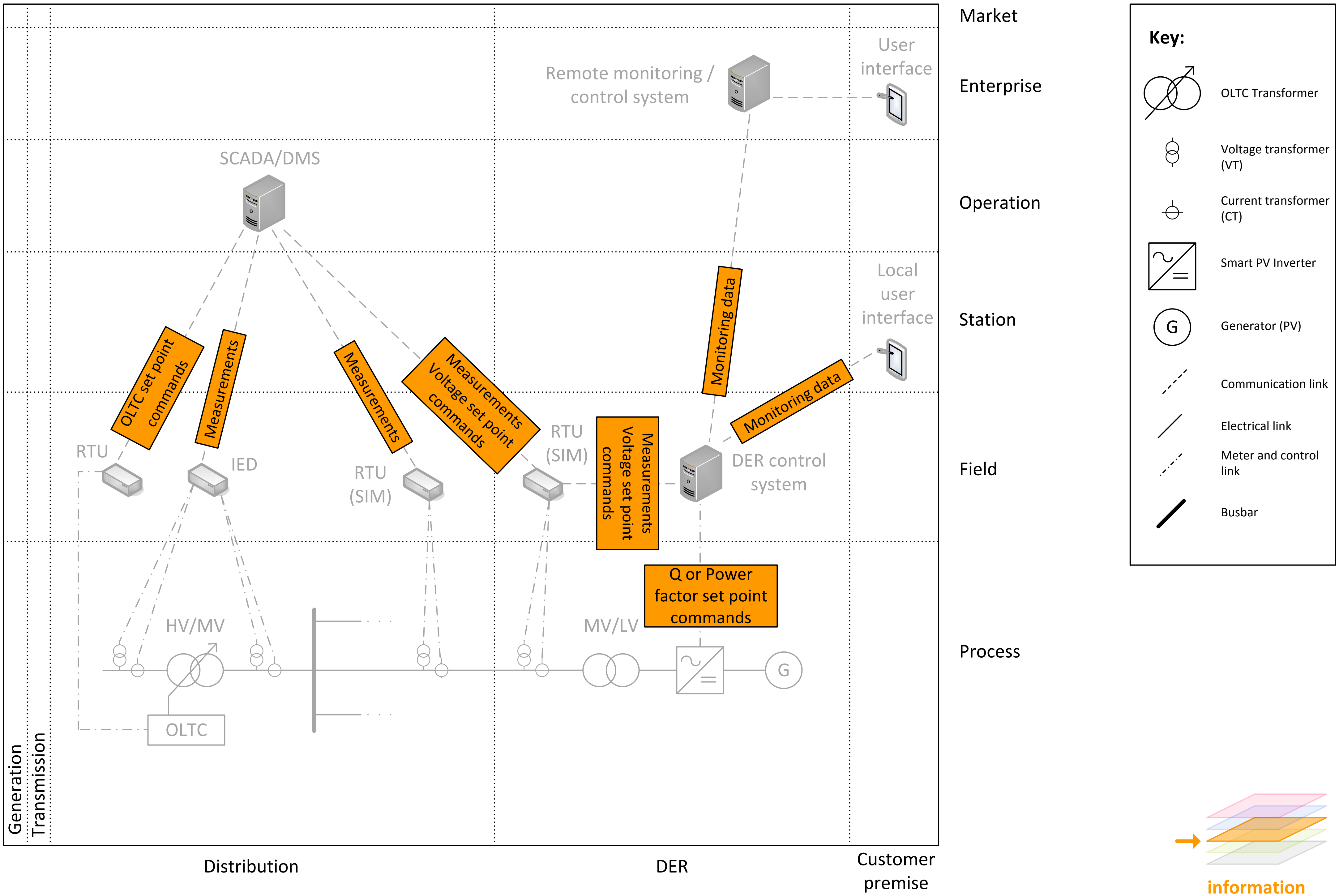
WP6 Use-case #2



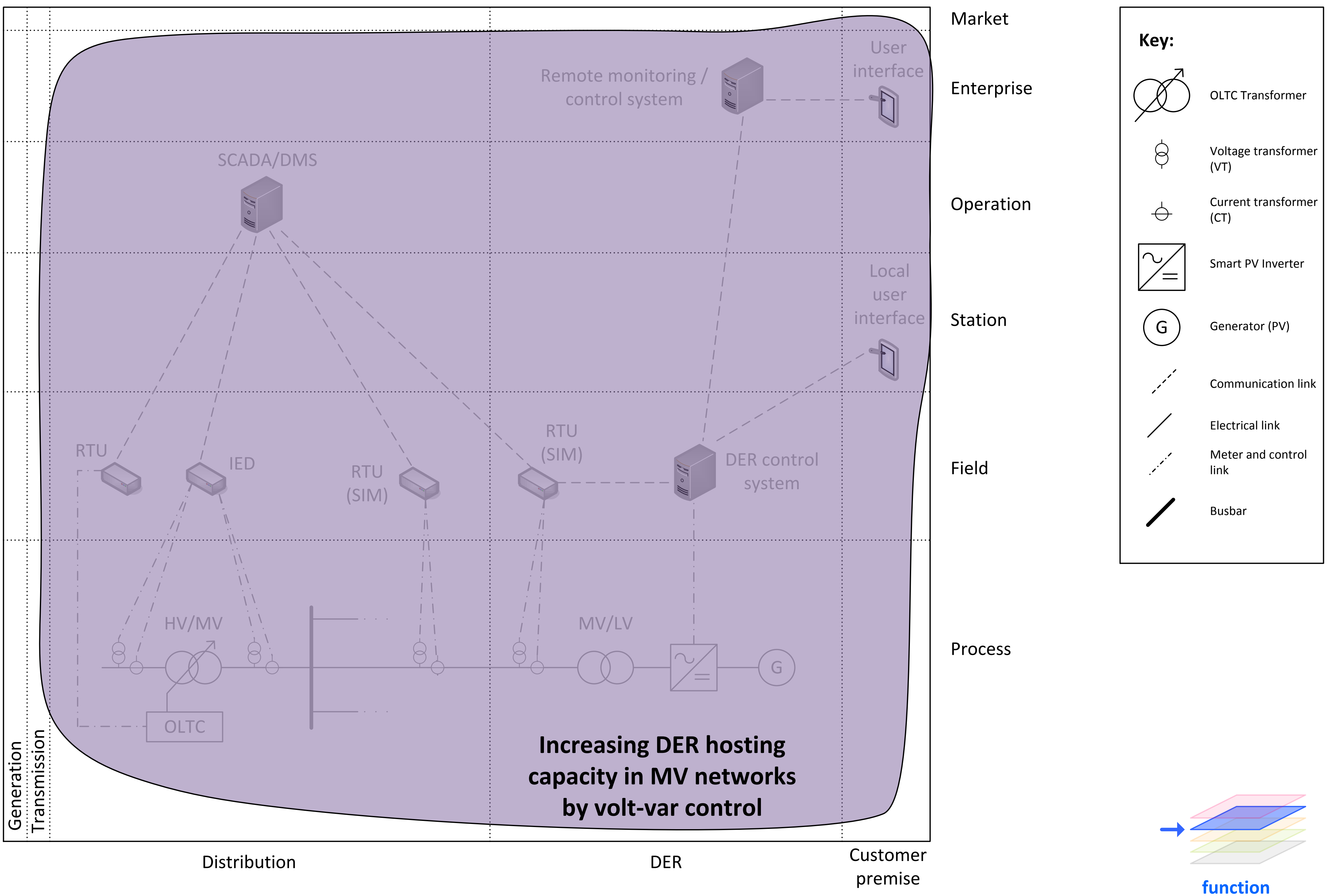
WP6 Use-case #2



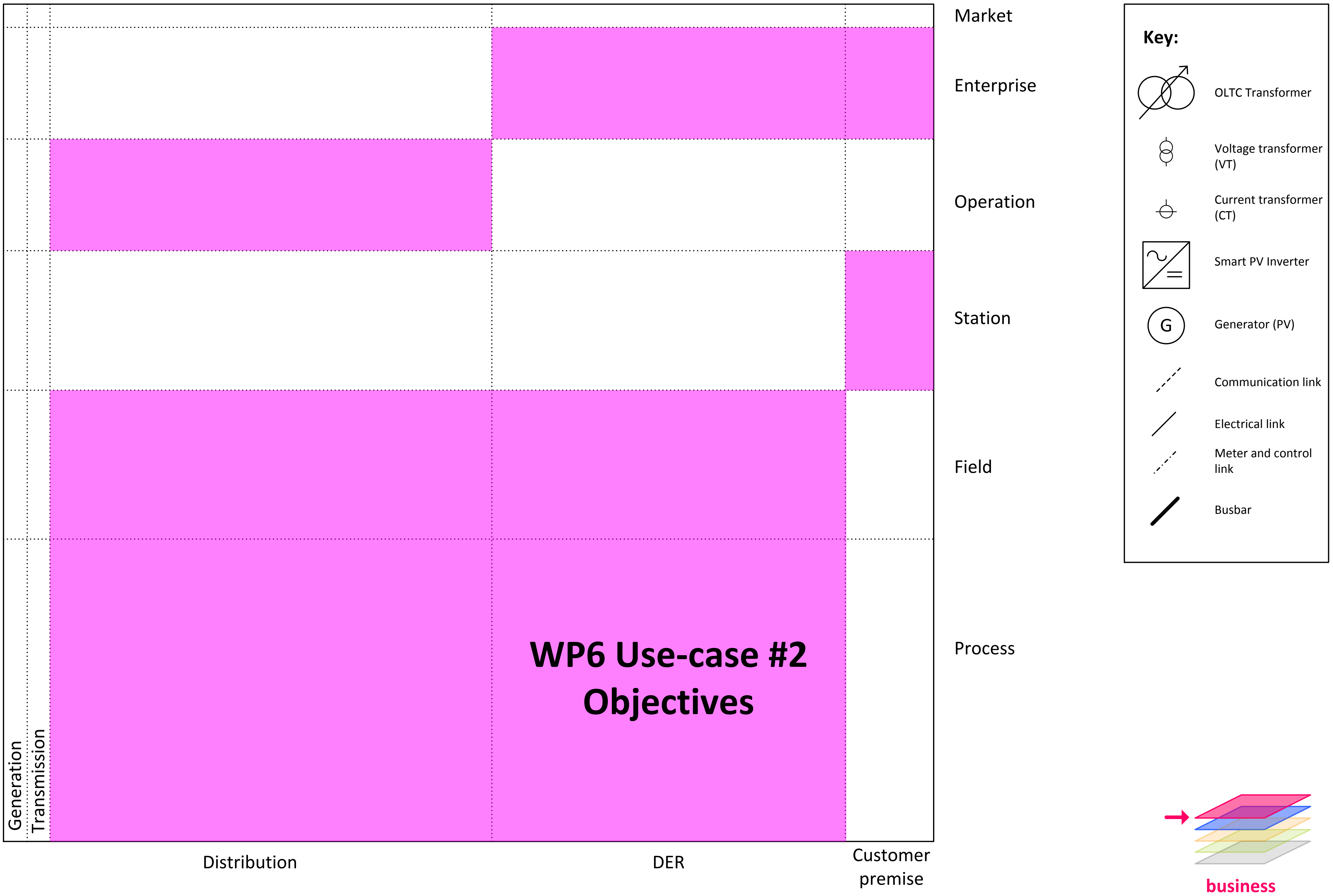
WP6 Use-case #2



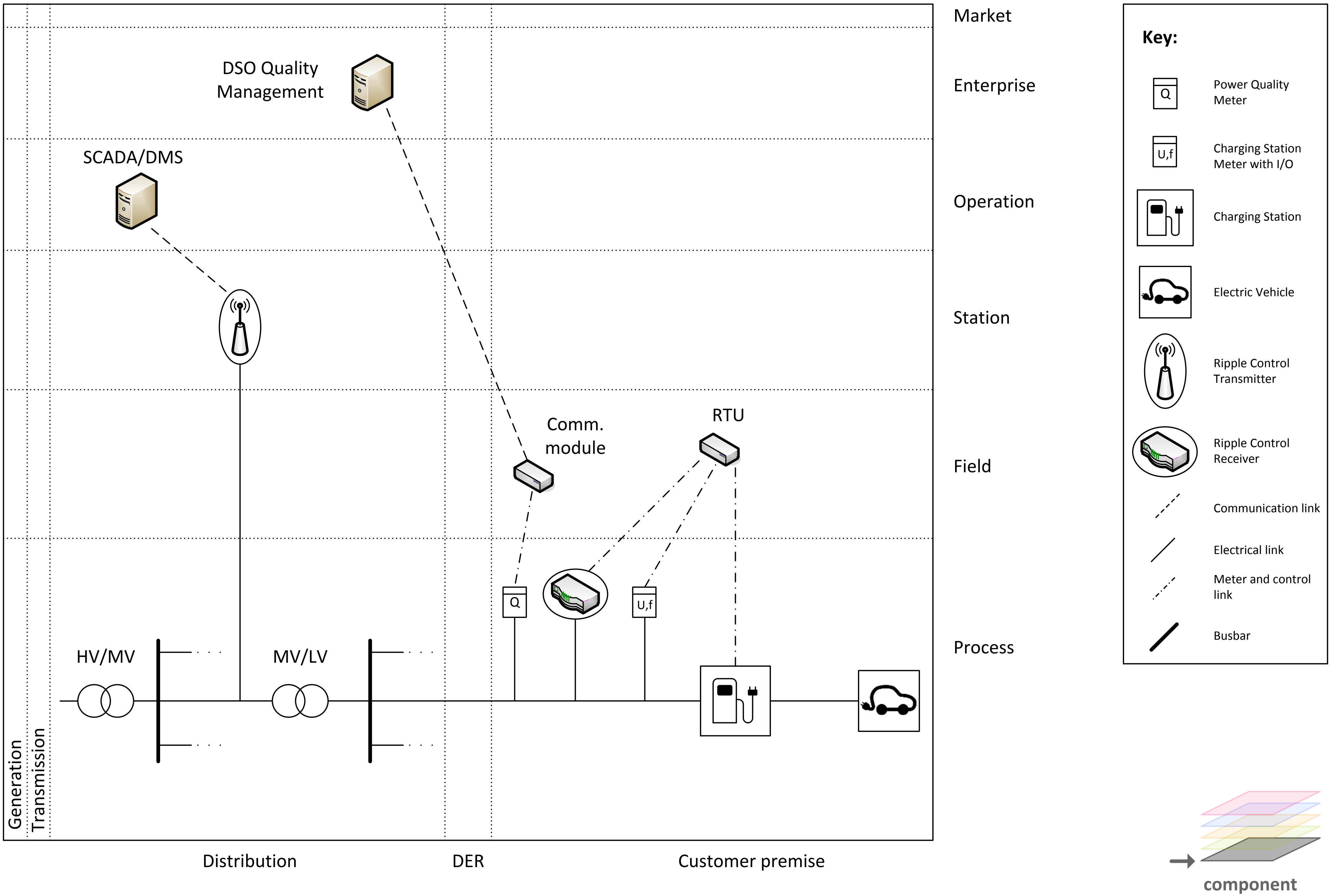
WP6 Use-case #2



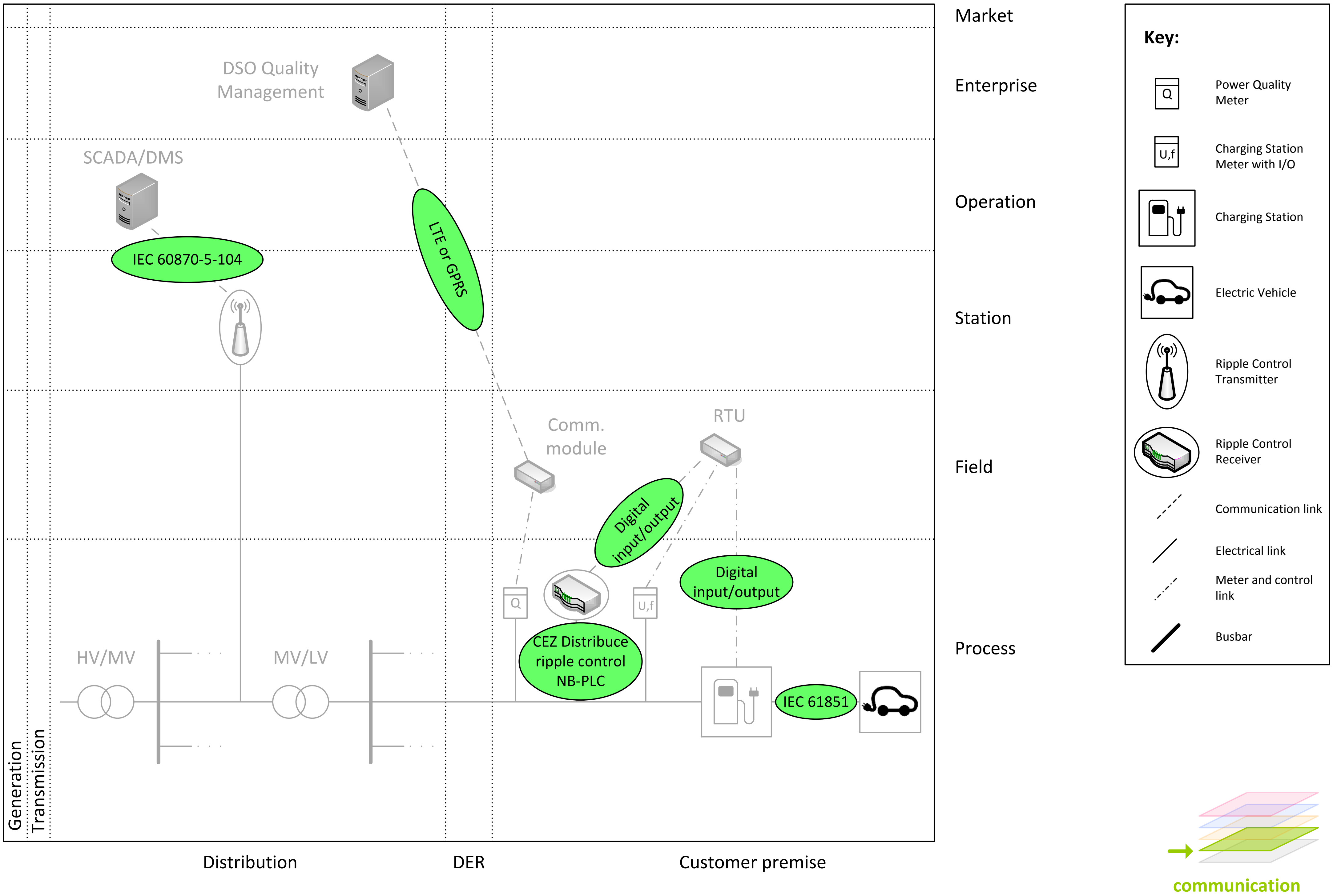
WP6 Use-case #2



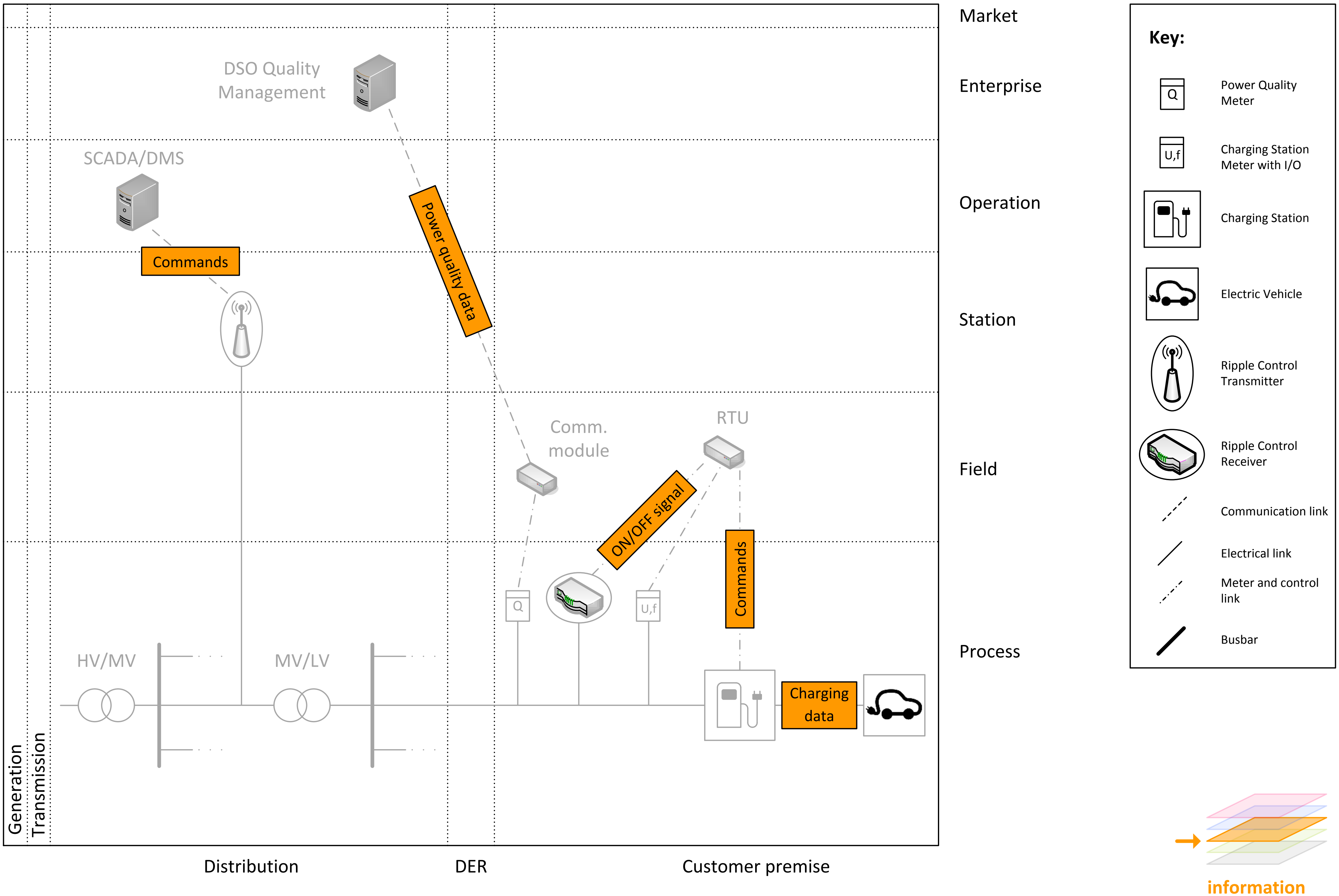
WP6 Use-case #3a



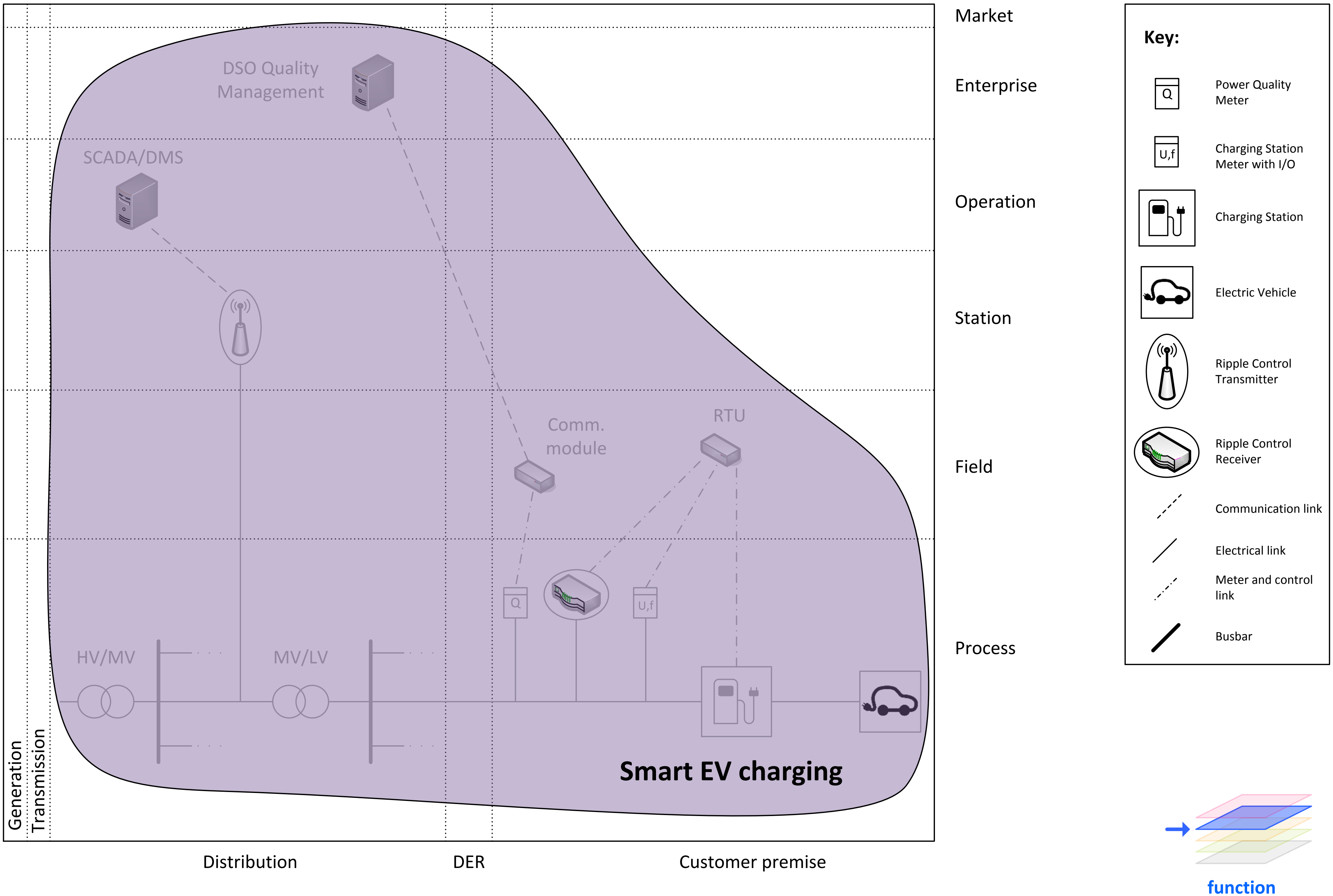
WP6 Use-case #3a



WP6 Use-case #3a

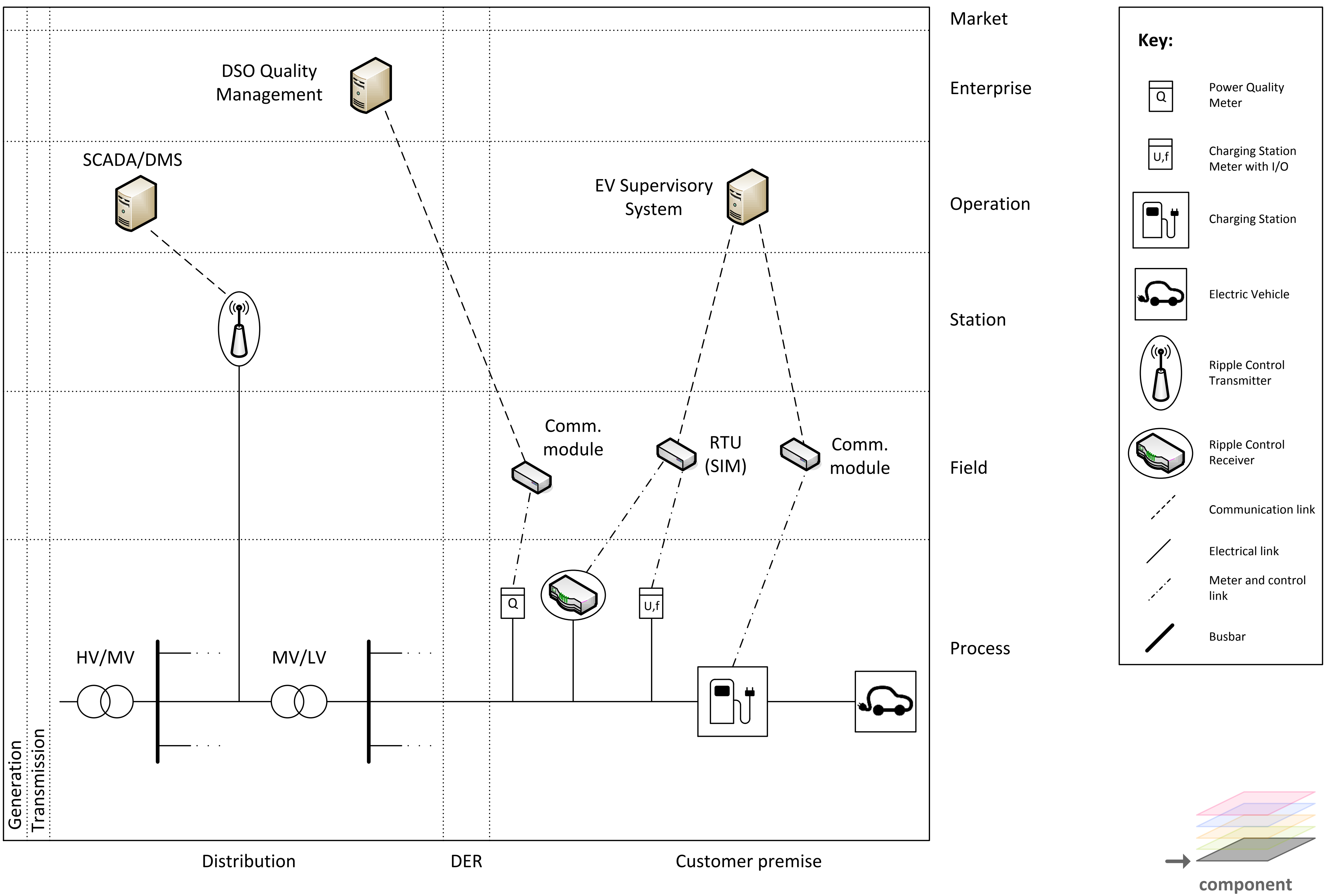


WP6 Use-case #3a

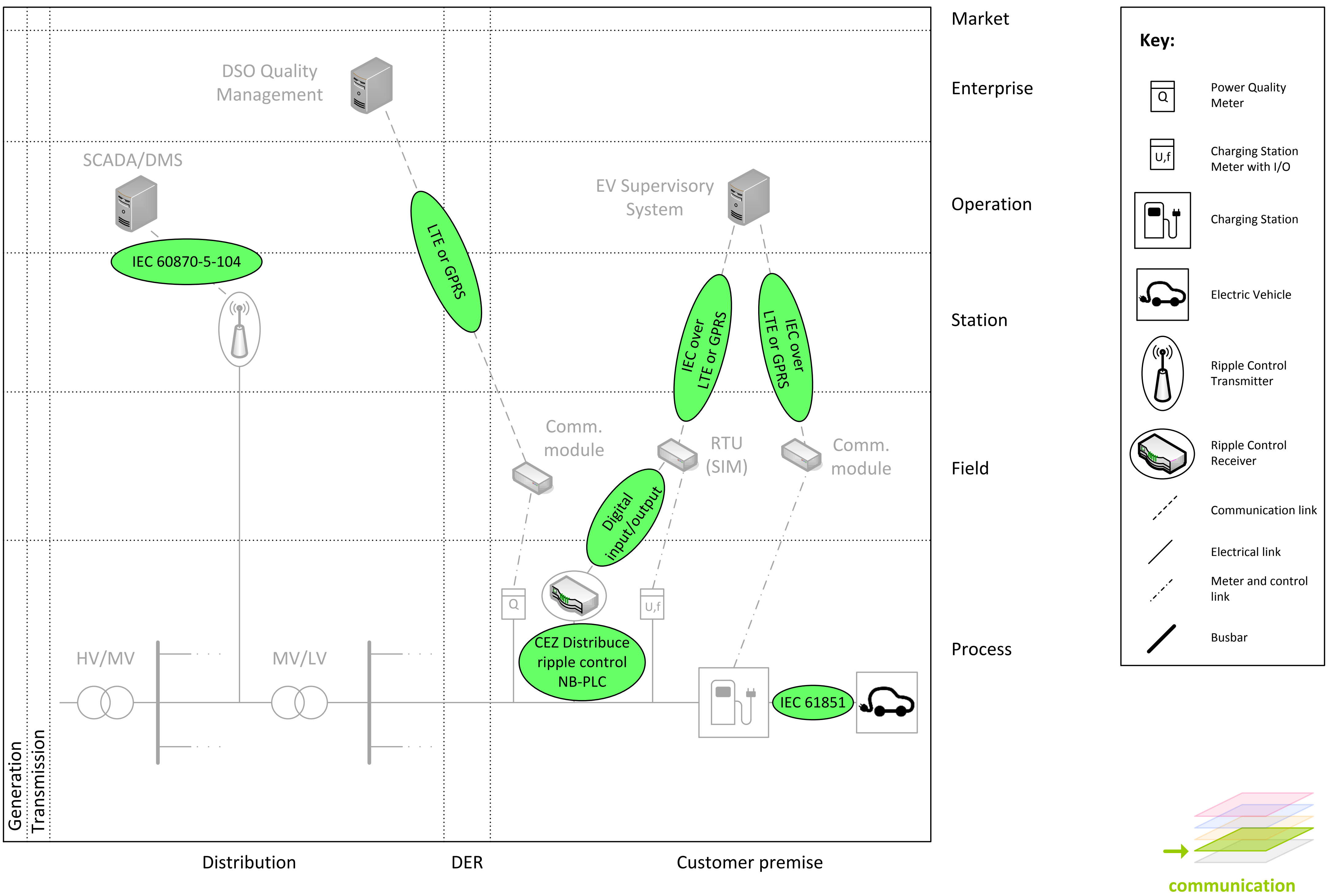


WP6 Use-case #3a

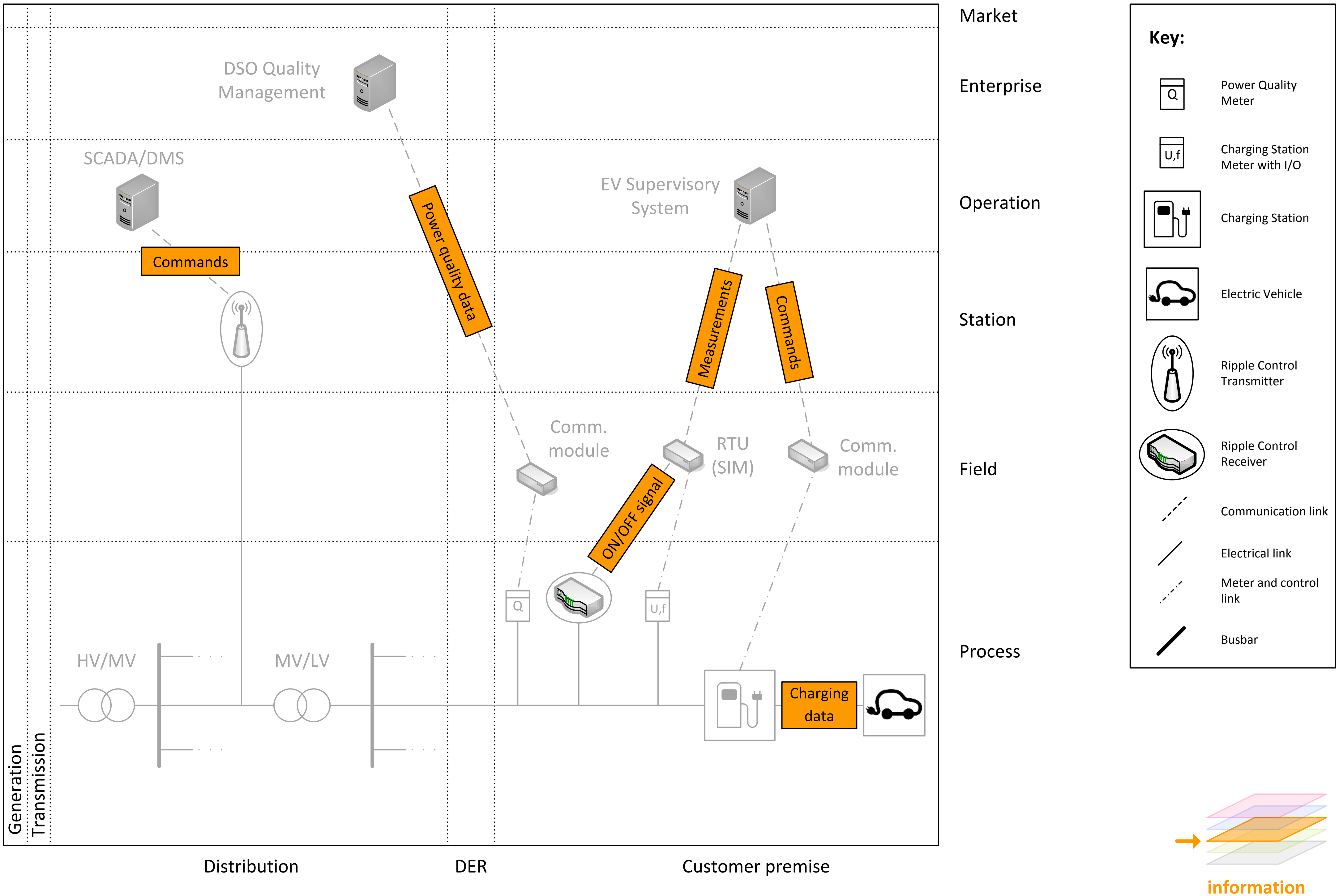
WP6 Use-case #3b



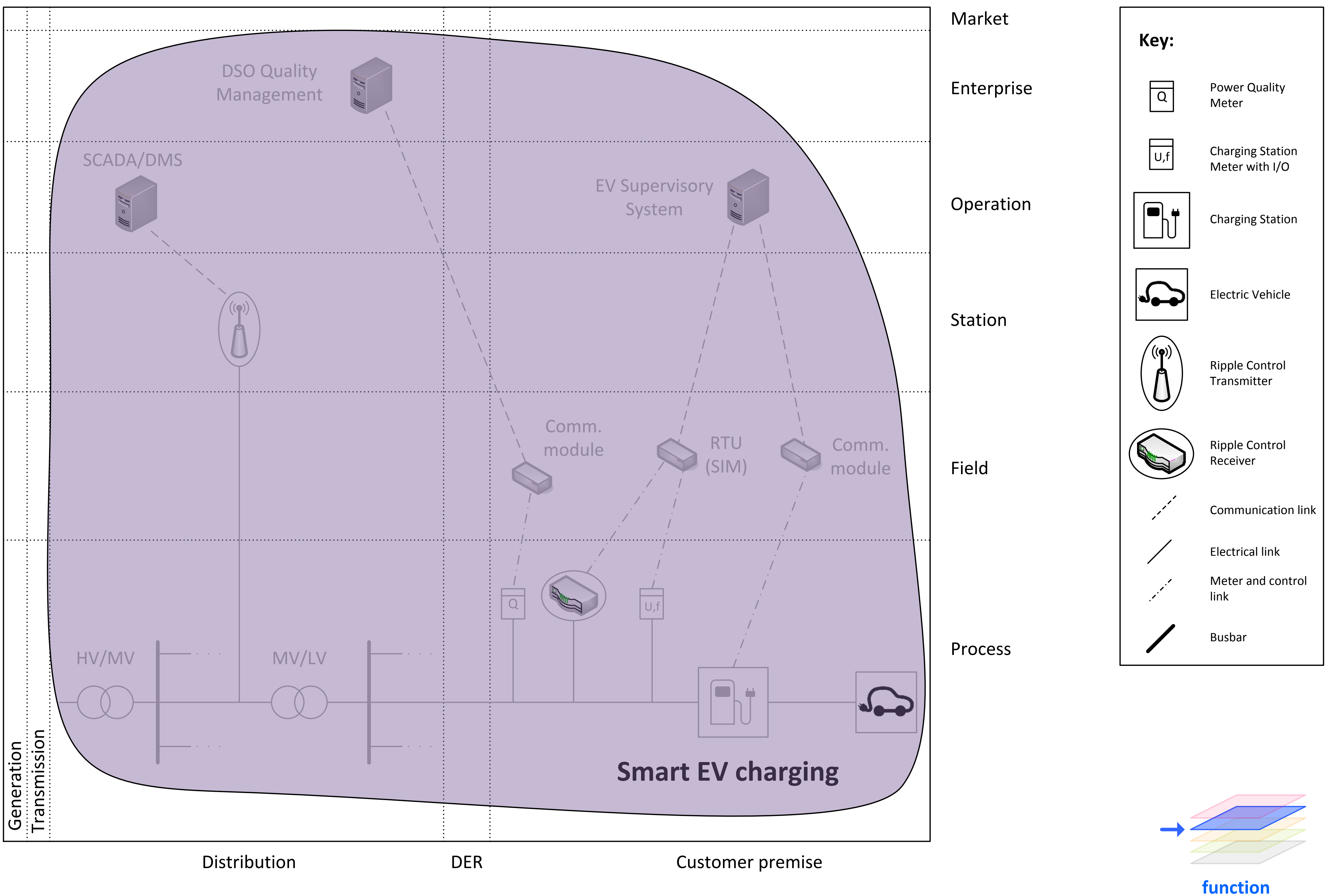
WP6 Use-case #3b



WP6 Use-case #3b

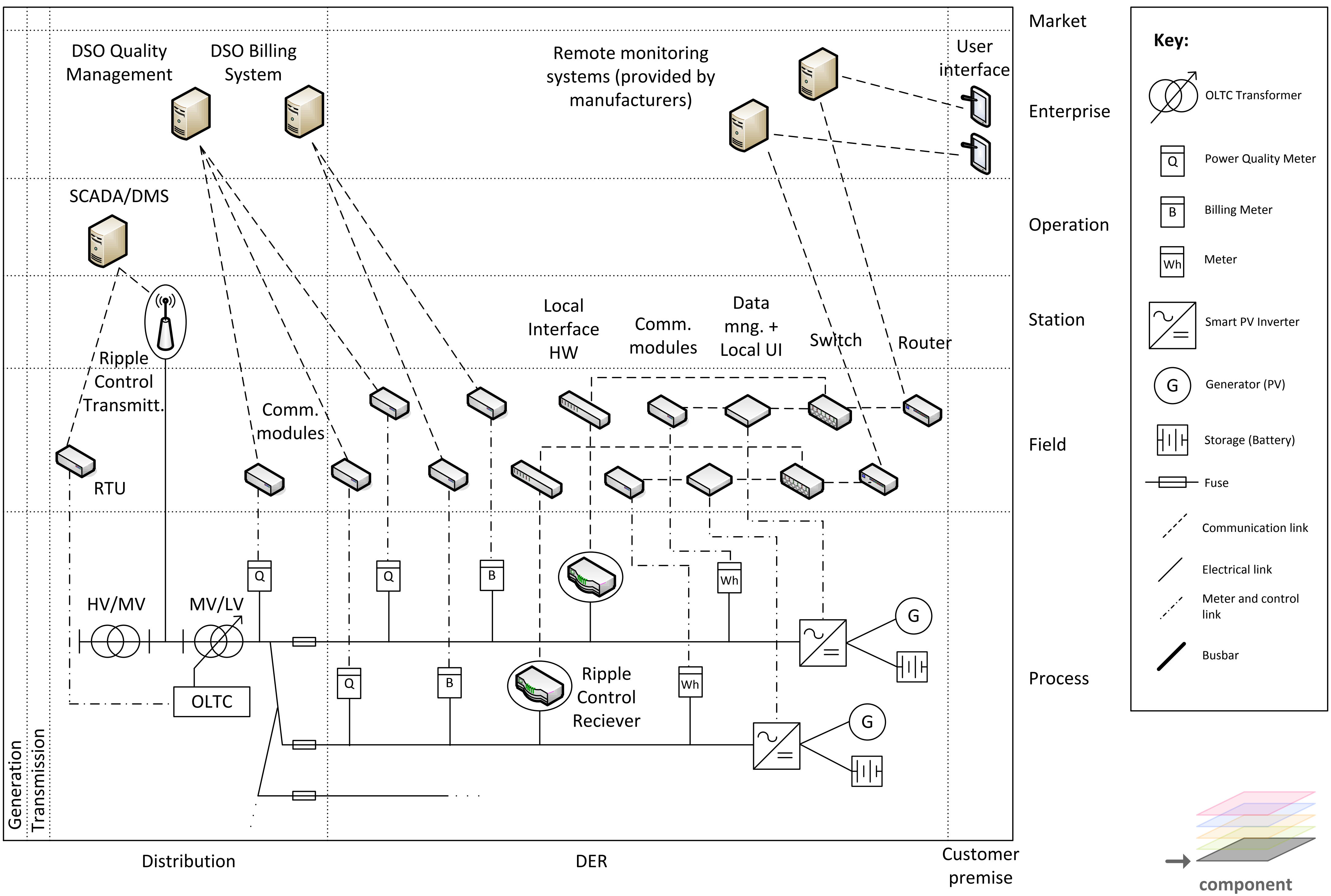


WP6 Use-case #3b

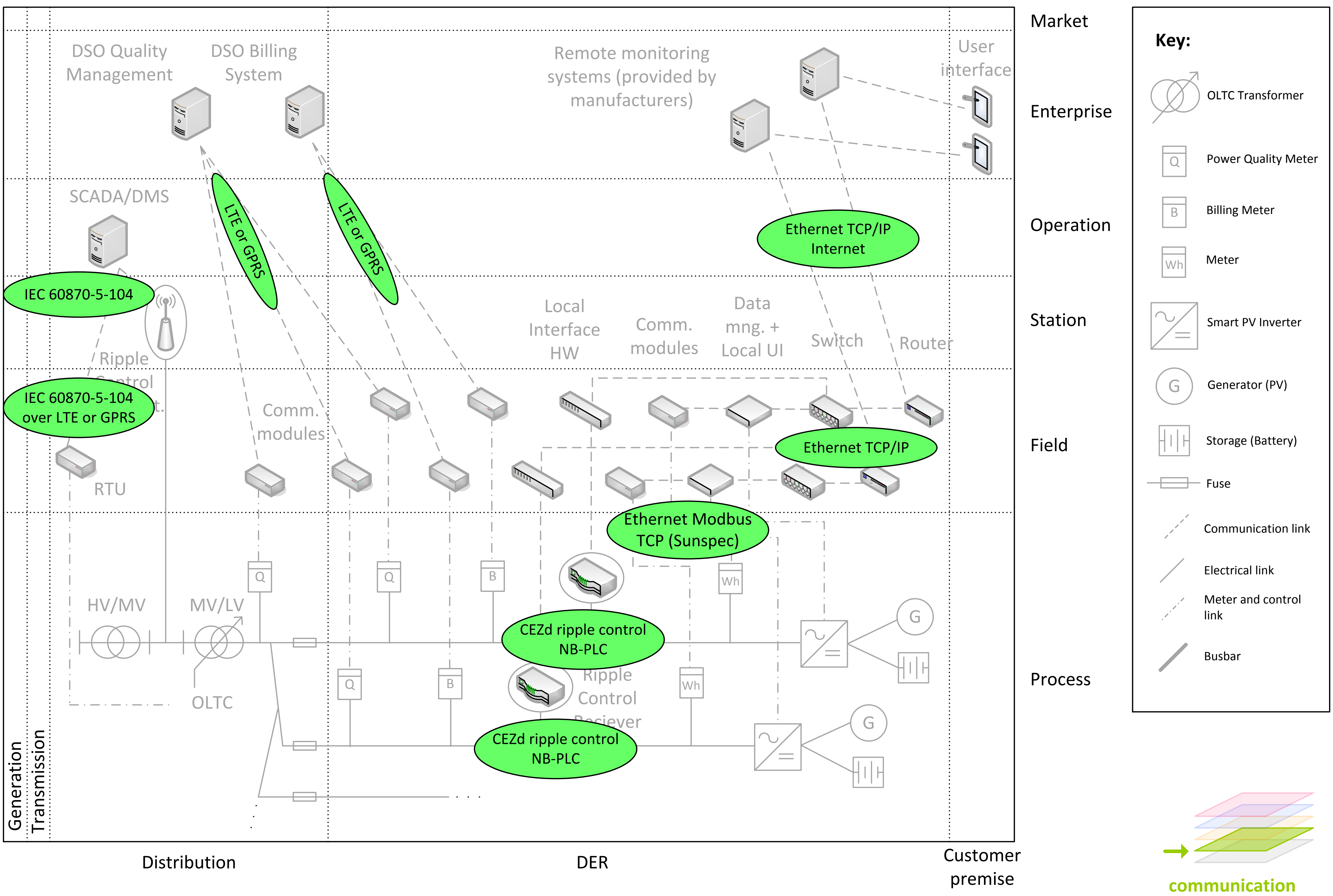


WP6 Use-case #3b

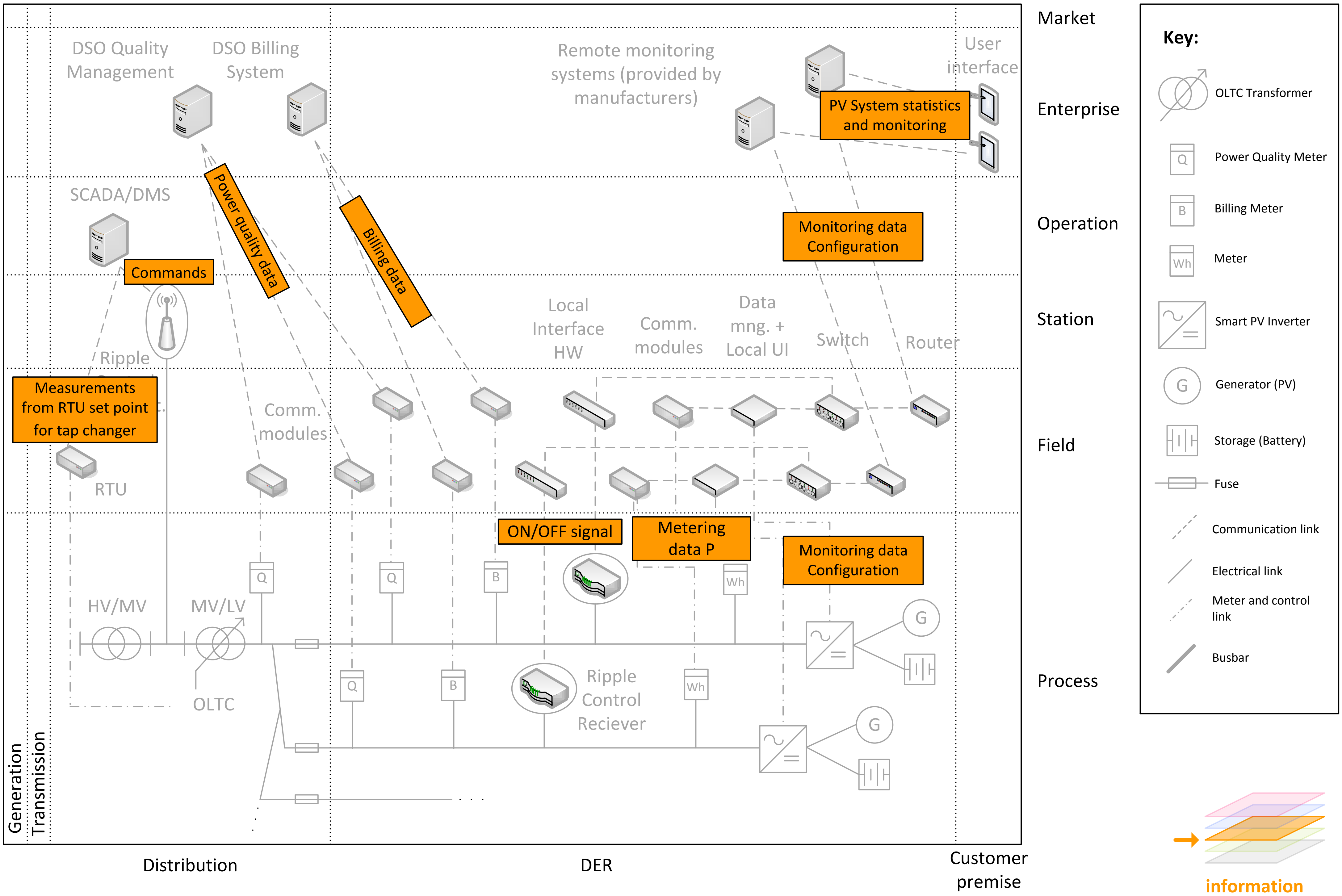
WP6 Use-case #4



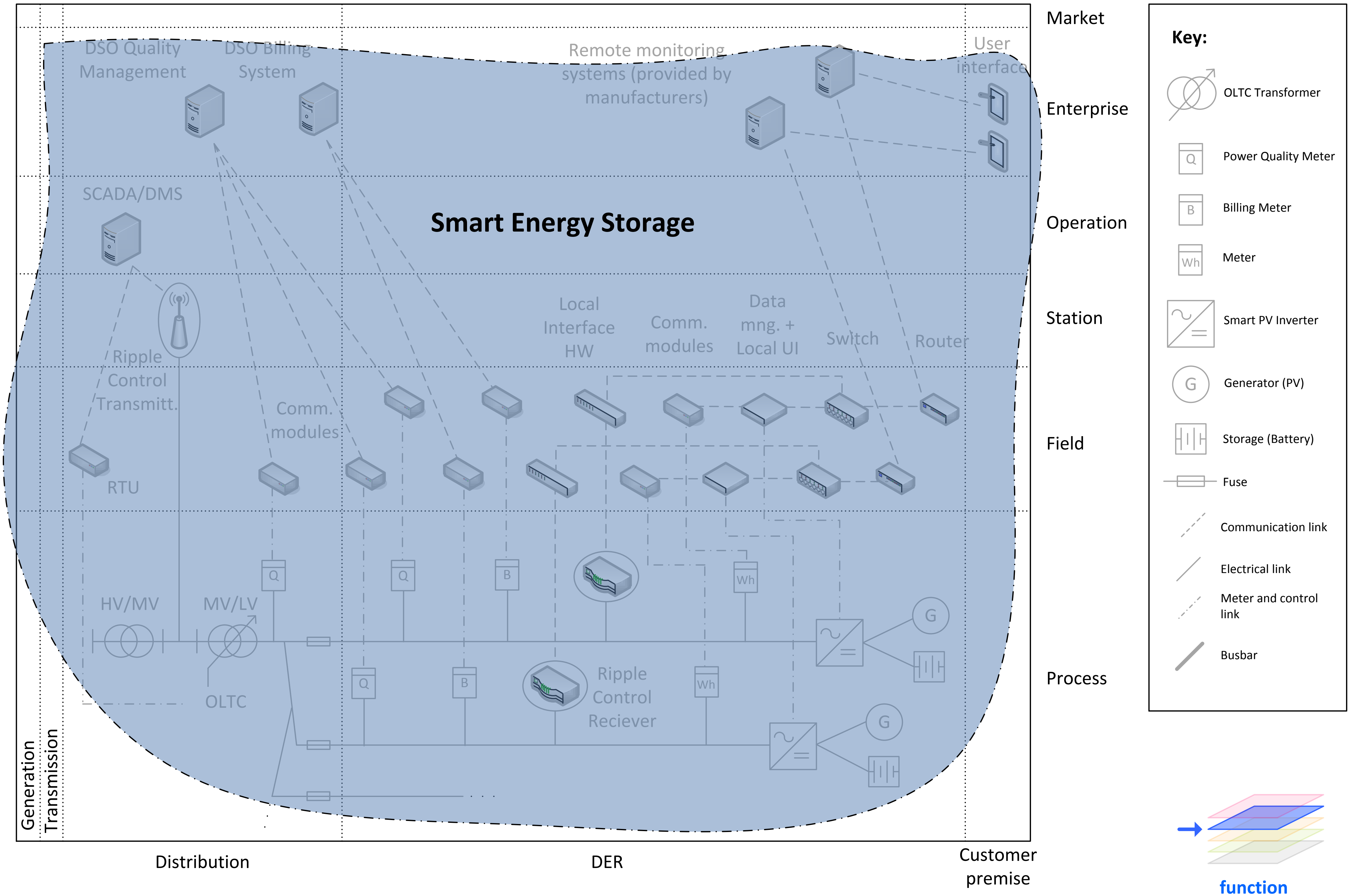
WP6 Use-case #4



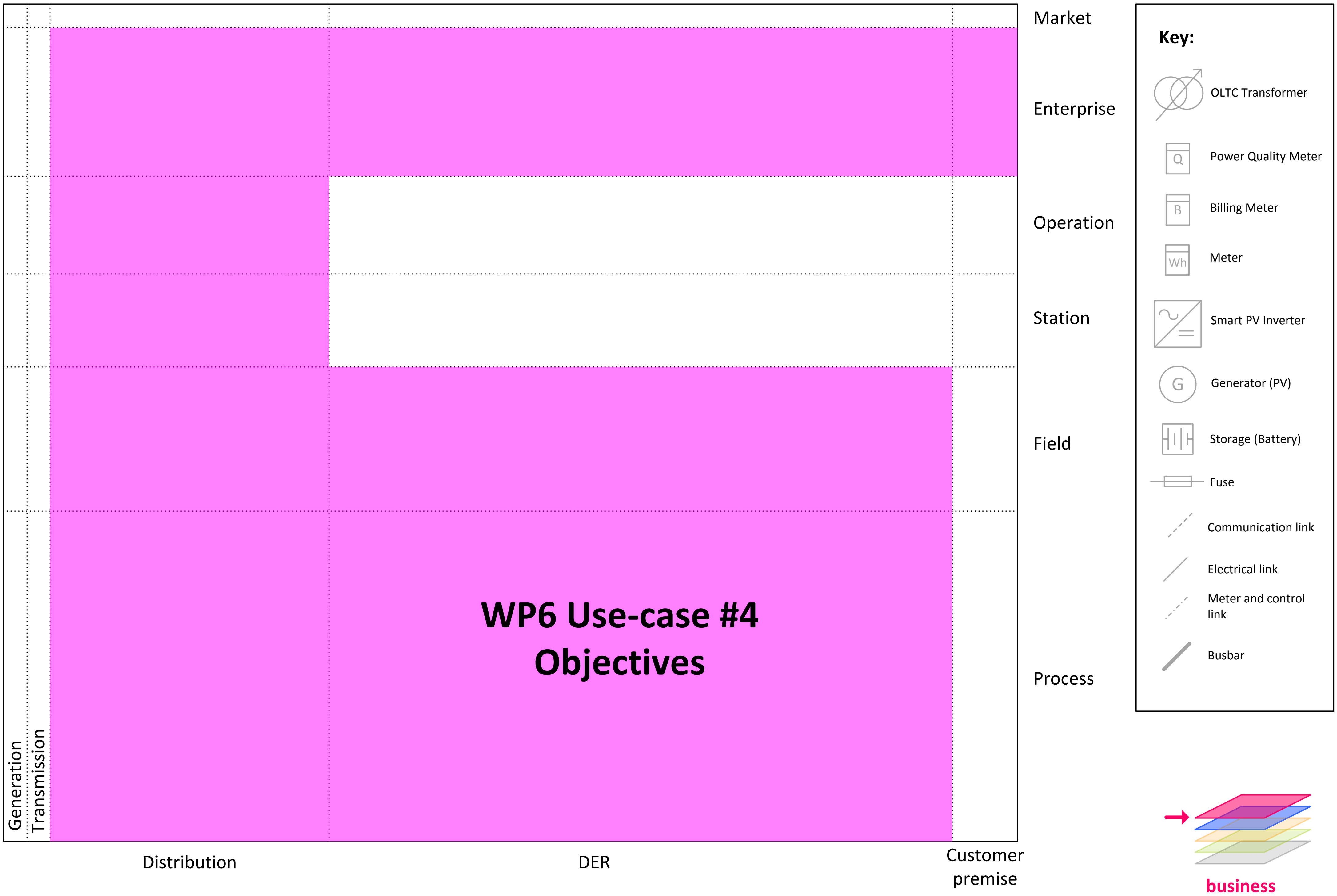
WP6 Use-case #4



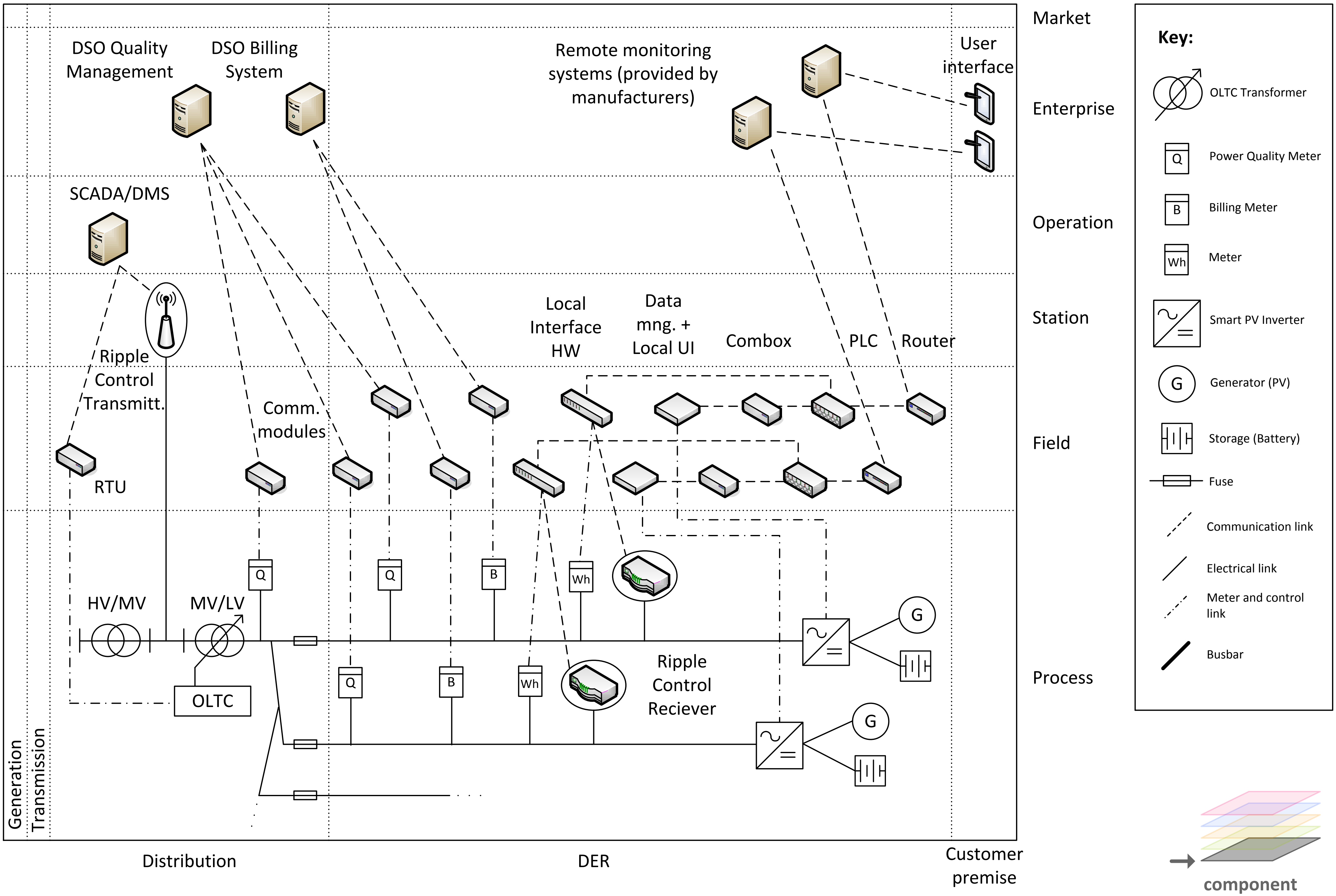
WP6 Use-case #4



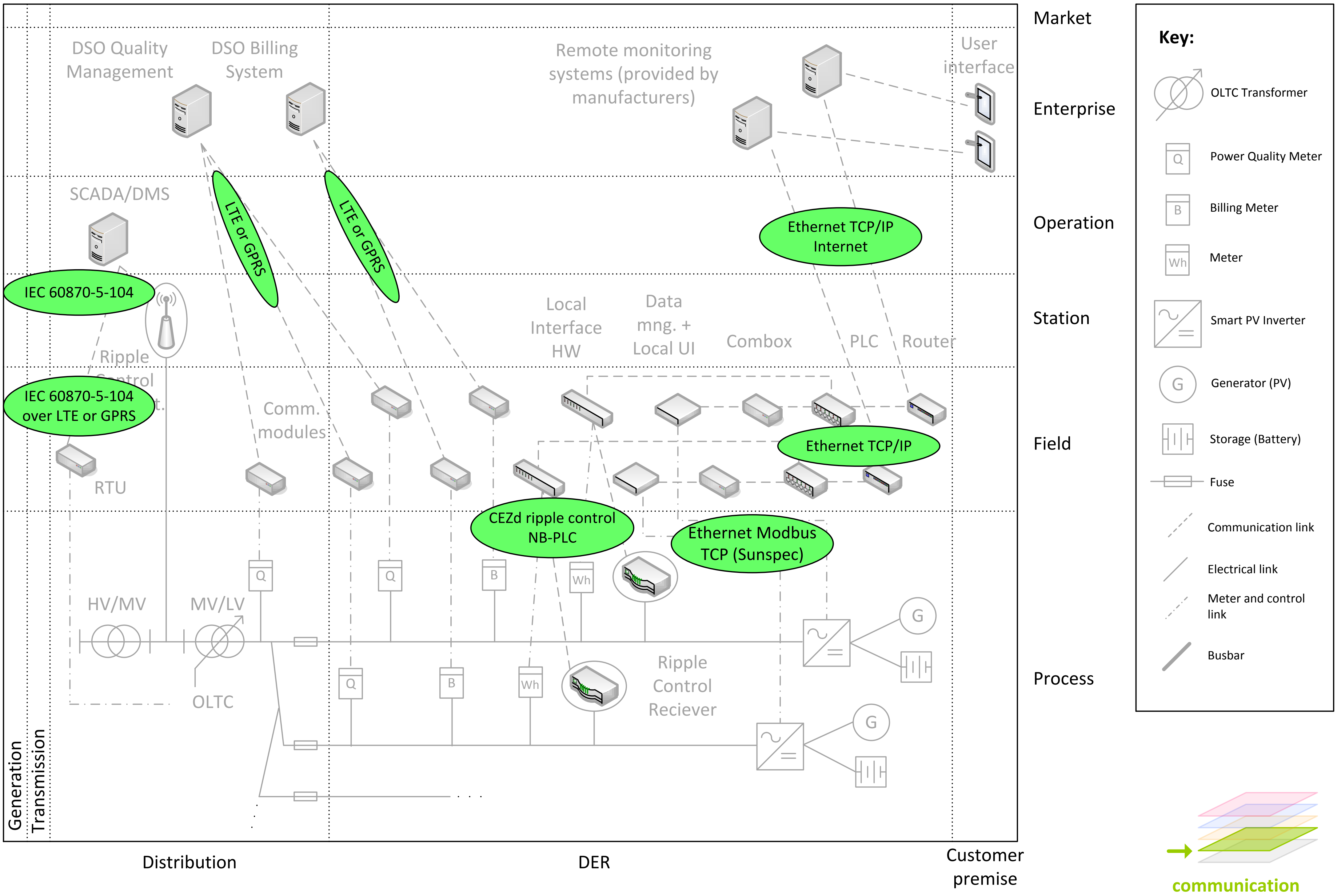
WP6 Use-case #4



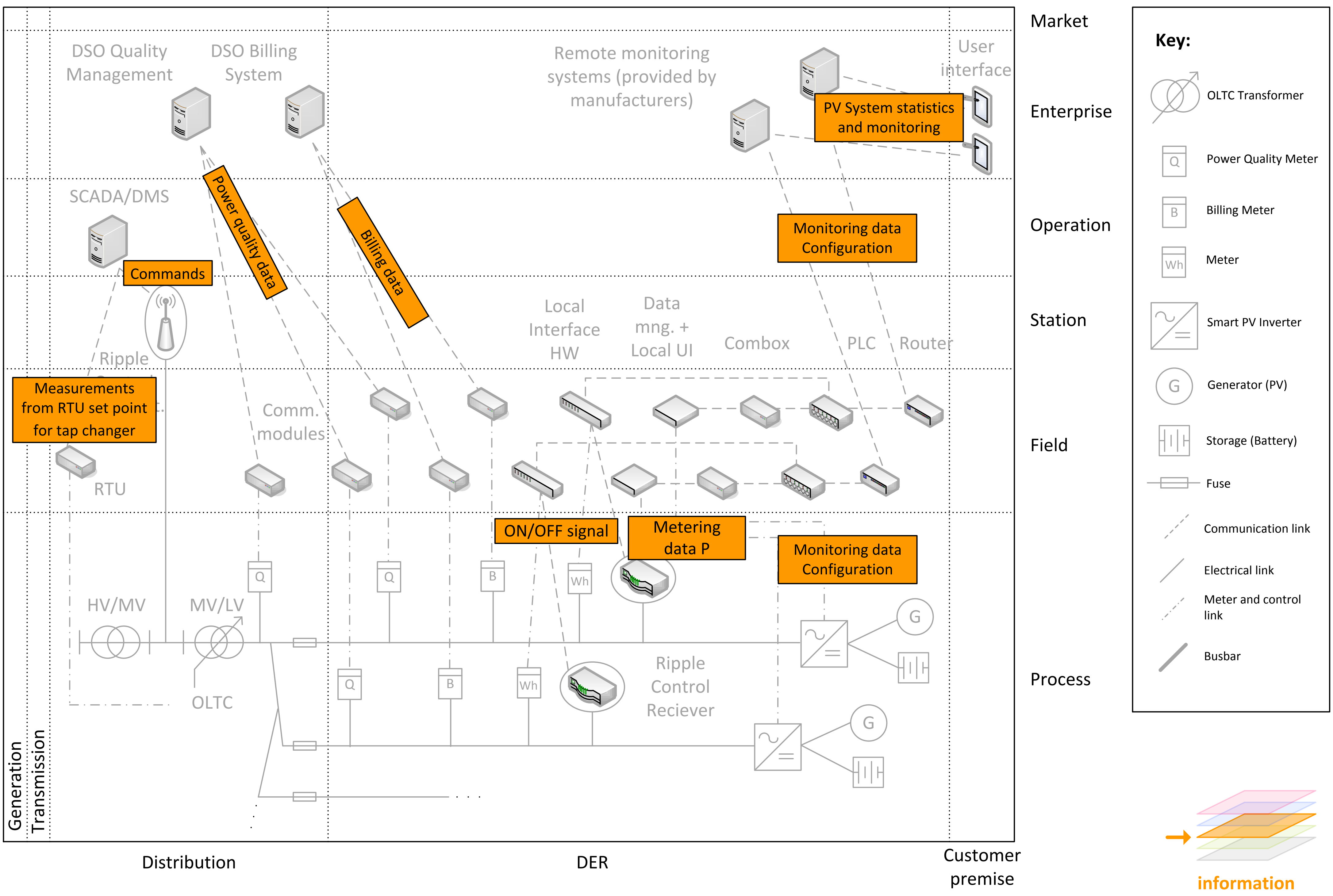
WP6 Use-case #4 (Schneider)



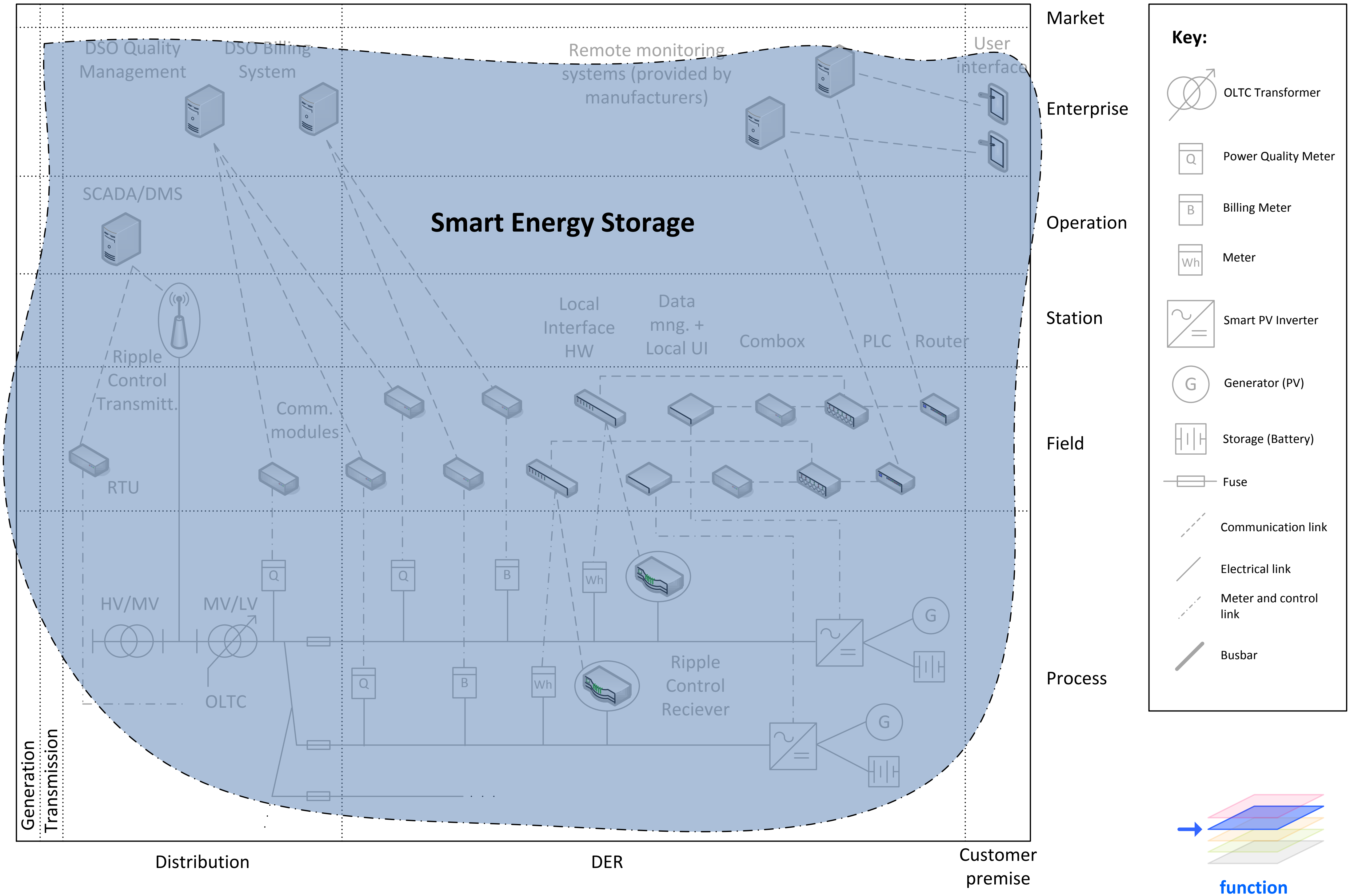
WP6 Use-case #4 (Schneider)



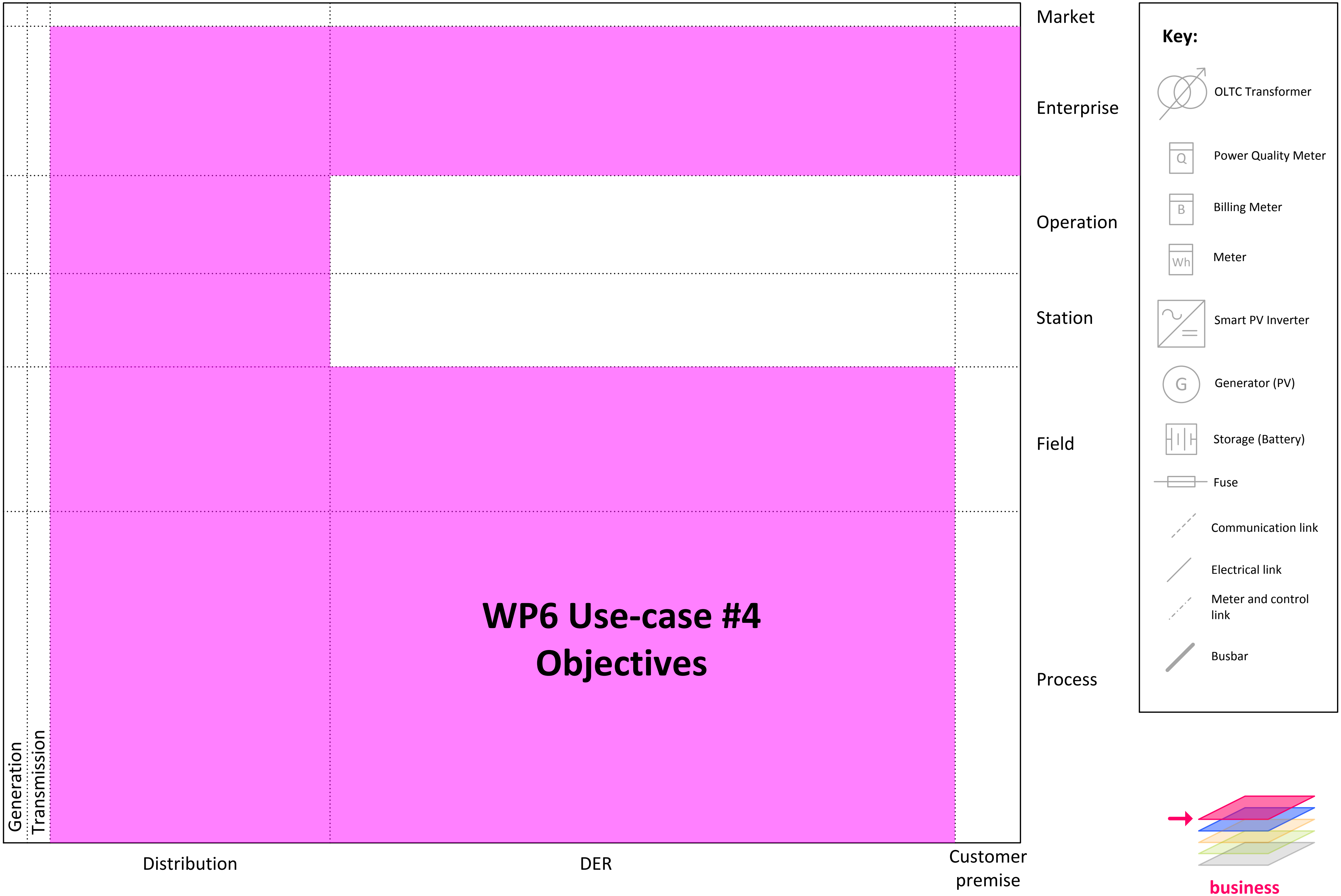
WP6 Use-case #4 (Schneider)



WP6 Use-case #4 (Schneider)



WP6 Use-case #4 (Schneider)



Annex 6.3

Interflex (Demo2): Key Performance Indicators

Internal Demo2 KPIs (defined in DoW)

May 2017

Version	Author
1.0	Stanislav Hes and Jan Kůla - CEZ Distribuce

<table>
<tr><th colspan="5">BASIC KPI INFORMATION</th></tr>
<tr><td>KPI Name</td><td colspan="2">Increasing DER hosting capacity</td><td>KPI ID</td><td>KPI6_1</td></tr>
<tr><td>Strategic Objective</td><td colspan="4">Increased DER integration in distribution grids</td></tr>
<tr><td>Owner</td><td colspan="4">Stanislav Hes, CEZ Distribuce</td></tr>
<tr><td>KPI Description</td><td colspan="4">This KPI will measure the potential increase hosting capacity for distributed energy resources with Smart Grid solutions compared to the baseline situation where no “smart” actions are performed on the network. The indicator will give a statement about the additional DER that can be installed in the network thanks to Smart Grid solutions without the need for conventional reinforcements (i.e. new grid lines).

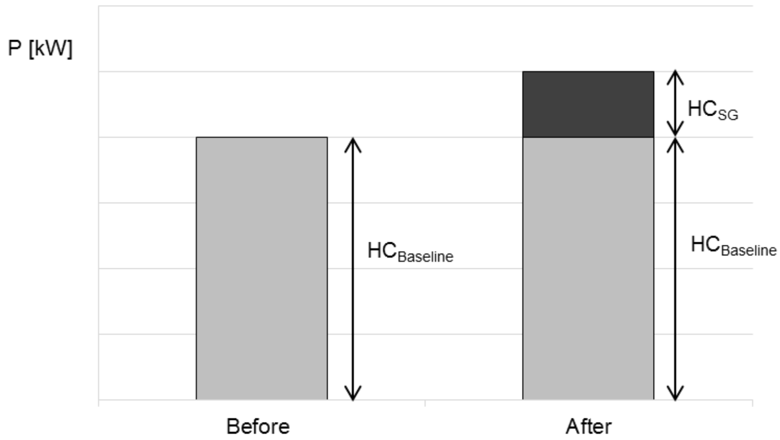


Figure 1: Comparison of DER hosting capacity for baseline and after smart grid solution implementation

This KPI will apply on WP6_1, WP6_2 and WP6_4 use cases (separately for each use case).</td></tr>
<tr><td>KPI Formula</td><td colspan="4">$$HC_{\%} = \frac{HC_{SG} - HC_{Baseline}}{HC_{Baseline}} \times 100$$
HC_{SG} Hosting Capacity for DER with Smart Grid solutions (kW). This hosting capacity should measure DER that can be connected (or that are already connected) to the grid after the Smart Grid solution is implemented.
$HC_{Baseline}$ Hosting Capacity for DER in Baseline situation (kW). This hosting capacity should measure DER that can be connected to the grid before the Smart Grid solution is implemented.
<u>Note:</u>
Positive value: HC gain
Negative value: HC loss</td></tr>
<tr><td>Unit of measurement</td><td colspan="4">% percentage base</td></tr>
<tr><td>Expectations</td><td colspan="4">Increase of DER hosting capacity:
WP6_1: +25%
WP6_2: +25%
WP6_4: +5%</td></tr>
<tr><td>Reporting Period</td><td colspan="4">Once a year</td></tr>
<tr><td>Relevant Standards</td><td colspan="4">EN 50438:2013, EN 50160</td></tr>
<tr><td>Connection / Link with other relevant defined KPIs</td><td colspan="4">Linked with KPI6_2 (which has to confirm that increasing of DER hosting capacity doesn’t cause voltage profile power quality issue) and KPI6_4 (which evaluate decrease of PV production peak of caused by PV + storage systems).</td></tr>
<tr><td>Reporting Audience and Access Rights</td><td>PUBLIC
☑</td><td>INTERFLEX PARTNERS
☐</td><td>DEMO PARTNERS
☐</td><td>OTHER (please specify)
☐</td></tr>
<tr><td>OTHER</td><td colspan="4">N/A</td></tr>
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(please specify)	

KPI CALCULATION METHODOLOGY

DEMO2 - ČEZ DISTRIBUCE

KPI Step Methodology ID [KPI ID #]	Step	Responsible
KPI6_1_1	Evaluation of baseline DER hosting capacity by simulation in DNCalc software by using baseline grid topology data from GIS system according to the standard rules for calculation of DER hosting capacity (standard approach).	Stanislav Hes, CEZ Distribuce
KPI6_1_2	After smart solution implementation - evaluation of DER hosting capacity by simulation in DNCalc software by using grid topology data from GIS system (standard approach) and with new rules for calculation of DER hosting capacity or installed power of DER physically connected to the grid after smart solution implementation.	Stanislav Hes, CEZ Distribuce

KPI DATA COLLECTION

DEMO2 - ČEZ DISTRIBUCE

Data	Data ID	Methodology for data collection	Source/Tools/Instruments for Data collection	Location of Data collection	Frequency of data collection	Minimum monitoring period	Data collection responsible
Number of DER which are possible to connect to the grid before smart solution implementation	$HC_{baseline}$	Download from CEZ Distribuce systems	GIS data	CEZ Distribuce systems	Only once in the beginning of the project	N/A	Stanislav Hes, CEZ Distribuce
Number of DER connected physically to the grid after smart solution implementation or hosting capacity calculated with new rules for DER hosting capacity calculation	HC_{SG}	Download from CEZ Distribuce systems	GIS data	CEZ Distribuce systems	Only once at the end of the project	N/A	Stanislav Hes, CEZ Distribuce

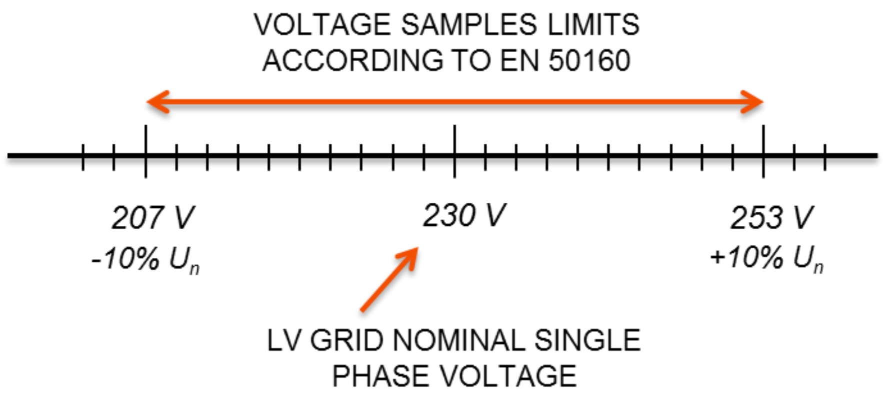
KPI BASELINE

DEMO2 - ČEZ DISTRIBUCE

Source of Baseline Condition	LITERATURE VALUES ☐	COMPANY HISTORICAL VALUES ☐	VALUES MEASURED AT START OF PROJECT ☑
Details of Baseline	Baseline grid topology for use cases WP6_1, WP6_2 and WP6_4 downloaded from GIS system.		
Responsible	Stanislav Hes, CEZ Distribuce		

GENERAL COMMENTS

KPI6_1 will be evaluated for use cases WP6_1, WP6_2 and WP6_4.

BASIC KPI INFORMATION			
KPI Name	Power quality (according to the standard EN 50160)	**KPI ID**	KPI6_2
Strategic Objective	Power quality (voltage levels) will not be negatively affected by smart solution implementations and have to sustain within tolerance given by EN 50160 power quality standard.		
Owner	Stanislav Hes, CEZ Distribuce		
KPI Description	With an increasing presence of DER in the LV network, line voltage profiles will vary not only because of the presence of different loads along the gird, but also the introduction of variable generation. This phenomenon must be clearly monitored and it must be ensured that desired voltage levels are kept within the defined standard limits according to the EN 50160 standard. In this way this KPI measures the number of voltage samples fulfilling the ± 10% voltage limits, as defined in EN 50160 standard before and after the smart grid solution implementation.  Figure 2: Example of voltage limits according to the EN 50160 standard This KPI will apply on WP6_1, WP6_2, WP6_3 and WP6_4 use cases (separately for each use case).		
KPI Formula	Related to percentage of measured voltage samples fulfilling the ± 10% voltage limits: $\Delta U_{limit\,\%} = \frac{U_{limit,SG} - U_{limit,baseline}}{U_{limit,baseline}} \times 100$ $\Delta U_{limit\,\%}$ — Percentage improvement in measured number of voltage samples fulfilling the ± 10% voltage limits, according to EN 50160 standard $U_{limit,SG}$ — Number of measured voltage samples fulfilling the ± 10% voltage limits condition according to EN 50160 standard (with smart grid solutions) $U_{limit,baseline}$ — Number of voltage samples fulfilling the ± 10% voltage limits condition as defined by EN 50160 standard (baseline situation) measured before smart grid implementation.		
Unit of measurement	% percentage basis		
Expectations	Number of measured voltage samples, not fulfilling the ± 10% voltage limits according to EN 50160, will not increase after implementation of smart grid solutions for all use cases (WP6_1, WP6_2, WP6_3 and WP6_4).		
Reporting Period	Once a year		
Relevant Standards	EN 50160		
Connection / Link with other relevant	Linked with KPI6_1 (which evaluates increasing of DER hosting capacity), KPI6_3 (which evaluates EV charging power curtailment in specific situations) and KPI6_4 (which evaluates		

defined KPIs	decrease of PV production peak of caused by PV + storage systems).			
Reporting Audience and Access Rights	PUBLIC ☑	INTERFLEX PARTNERS ☐	DEMO PARTNERS ☐	OTHER (please specify) ☐
OTHER (please specify)	N/A			

KPI CALCULATION METHODOLOGY

DEMO2 - ČEZ DISTRIBUCE

KPI Step Methodology ID [KPI ID #]	Step	Responsible
KPI6_2_1	Baseline power quality data for use cases WP6_1, WP6_2, WP6_3 and WP6_4 will be downloaded from power quality management system (DAM) or directly from existing power quality measurement devices installed in the grid (MEg30) or downloaded from DMS/SCADA system.	Stanislav Hes, CEZ Distribuce
KPI6_2_2	After smart solution implementation power quality data for use cases WP6_1, WP6_2, WP6_3 and WP6_4 will be downloaded from power quality management system (DAM) or directly from newly installed power quality measurement devices installed in the grid (MEg38) or downloaded from DMS/SCADA system.	Stanislav Hes, CEZ Distribuce

KPI DATA COLLECTION

DEMO2 - ČEZ DISTRIBUCE

Data	Data ID	Methodology for data collection	Source/Tools/Instruments for Data collection	Location of Data collection	Frequency of data collection	Minimum monitoring period	Data collection responsible
Number of voltage samples fulfilling the ± 10% voltage limits condition as defined by EN 50160 standard (baseline situation) measured before smart grid implementation	$U_{limit,baseline}$	Download from CEZ Distribuce systems (standard approach)	Power quality measurements (from MEg30 devices through DAM or downloaded directly; or from DMS/SCADA)	CEZ Distribuce systems	Once a month	10min values (for EN 50160 voltage level evaluation)	Stanislav Hes, CEZ Distribuce
Number of measured voltage samples fulfilling the ± 10% voltage limits condition according to	$U_{limit,SG}$	Download from CEZ Distribuce systems (standard approach)	Power quality measurements (from MEg38 devices through DAM or downloaded directly; or from DMS/SCADA)	CEZ Distribuce systems	Once a month	10min values (for EN 50160 voltage level evaluation)	Stanislav Hes, CEZ Distribuce

EN 50160 standard (with smart grid solutions)							

KPI BASELINE			
DEMO2 - ČEZ DISTRIBUCE			
Source of Baseline Condition	LITERATURE VALUES ☐	COMPANY HISTORICAL VALUES ☐	VALUES MEASURED AT START OF PROJECT ☑
Details of Baseline	Baseline power quality data for use cases WP6_1, WP6_2, WP6_3 and WP6_4 will be downloaded from power quality management system (DAM) or directly from existing power quality measurement devices installed in the grid or downloaded from DMS/SCADA system. Data from MEg30 power quality measurement devices have to be downloaded manually.		
Responsible	Stanislav Hes, CEZ Distribuce		
GENERAL COMMENTS			
KPI6_2 will be evaluated for use cases WP6_1, WP6_2, WP6_3 and WP6_4.			

<table>
<tr><th colspan="4">BASIC KPI INFORMATION</th></tr>
<tr><td>KPI Name</td><td>EV charging stations load curtailment in emergency situations</td><td>KPI ID</td><td>KPI6_3</td></tr>
<tr><td>Strategic Objective</td><td colspan="3">Decrease of EV charging power in case of emergency situations in distribution grid = increasing of flexibility.</td></tr>
<tr><td>Owner</td><td colspan="3">Stanislav Hes, CEZ Distribuce</td></tr>
<tr><td>KPI Description</td><td colspan="3">This KPI will measure the decrease of EV charging power of smart EV charging station in case of under voltage or under frequency in the grid and also in case of DSO command (send through narrow band simple PLC communication). Standard EV charging stations are not flexible and are not able to reduce charging power in case of emergency situations.

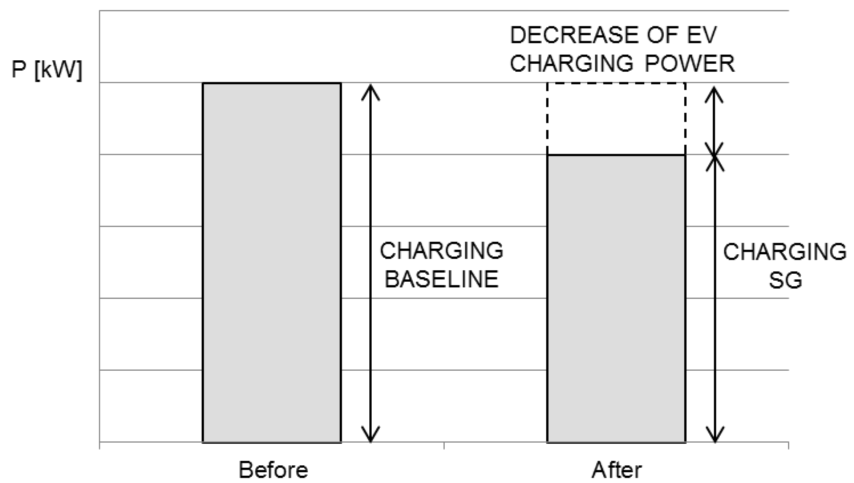


Figure 3: Example of EV charging station charging power decrease.

This KPI will apply on WP6_3 use case.</td></tr>
<tr><td>KPI Formula</td><td colspan="3"></td></tr>
</table>

	$$\mathrm{CHARGING}_{\%} = \frac{\mathrm{CHARGING}_{\mathrm{SG}} - \mathrm{CHARGING}_{\mathrm{Baseline}}}{\mathrm{CHARGING}_{\mathrm{Baseline}}} \times 100$$ $\mathrm{CHARGING}_{\mathrm{SG}}$ Charging power with Smart Grid solutions (kW). $\mathrm{CHARGING}_{\mathrm{Baseline}}$ Charging power in Baseline situation (kW) – without any curtailment. *Note:* Positive value: charging power increase Negative value: charging power decrease
Unit of measurement	% percentage base
Expectations	Decrease of EV charging power in case of emergency situations in distribution: WP6_3: -40%
Reporting Period	Once a year
Relevant Standards	EN 50160
Connection / Link with other relevant defined KPIs	Linked with KPI6_2 (which has to confirm that smart EV charging doesn't cause voltage profile power quality issue).

Reporting Audience and Access Rights	PUBLIC	INTERFLEX PARTNERS	DEMO PARTNERS	OTHER (please specify)
	☑	☐	☐	☐
OTHER (please specify)	N/A			

KPI CALCULATION METHODOLOGY

DEMO2 - ČEZ DISTRIBUCE

KPI Step Methodology ID [KPI ID #]	Step	Responsible
KPI6_3_1	Evaluation of EV charging station power will be checked from the device specification (manufactures datasheet).	Stanislav Hes, CEZ Distribuce
KPI6_3_2	After smart solution implementation - evaluation of EV charging station charging power curtailment in case of under frequency or in case of under voltage or in case of DSO command will be evaluated by field tests.	Stanislav Hes, CEZ Distribuce

KPI DATA COLLECTION

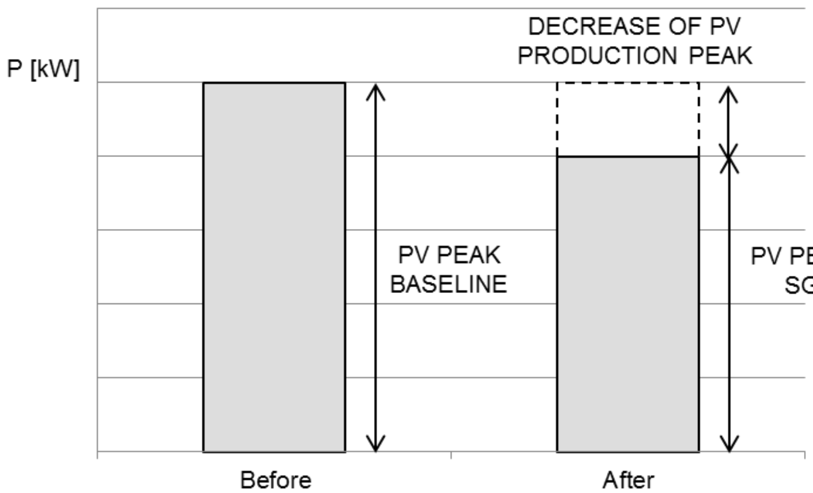
DEMO2 - ČEZ DISTRIBUCE

Data	Data ID	Methodology for data collection	Source/Tools /Instruments for Data collection	Location of Data collection	Frequency of data collection	Minimum monitoring period	Data collection responsible
Nominal charging power of EV charging station	CHARGING $\mathrm{POWER}_{\mathrm{baseline}}$	Datasheet specification	Manufacturer of EV charging station	CEZ Distribuce systems	Only once in the beginning of the project	N/A	Stanislav Hes, CEZ Distribuce
Charging power of EV charging station in emergency situation (or during field test)	CHARGING $\mathrm{POWER}_{\mathrm{baseline\ SG}}$	Field test measurements	Meg38 power quality device	CEZ Distribuce systems	Every field test or every emergency situation	1 minute values	Stanislav Hes, CEZ Distribuce

KPI BASELINE

DEMO2 - ČEZ DISTRIBUCE

Source of Baseline Condition	LITERATURE VALUES ☑	COMPANY HISTORICAL VALUES ☐	VALUES MEASURED AT START OF PROJECT ☐
Details of Baseline	Baseline EV charging stations charging power values could be simply checked from manufactures datasheets.		
Responsible	Stanislav Hes, CEZ Distribuce		
GENERAL COMMENTS			
KPI6_3 will be evaluated for use cases WP6_3.			

BASIC KPI INFORMATION			
KPI Name	PV production peak shaving	**KPI ID**	KPI6_4
Strategic Objective	Decrease of PV production peak thanks to the installation of home energy storage systems (batteries) = increasing of flexibility.		
Owner	Stanislav Hes, CEZ Distribuce		
KPI Description	This KPI will measure the decrease of PV production peak which overflow to the distribution grid thanks to the installation of PV together with home energy storage systems. PV + home energy storage systems will secure lower overflow of solar power to the distribution grid thanks to the smart control.  Figure 4: Example of PV production peak shaving. This KPI will apply on WP6_4 use case.		
KPI Formula	$$\text{PV PEAK}_{\%} = \frac{\text{PV PEAK}_{\text{SG}} - \text{PV PEAK}_{\text{Baseline}}}{\text{PV PEAK}_{\text{Baseline}}} \times 100$$ $PV\ PEAK_{SG}$ PV production peak with Smart Grid solutions (kW). $\text{PV PEAK}_{\text{Baseline}}$ PV production peak in Baseline situation (kW) – without any smart charging of home energy storage systems. *Note:* Positive value: PV production peak increase		

	Negative value: PV production peak decrease
Unit of measurement	% percentage base
Expectations	Decrease of PV production peak: WP6_4: -20%
Reporting Period	Once a year
Relevant Standards	EN 50160
Connection / Link with other relevant defined KPIs	Linked with KPI6_2 (which has to confirm that PV production peak shaving doesn't cause voltage profile power quality issue).

Reporting Audience and Access Rights	PUBLIC ☑	INTERFLEX PARTNERS ☐	DEMO PARTNERS ☐	OTHER (please specify) ☐
OTHER (please specify)	N/A			

KPI CALCULATION METHODOLOGY

DEMO2 - ČEZ DISTRIBUCE

KPI Step Methodology ID [KPI ID #]	Step	Responsible
KPI6_4_1	Evaluation of PV production peak will be checked from the PV systems specifications (sum of PV modules power under Standard Test Conditions).	Stanislav Hes, CEZ Distribuce
KPI6_4_2	After smart solution implementation (smart charging of home energy storage) - evaluation of PV production peak will be secured by field measurements for PV systems.	Stanislav Hes, CEZ Distribuce

KPI DATA COLLECTION

DEMO2 - ČEZ DISTRIBUCE

Data	Data ID	Methodology for data collection	Source/Tools /Instruments for Data collection	Location of Data collection	Frequency of data collection	Minimum monitoring period	Data collection responsible
PV production peak determined as a sum of PV modules power	$PV\ PEAK_{baseline}$	Datasheet specification	Manufacturer of PV modules	CEZ Distribuce systems	Only once in the beginning of the project	N/A	Stanislav Hes, CEZ Distribuce
PV production peak after smart charging of home energy storage is implemented	$PV\ PEAK_{baseline\ SG}$	Field measurements	Meg38 power quality device	CEZ Distribuce systems	Once a month	1 minute values	Stanislav Hes, CEZ Distribuce

KPI BASELINE

DEMO2 - ČEZ DISTRIBUCE

Source of Baseline Condition	LITERATURE VALUES ☑	COMPANY HISTORICAL VALUES ☐	VALUES MEASURED AT START OF PROJECT ☐
Details of Baseline	Baseline PV module power values under Standard Test Conditions could be simply checked from manufactures datasheets.		
Responsible	Stanislav Hes, CEZ Distribuce		

GENERAL COMMENTS

KPI6_4 will be evaluated for use cases WP6_4.

Annex 6.4

Project InterFlex
CZ Demo

Test procedure for the lab tests

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Revison	Date	Author	Change
0.1	29.05.2017	Benoît Bletterie	First version (structure and first content in chapter 2)
0.2	21.06.2017	Stefanie Kaser, Benoît Bletterie	Update of chapter 3
0.3	22.08.2017	…	Completion of chapter 4.3
0.4	29.08.2017	…	Completion of chapter 0
0.5	31.08.2017	…	Update with comments from meeting on 30.08.2017
1.0	30.11.2017	Stefanie Kaser	Update with comments from meeting on 30.08.2017 and learnings from first lab tests

Content

List of Figures

List of Tables

List of Abbreviations

DAQ	Data Acquisition
EUT	Equipment Under Test

1 Content & Scope

This documents presents the laboratory tests to be performed in the frame of the InterFlex project for the Czech Demo.

2 Overview of the use-cases

This chapter provides an overview of the use-cases covered by the Czech Demo.

2.1 UC1: Increase the DER hosting capacity of LV distribution networks by combining smart PV inverter functions (demonstration of Q(U) and P(U))

2.1.1 Implemented functions and functions to be tested

UC1 is based on the following two local control functions, which can be used separately or in combination:

- Q(U): control of the reactive power exchange (injection or consumption) according to the voltage
- P(U): reduction of the injected active power in case of over-voltage

2.1.2 Scope of the lab tests / equipment under test

Since this use-case purely relies on local control functions, the communication infrastructure is not in the scope of the testing, as visible on the SGAM diagram (Figure 1).

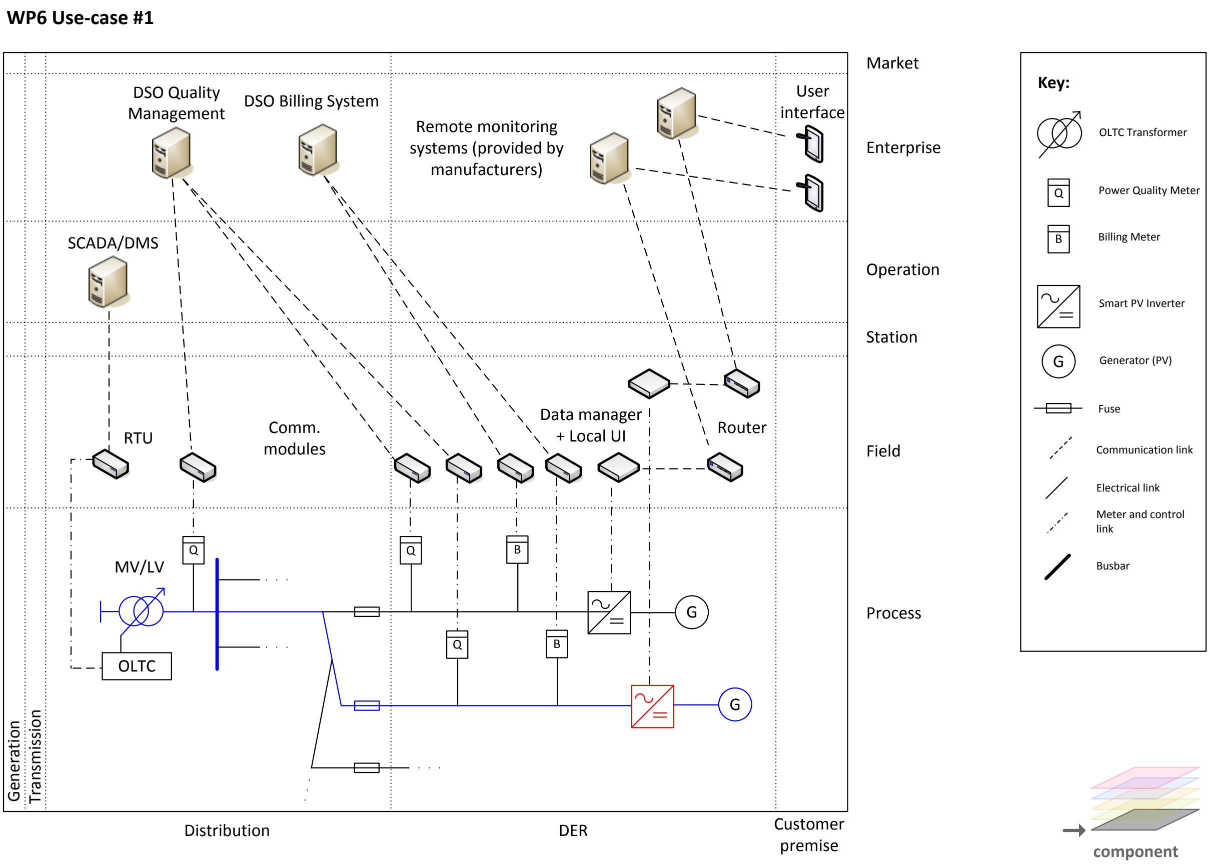

Figure 1 – Scope of lab tests shown on the SGAM description of UC1 (red: Equipment Under Test / blue: emulated part)[1]

The devices used for the testing (Equipment Under Test - EUT) are shown in Table 1.

Table 1 – EUT for UC1

	Fronius	**Schneider**
Model	- Symo Hybrid 5.0-3-S[2]	- Conext RL 3000 E - External hardware for P(U)
AC nominal output (kW)	5.0	3.0
AC nominal apparent power (kVA)	5.0	3.0
Grid connection	3~NPE 400 V	1~NPE 230 V
Power factor range	0.85	0.80

2.2 UC2: Increase the DER hosting capacity in MV distribution network by volt-var control (V/Q regulation)

No lab testing foreseen.

2.3 UC3: Smart EV charging

2.3.1 Implemented functions and functions to be tested

UC3 "Smart EV charging" consists in constraining the charging of e-vehicles in case of network constraints. The charging stations allow the reduction of the charging power (to 50 % of the maximal power for each phase) in case of:

- Under-frequency (function implemented locally – default threshold: 49.9 Hz). A reset/restart after f > 49.9Hz for 5 minutes is included according to CEZ Distribuce requirements.
- Under-voltage (function implemented locally – default threshold: 95 % of the nominal voltage = 380 V, reset when the voltage has remained for at least 5 minutes above the threshold)
- Request from the DSO (function requiring a communication interface (ripple control for the demonstration))

2.3.2 Scope of the lab tests / equipment under test

Since this use-case relies on both local and centralized functions, the communication infrastructure is in the scope of the testing, as visible on the SGAM diagram (Figure 2 and Figure 3) for the two implementations of UC3 (UC3a and UC3b).

[1] For the P(U) function, additional hardware is necessary (not shown on this figure)
[2] For UC1, the devices used in the field will be from the series *Fronius Symo* but given that these devices are identical to those of the *Fronius Symo Hybrid* in regard to this network support function, the *Fronius Symo Hybrid* will be used for UC1 and for UC4a.

WP6 Use-case #3a

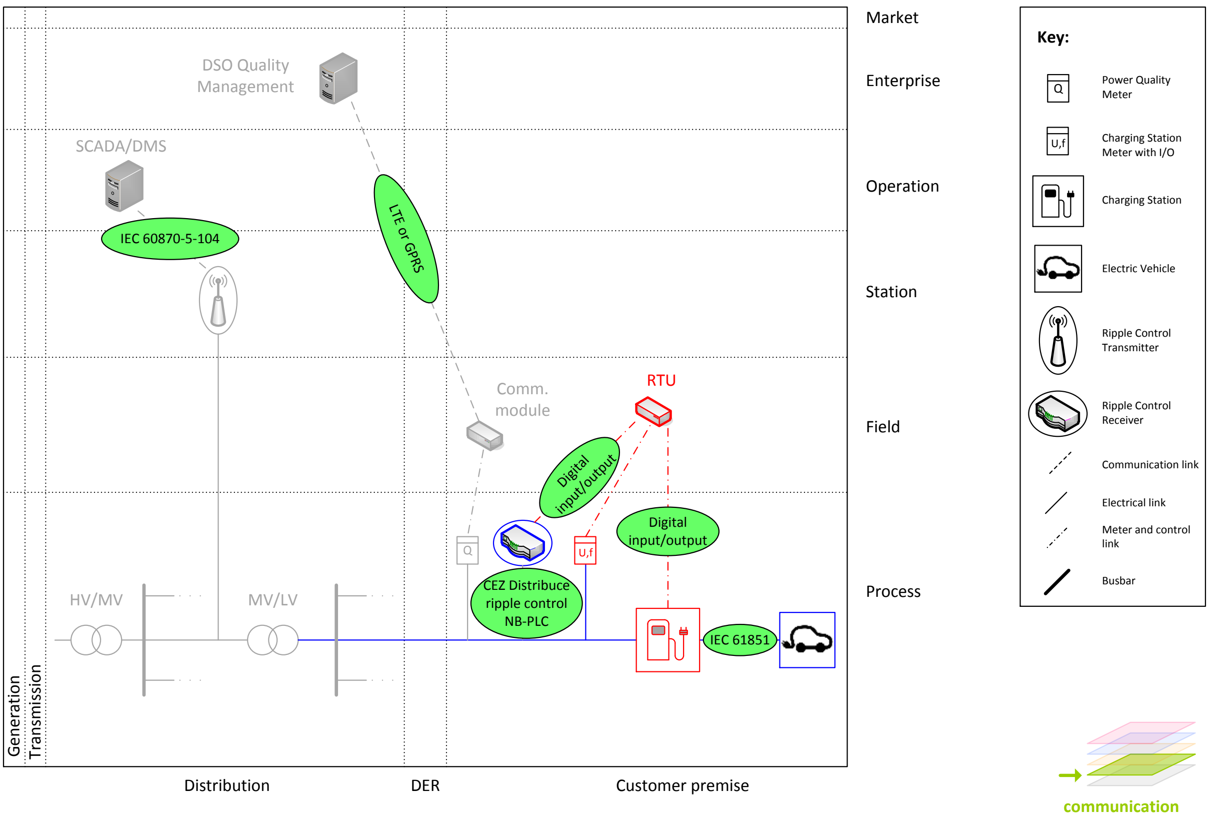

Figure 2 – Scope of lab tests shown on the SGAM description of UC3a (Schneider) (red: Equipment Under Test / blue: emulated part)

WP6 Use-case #3b

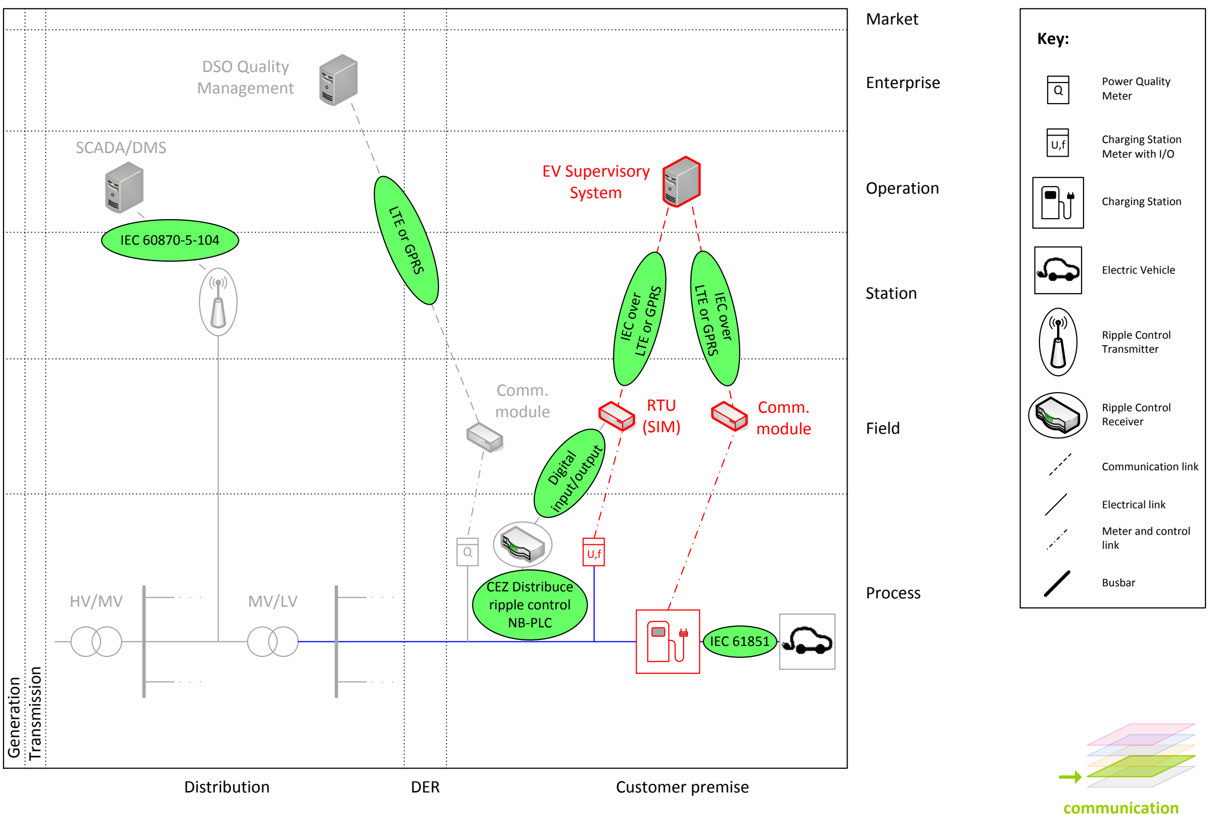

Figure 3 – Scope of lab tests shown on the SGAM description of UC3b (Siemens) (red: Equipment Under Test / blue: emulated part)

The devices used for the testing (Equipment Under Test - EUT) are shown in Table 1.

Table 2 – EUT for UC1

	Schneider		Siemens
Model	- EV Link Parking - measurement device (outside) the charging station	- EVlink Smart Wallbox - measurement device (outside)[3]	DUCATI energia
AC maximal power (kW)	22.1 kW and 2 kW	22.1 kW and 2 kW (only one at the same time)	22.1 x 2
Grid connection	3~NPE 400 V	3~NPE 400 V	3~NPE 400 V

In addition to the charging station, further following components which are necessary for the remote control will be used: RTU, Comm. module (Figure 2 and Figure 3). Some of them are included in the charging station.

2.4 UC4: Smart energy storage

2.4.1 Implemented functions and functions to be tested

The hybrid PV storage systems will feature the control functions covered in UC1 (Q(U), P(U), see chapter 2.1) and will, in addition, offer the following functions (partly based on UC3):

Local functions:

- Permanent limitation of the power surplus injected into the network to 50 % of the nominal power of the PV generation.
- Under-frequency stage 1 (function implemented locally – default threshold: 49.9 Hz): stop the charging of the battery. The charging can restart if the frequency is above 49.9 Hz for at least 5 minutes
- Under-frequency stage 2 (function implemented locally – default threshold: 49.85 Hz): discharge of the battery at 100 % of nominal power until the min. allowed SoC (70 %) of the battery is reached or the frequency exceeds 50.1 Hz
- Under-voltage stage 1 (function implemented locally – default threshold: 95 % of the nominal voltage = 380 V): stop the charging of the battery. The charging can restart if the frequency is above 380 V for at least 5 minutes
- Under-voltage stage 2 (function implemented locally – default threshold: 92.5 % of the nominal voltage = 370 V): discharge of the battery at 100 % of nominal power until the min. allowed SoC (70 %) of the battery is reached or the voltage exceeds 420 V

Remote functions:

As in UC3, a remote control is included: the PV + storage system must allow the discharge at 100 % of the nominal power of battery system after activation via ripple control from DSO until the min. allowed SoC (70 %) of the battery is reached.

[3] Only one power measurement device will be provided for the lab tests (for the - EV Link Parking and the EVlink Smart Wallbox)

2.4.2 Scope of the lab tests / equipment under test

Since this use-case relies on both local and centralized functions, the communication infrastructure is in the scope of the testing, as visible on the SGAM diagram, Figure 4 and Figure 5) for the two implementations of UC4 (UC4a and UC4b).

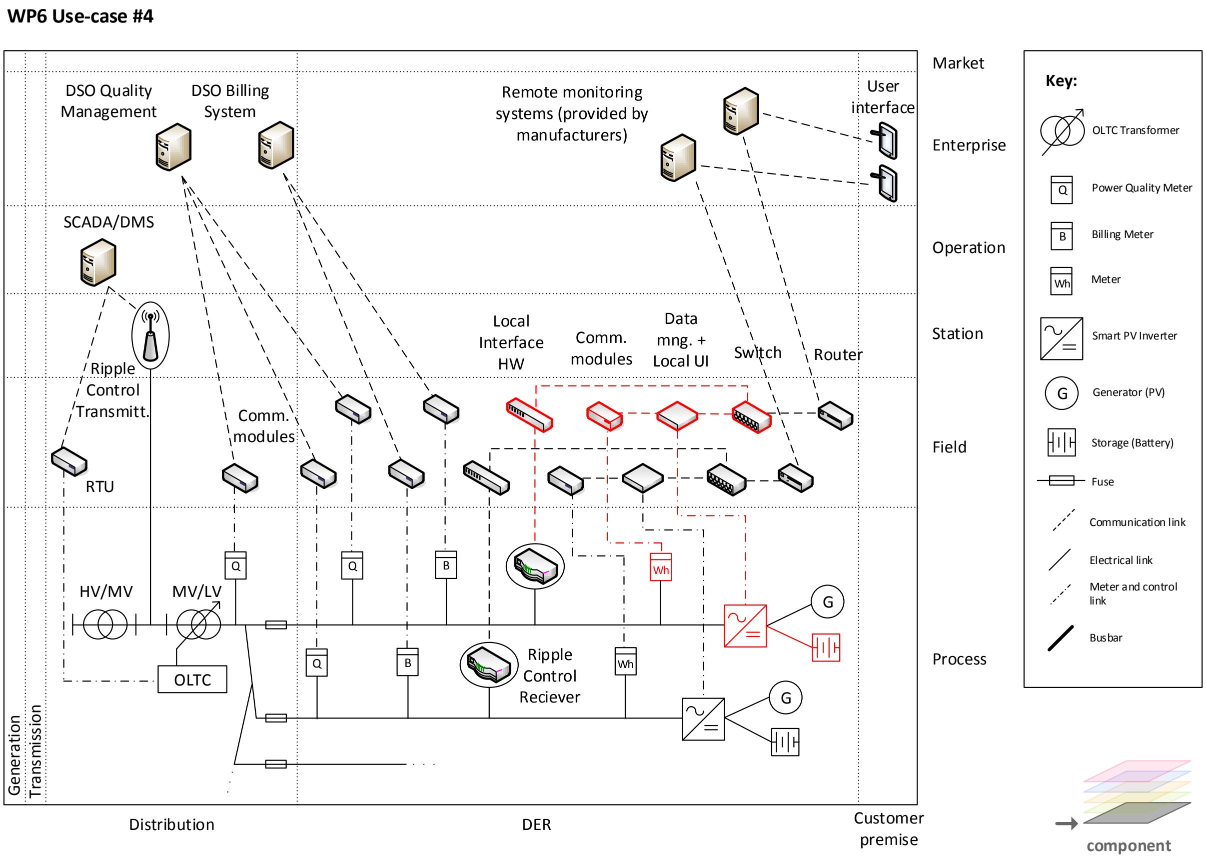

Figure 4 – Scope of lab tests shown on the SGAM description of UC4a (Fronius) (red: Equipment Under Test / blue: emulated part)

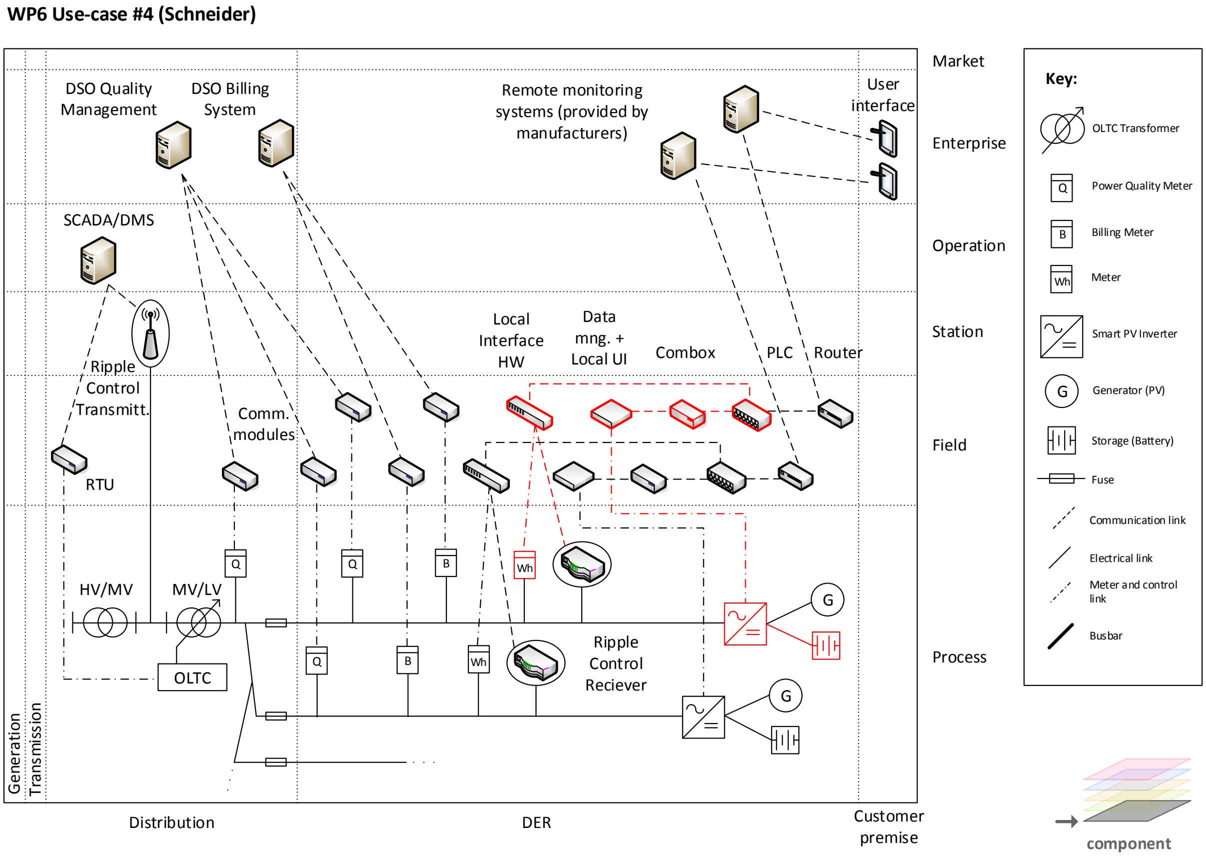

Figure 5 – Scope of lab tests shown on the SGAM description of UC4b (Schneider) (red: Equipment Under Test / blue: emulated part)

The devices used for the testing (Equipment Under Test - EUT) are shown in Table 3.

Table 3 – EUT for UC4

	Fronius
Model	- Symo Hybrid 5.0-3-S[4] - solar Battery - meter - external hardware
AC nominal output (kW)	5.0
AC nominal apparent power (kVA)	5.0
Grid connection	3~NPE 400 V
Power factor	0.85
Battery capacity (kWh)	9.6 kWh

[4] For UC1, the devices used in the field will be from the series *Fronius Symo* but given that these devices are identical to those of the *Fronius Symo Hybrid* in regard to this network support function, the *Fronius Symo Hybrid* will be used for UC1 and for UC4a.

	Schneider
Model	- solar charger MPPT 80 160 - hybrid inverter XW+7048E - power measurement device PM - BMS - Combox - Battery (LiFeYPO4 3.2V/160Ah WIDE)
AC nominal output (kW) XW+	5,5
Grid sell current max (A) XW+	20
DC nominal output (kW) MPPT **100 % of the nominal power**	2,8
Grid connection	1~NPE 230 V
Battery capacity (Ah)	160
Battery capacity (Wh)	512

In addition to PV, inverter and battery system, further following components which are necessary for the remote control will be used: RTU, Comm. module (Figure 4 and Figure 5).

3 Testing infrastructure

3.1 Overview

The test environment of the AIT SmartEST research test stand developed by AIT consists of the following components:

- AC supply: The connection to the public grid and a grid simulator are available for the testing procedure (for technical specifications see Chapter 3.2).
- AC load: The AC load is connected to all three phases and can either be set symmetrical or individually (for technical specifications see Chapter 3.2).
- DC supply: Generally, the DC power for the equipment under test (EUT) is provided by a PV simulator. If needed, there are also two bidirectional DC sources available (for technical specifications see Chapter 3.3).
- Real time system: The OPAL-RT system is able to run MATLAB simulink models. It has 32 analogue in- and outputs. It can perform up to 10 µs increment and has two Intel Quad-Core i7 processors.

The measurement of voltage and current are done with DEWETRON. The data recording and analysis is done with Dewesoft 7.1.3. The general measurement surface is shown in ScadaBR.

In Figure 6, an overview of the components of the AIT SmartEST research test stand is given. In Figure 7, the general measuring surface as shown in ScadaBR can be seen.

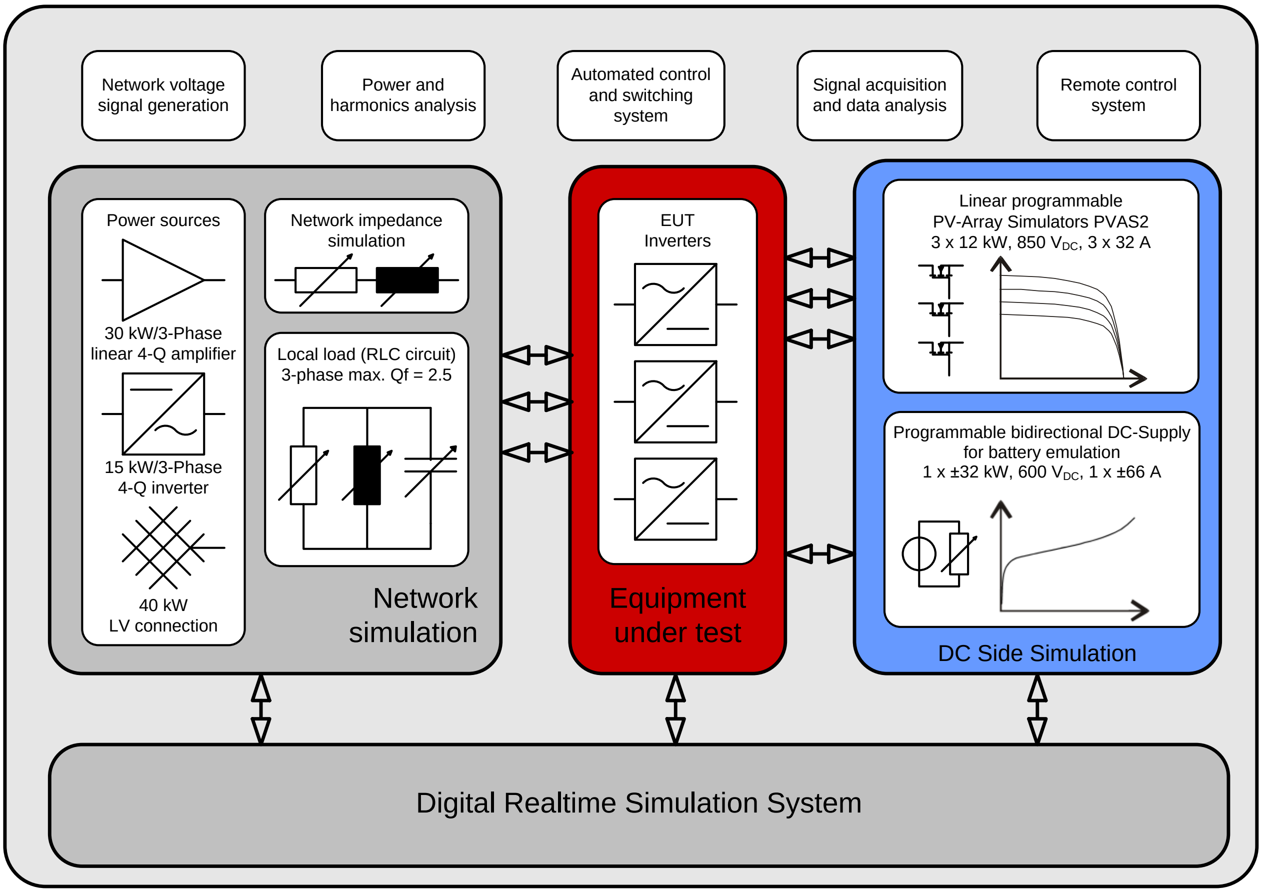

Figure 6 – Overview of AIT SmartEST research test stand

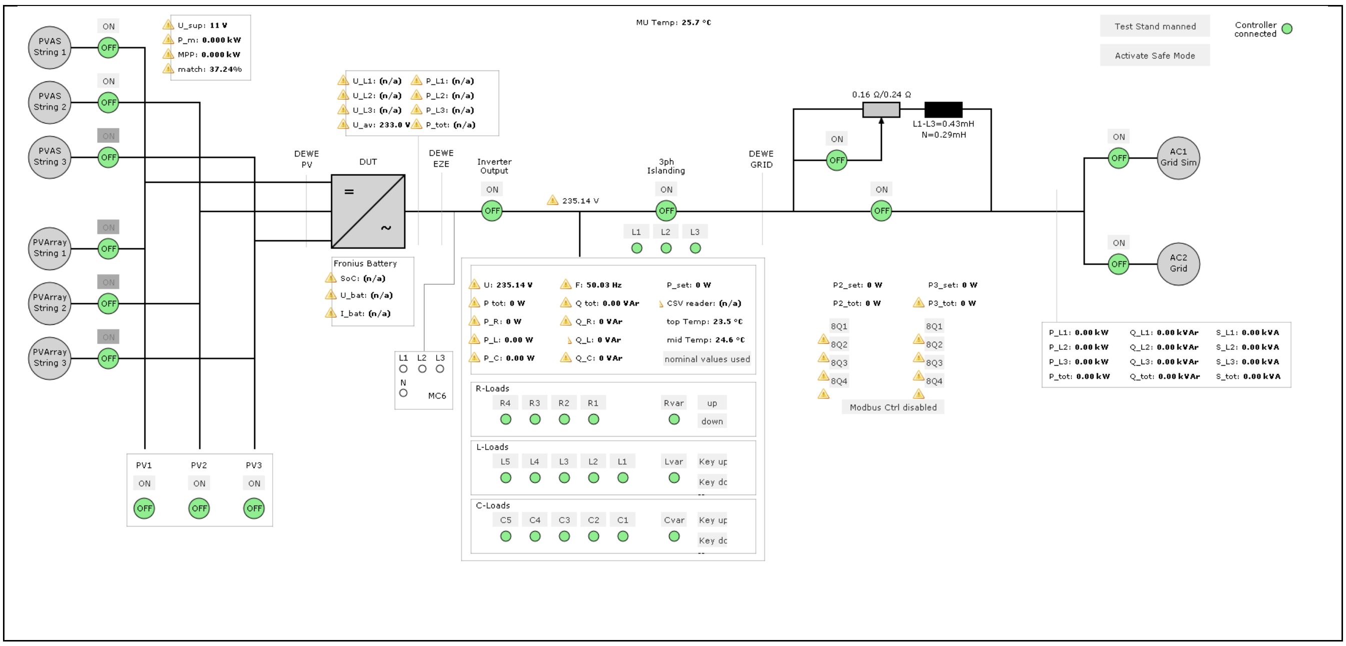

Figure 7 –Measurement surface as shown in ScadaBR

3.2 AC side

There are two possibilities for AC supply at the AIT SmartEST research test stand. For some tests (e.g. efficiency tests), the connection to the public grid is used. On the other hand, the grid simulator (used for all the tests requiring frequency variations) can be used. Specifications of the AC sources can be found in Table 4 and Table 5.

The AC load can be set through ScadaBR. All three phases can be used symmetrical or they can be set individually. Technical specifications of the AC load can be found in Table 6.

Table 4 – Specification of AC source 1 – Public Grid

Technical specification of the AC source	
AC Source	Public grid
Nominal voltage (V)	230 V ±10 %
Nominal frequency (Hz)	50 Hz

Table 5 – Specification of AC source 2 – grid simulator

Technical specification of the AC source	
AC source	3x Spitzenberger PAS 10000
Nominal voltage (V)	230 V
Nominal frequency (Hz)	50 Hz

Table 6 – Specification of AC load

Technical specification of the AC load	
AC load	AIT – in-house development V1.0 (3x 11kW)
Version	1.0
Connection	3-phase (symmetrical / individual)
Power per phase	11 kW
Resolution	2,9 W at nominal power

3.3 DC side for PV and storage systems

The DC power is provided by a PV simulator (standard). Technical specifications can be found in Table 7. For some tests, a bidirectional DC source is needed (battery emulation); there are two of them available at the AIT SmartEST research test stand. Technical specifications can be found in Table 8 and Table 9.

Table 7 – Specification of DC source 1 – PV simulator

Technical specification of the DC source	
DC source (PV simulator)	AIT PV Array Simulator PVAS3
DC – voltage range	0-800 V
DC – current range (1 String)	0-32 A
DC – power range (1 String)	Max. 12 kW
Accuracy	< 0.4 % (full scale range)
Operation mode	Standard: 1 String

	If needed, up to 3 phases can be used.

Table 8 – Specification of DC source 2 - TC.GSS.20.130.4WR.S

Technical specification of the DC source	
DC source	TC.GSS.20.130.4WR.S
DC – voltage range	0-130 V
DC – current range (1 String)	+/- 192 A
DC – power range (1 String)	+/- 20 kW
Accuracy	0,1 % (full scale range)
Operation mode	1 String

Table 9 – Specification of DC source 3 - TC.GSS.32.600.4WR.S

Technical specification of the DC source	
DC source	TC.GSS.32.600.4WR.S
DC – voltage range	0-600 V
DC – current range (1 String)	+/- 66 A
DC – power range (1 String)	+/- 32 kW
Accuracy	0,1 % (full scale range)
Operation mode	1 String

3.4 Load for testing charging stations

For UC3, one a charging emulator (device accepting as input the PWM signal from the charging station) and controlling a variable load will be used. The charging power will be set to 22 kW.

3.5 Data acquisition and processing

3.5.1 Measurement devices

Table 10 gives a short overview of the test equipment available at the AIT SmartEST research test stand.

Table 10 – Overview of the used test equipment

Test Equipment	

Current transformer	• LEM LF 205-S/SP3 (standard)
	  ○ Accuracy: 0.5%
	• LEM IT 200-S ULTRASTAB (if higher accuracy is needed)
	  ○ Accuracy: 0.0084 %

Measuring equipment	DEWETRON – measuring system • Measuring cards for voltage measurement: DAQP-HV *(DC Accuracy: ±0.05 % of reading ±0.05 % of range)* • Measuring cards for current measurement: DAQP-LA *(Accuracy: ±0.05 % of reading ±0.05 % of range)*
DC source	• AIT PV Array Simulator PVAS3 (standard) • TC.GSS.20.130.4WR.S • TC.GSS.32.600.4WR.S
AC source	• Public grid • Grid simulator: 3x Spitzenberger PAS 10000
Other test equipment	Temperature measurement (ADAM-6018; 8-channel isolated thermocouple input Modbus TCP module with 8-channel DO)

3.5.2 Software

Table 11 gives a short overview of the software used at the AIT SmartEST research test stand.

Table 11 – Software used for measurement, data analysis and control

Used software			
Manufacturer	Identification:	Usage:	Version:
Dewesoft™	Dewesoft™ 7	Measurement and data analysis	7.1.3
National Instruments	LabVIEW 2013	Control of PV simulator	2013
	ScadaBR	Measurement surface	

3.5.3 Measurement accuracy

Measurement of U,I,P,Q (phase and sequence magnitudes where applicable) with:

- The following time resolution:
  - Raw data - instantaneous values (sampling rate: 300 kHz)
  - RMS-values of one or more cycles
  - RMS-values of optional duration (overlapping or non-overlapping)
- The following accuracy:
  - Voltage: <0.1 %
  - Current: <1 %

4 Description of the tests

4.1 UC1: reactive power control - Q(U)

4.1.1 Control function to be tested

The reactive power control to be tested under UC1 is a local control of the voltage through a voltage-dependant reactive power injection or consumption (Q(U)). The default Q(U)-characteristic is shown on Figure 8.

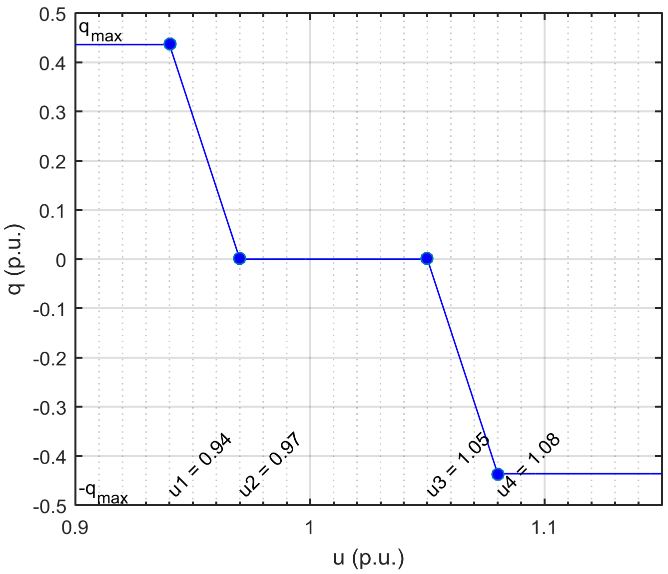

Figure 8 – Default Q(U)-curve for ČEZ Distribuce[5]

4.1.2 Purpose

The purpose of these tests is to verify the proper functioning of the reactive power control mode Q(U) and to characterise the control in terms of:

- Accuracy
- Time behaviour
- Stability under worst-case conditions

4.1.3 Activated function(s) and test conditions

The function Q(U) will be activated and parametrised with the settings mentioned in the test cases (chapters 4.1.4.1 to 4.1.4.3).

The overview of the available parameters is provided in Table 12 and Table 13 for both manufacturers.

[5] Parameter naming according to [1]

Table 12 – Settings for the Q(U) control - Fronius

Item	Parameter name	Default value for UC1	Comment
React. P. Mode	Q/U	Q/U	
Time constant (s)	Ch Q (U) TimeC.	will be varied[6] (0.01s for worst case)	Range: 0.01- 60 s
Active power above which Q(U) is activated	Ch Q (U) P-LockI	0	
Active power below which Q(U) is deactivated	Ch Q (U) P-LockOut	0	
Minimal power factor	Ch Q (U) Cos. φ Min.	0	For a rectangular PQ-diagram
X-coordinate Point 0 (%)	0-0 (x)	94 (96.5 for worst case)	
Y-coordinate Point 0 (%)	0-1 (y)	43	
X-coordinate Point 1 (%)	1-0 (x)	97	
Y-coordinate Point 1 (%)	1-1 (y)	0	
X-coordinate Point 2 (%)	2-0 (x)	105	
Y-coordinate Point 2 (%)	2-1 (y)	0	
X-coordinate Point 3 (%)	3-0 (x)	108 (105.5 for worst case)	
Y-coordinate Point 3 (%)	3-1 (y)	-43	
Parameter adjustment[7]	m/s[8]		

Table 13 – Settings for the Q(U) control – Schneider

Item	Parameter name	Default value for UC1	Comment
React. P. Mode	ReactivePow-er_Mode	Qof U cntrl	
Time constant / Response time (s)	Response Time	10s	Range: 10- 60 s
Active power above which Q(U) is activated	Lock-in Power	0	
Active power below which Q(U) is deactivated	Lock-out Power	0	
Qmax (%)	Upper	43	
Qmin (%)	Lower	-43	
Vmax (V)	Vmax	248,4 (242,65 for worst case)	
Vmin (V)	Vmin	216,2 (221,95 for worst case)	
Upper(V2) (V)	Upper(V2)	241,5	

[6] a preferred time constant of 5 s has been discussed previously.
[7] m: manually / r: remotely / s: with service software
[8] if necessary only

Lower(V1) (V)	Lower(V1)	223,1	
Parameter adjustment[9]	s		

4.1.4 Test procedure

Although this type of control has been introduced in some countries for many years (e.g. since 2008 at MV level in Germany [2] or 2013 at LV level in Austria [3]), well-established dedicated testing procedures are still missing, with the exception of [4].

The three tests foreseen for this type of control (chapters 4.1.4.1, 4.1.4.2 and 4.1.4.3) will be performed for two levels of output power[10].

- 80 % of the nominal apparent power
- 100 % of the nominal apparent power

In the first case, the inverter should be able to fully inject or consume the maximal amount of reactive power (43 % of the apparent power) while in the second case, the inverter is not able to fully inject or consume the maximal amount of reactive power and the injected active power must be reduced not to exceed the maximal apparent power.

For the test cases TC1 and TC2 (chapters 4.1.4.1 and 4.1.4.2), the inverter will be connected directly to the network simulator (see Figure 7) while for test case TC3 (chapter 4.1.4.3), a network impedance will be added to emulate weak network conditions.

4.1.4.1 UC1-TC1: Characterisation of the control accuracy

The purpose of this test is to evaluate the accuracy of the control. This test will be conducted without any additional impedance between network simulator and EUT.

The voltage will be varied via the network simulator between -10 % and + 10 % of the nominal voltage via a stair function. The duration of each stair and the response time are chosen to ensure that the steady-state is reached before the next step. To limit the duration of the tests, the inverter will be parametrized as fast as possible. In total, 20 points are spread along the voltage band (step of 0.5 % of the nominal voltage[11])

4.1.4.1.1 Test signals and operating point

The voltage will follow the test signal shown on Figure 9. On the lower part of this figure, the expected response is shown (without considering the time behaviour).

[9] m: manually / r: remotely / s: with service software
[10] In a few documents [4], [5], a lock in and lock out power are defined to deactivate the Q(U) control at low output power levels. This is however not considered here since it is not systematically used.
[11] This step is close to the steps of 1 V mentioned in [4].

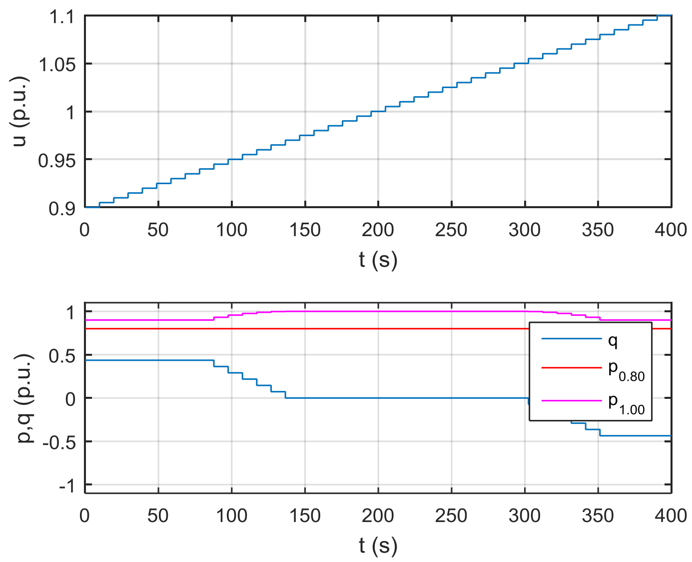

Figure 9 – Test signal for the evaluation of the accuracy of the Q(U)-control[12]
$p_{0.80}$: active power curve for an available PV power from 80 % of the maximal apparent power
$p_{1.00}$: active power curve for an available PV power from 100 % of the maximal apparent power

4.1.4.1.2 Evaluation

The accuracy will be evaluated as the deviation between the expected and the actual reactive power, normalized to the maximal apparent power (equation (1)). As an example, [4], [5] and [6], [7] specify respectively a maximal deviation of 2.5 %, 2 % and 5 % of the maximal apparent power for the reactive power accuracy (not specifically to the control mode Q(U)).

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

4.1.4.2 UC1-TC2: Characterisation of the time behaviour

The purpose of this test is to characterise the time behaviour of the Q(U) control. This test will be conducted without any additional impedance between network simulator and EUT.

The response of the inverter to voltage jumps will be recorded and analysed for the default settings of the Q(U) control mode (Q(U) curve and response time - see Table 12 and Table 13).

4.1.4.2.1 Test signals and operating point

The voltage will be varied step-wise in both directions (over-voltage and under-voltage) at the output of the network simulator between

- the nominal voltage and a voltage in the droop area close to the droop start
- a voltage in the droop area close to the droop start and a voltage in the droop area close to the droop end
- a voltage in the droop area close to the droop end and the nominal voltage

The test signal is shown on Figure 10.

[12] The duration of each step is set to 20 s which allows to reach the steady-state between each step.

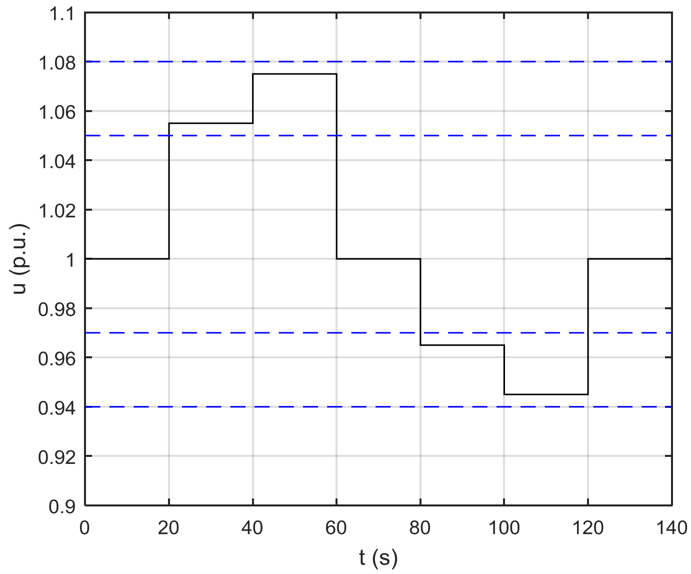

Figure 10 – Test signal for the evaluation of the step response[13]

4.1.4.2.2 Evaluation

The response time will be determined using a tolerance band of ±5 % of the maximal reactive power around the expected value. This value will be compared to the target response time adjusted prior the tests.

[13] The duration of each step is set to 20 s which allows to reach the steady-state between each step.

4.1.4.3 UC1-TC3: Investigation of the stability under worst-case conditions

The purpose of this test is to evaluate the stability of the control under worst-case conditions. This test will be conducted with an additional impedance between network simulator and EUT, adjusted to represent the worst-case conditions (see below).

Since most of the standards do not specify a default Q(U) curve (except [6] and [4]), the stability will be evaluated for a worst-case.

4.1.4.3.1 Definition of the worst-case

The purpose of this test is to evaluate the stability of the control under worst-case conditions. The stability of a Q(U) control has been investigated and presented in a number of papers. In [8], a stability criterion has been established and the authors have come to the conclusion that the stability is mainly influenced by the following factors:

- Maximal reactive power compared to the network impedance or short-circuit power at the point of connection
- Slope of the Q(U) curve
- Response time of the control
- (unwanted) time delay in the control

A brief discussion on these factors and their selection is given below.

1. **Maximal reactive power compared to the network impedance or short-circuit power at the point of connection**

The worst case is given by the maximal ratio between maximal reactive power and maximal expectable network impedance (or minimal expectable short-circuit power).

The open-loop gain of the transfer function determining the stability of one or several inverters operating in Q(U) control mode is given by (2) [8].

$$K_{ol} = \frac{\Delta U_{PV0}}{\Delta U_{droop}} \times \frac{\tan \varphi_{max}}{R/X} \tag{2}$$

Where ΔU_{PV0} is the voltage rise caused by the PV inverter without Q(U) control (depending on the maximal active power and on the network impedance), ΔU_{droop} is the droop area, $\tan \varphi_{max}$ is the maximal $\tan \varphi$ (corresponding to the maximal reactive power in p.u.) and R/X is the ratio between real and imaginary part of the network impedance at the point of connection.

The worst case is therefore obtained for networks in which reactive power control is very effective and leads to a large increase of the hosting capacity. This is obtained for small R/X ratios (overhead lines with a large cross-section). For an overhead line with 70 mm^2 cross-section (70/11_AlFe6), the R/X ratio is 0.401/0.28=1.43. The effective R/X ratio at the connection point might even be smaller, in particular small distribution transformer (e.g. 100 kVA with a short circuit voltage u_k = 6 %). In such cases, the R/X ration might even fall to values close to 1. Under such conditions, the voltage rise caused by the PV infeed can be reduced by a factor of about 2 (easily estimated by (3) [9]) and the hosting capacity can increased by about +100 % (considering , $\tan \varphi_{max}$=0.48 ($\cos \varphi = 0.90$) and R/X=1), which corresponds to the objective of UC1 (significant increase of the hosting capacity).

$$\Delta U_{PV-Q(U)} \approx \Delta U_{PV0} \times \left(1 - \frac{\tan \varphi_{max}}{R/X}\right) \approx 0.5 \times \Delta U_{PV0} \tag{3}$$

Considering that the maximal allowed voltage rise caused by the infeed of LV-connected generator(s) is +3 % (in Germany [10], Austria [11] and Czech Republic) a voltage rise of 6 % (without Q(U) control: ΔU_{PV0}) will be assumed (same assumption as in [8]).

For both inverters to be tested, the reactance to be used for the testing can be computed by (4) with $\Delta U_{PV0} = 6\,\%$ and $U_N = 0.4\,kV$ (and P_N is in MW). The numeric values are provided for both inverters in Table 14.

$$X = R \approx \Delta U_{PV0} \times \frac{U_N^2}{P_N} \tag{4}$$

Table 14 – Reactance to be used for the worst-case stability evaluation

Inverter	Nominal power (kVA)	Reactance (Ω)[14]
Fronius Symo Hybrid 5.0-3-S	5.0	1.9
Schneider Conext RL 3000 E	3.0	0.533[15]

2. Slope of the Q(U) curve

The worst case corresponds to steep Q(U) curves. Out of the four documents covering the Q(U) control in the considered countries, only two specify a default Q(U) curve ([6] in France and [4] in Italy). [12] (still draft) mentions as maximal gradient defined by Q_{max}/P_{max}=48 % and a droop area corresponding to 2 % of the nominal voltage. And [13] refers to the maximal adjustable slope declared by the manufacturer to define a set of three Q(U) curves: “most aggressive”, “average” and “least aggressive”. An overview is given in Table 15.

Table 15 – Default and maximal Q(U) droop factors in selected countries using a Q(U) control

Country	Reference	Default / maximal droop
DE	[12]	Default not specified Maximal: [0-Qmax] for 2 % of the nominal voltage
FR	[6]	“Universal” settings: [0-Qmax] for 1.25 % of the nominal voltage
IT	[4]	Default: [0-Qmax] for 2 % of the nominal voltage Maximal not specified
US	[13]	Default and maximal not specified (the maximal adjustable slope (declared by the manufacturer) should be used for testing)

In order to test the equipment used in UC1, the settings will be tuned to obtain the steepest Q(U), which might be different for each manufacturer. The width of the droop area should not be larger than 1 % of the nominal voltage for this particular test (without dead-band) – being even more severe than the previous cited documents.

3. Response time of the control

[14] Due to the condition of the testing environment, these values cannot be set exactly. Therefore the impedance will be set to the value as close as possible to the proposed value.

[15] The reactance is here the sum of the reactance of the phase and neutral conductors

The worst-case in terms of response time corresponds to short values (fast response). For this reason, the response time will be set to the lowest possible value (which should not be greater than 3 s which is the fastest response time mentioned in the considered documents).

Table 16 – Default and minimal response time in selected countries using a Q(U) control

Country	Reference	Default / minimal response time
DE	[12]	The inverter should respond with a first order-like response Response time 3×τ should be adjustable between 6 s and 60 s (default value of 3×τ=10 s)
FR	[6]	Response time of 30 s
IT	[4]	Maximal response time of 10 s (defined actually for the provision of a given reactive power)
US	[13]	No default / minimal response time.
EU	[5]	The inverter should respond with a first order-like response Response time 3×τ should be adjustable between 3 s and 60 s

4. (unwanted) time delay in the control

The worst-case in terms of (unwanted) time delay corresponds to large values (large delay). In general, this delay depends on the very specific way that the control is implemented (e.g. delay introduced by the voltage measurement) is unknown. Only one document [6] specifies how the voltage should be measured: with a 10 s moving average, which can be translated into a delay.

This delay (or the way of implementing the voltage measurement) is usually not adjustable.

4.1.4.3.2 Test signals and operating point

The test signal to be used is shown on Figure 11. However, the signal will be adapted to the new values for the Q(U) curve which are set in the worst case scenario.

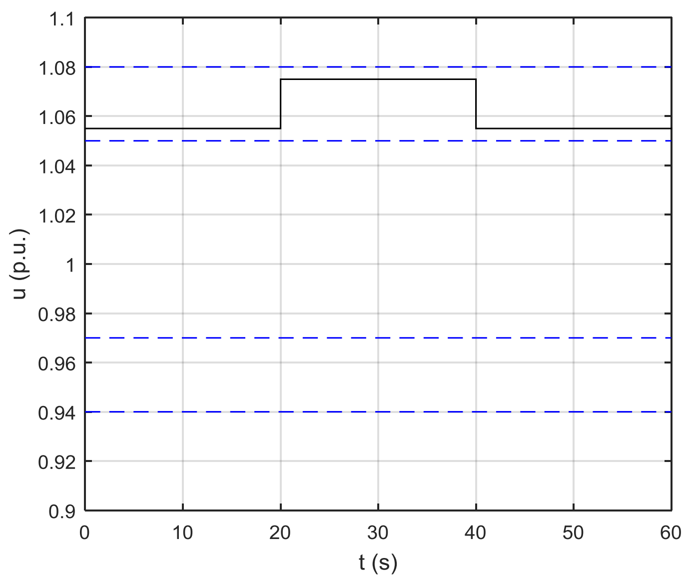

Figure 11 – Test signal for the evaluation of the stability under worst-case conditions

4.1.4.3.3 Evaluation

The response of the Q(U) control to the voltage step will be analysed. If (damped) oscillations are visible (underdamped systems), the damping ratio will be evaluated using the logarithmic decrement according to (5) and (6), where ζ is the damping ratio, δ the logarithmic decrement and q_1 and q_2 two successive amplitudes (valid only for underdamped systems only).

$$\zeta = \frac{\delta}{2\pi} \tag{5}$$

$$\delta = ln\left(\frac{q_1}{q_2}\right) \tag{6}$$

4.2 UC1: active power control - P(U)

4.2.1 Control function to be tested

The active power control to be tested under UC1 is a local control of the voltage through a voltage-dependant active power reduction (P(U)). The default P(U)-characteristic is shown on Figure 12. As the function Q(U) will remain activated during the tests, the active power will be lower than P_{max}. The tests will be conducted with the maximal possible value for the active power.

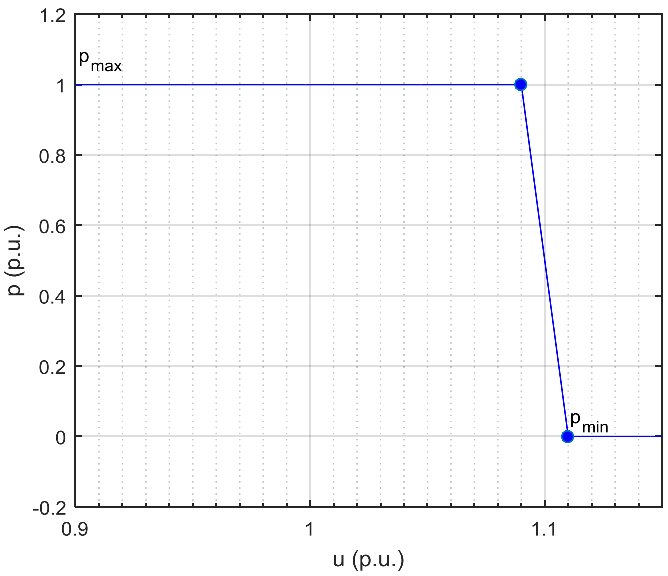

Figure 12 – Default P(U)-curve for ČEZ Distribuce[16]

4.2.2 Purpose

The purpose of these tests is to verify the proper functioning of the reactive power control mode P(U) (also in combination with the Q(U) control) and to characterise the control in terms of:

- Accuracy
- Time behaviour
- Stability under worst-case conditions

[16] Parameter naming according to [1]

4.2.3 Activated function(s) and test conditions

The function Q(U) will be activated and parametrised with the settings mentioned in the test cases (chapters 4.1.4.1 to 4.1.4.3). The tests will only be done at P_{max}; this power will however be reduced due to the activated Q(U) control.

The overview of the available parameters is provided in **Table 17** and Table 18 for both manufacturers.

Table 17 – Settings for the Q(U) control - Fronius

Item	Parameter name	Default value for UC1	Comment
Voltage Dependent Power Reduction Mode	GVDPR On/Off	On	
Change Time Constant (s)	Change Time Constant	5s (0.01s for worst case)	Range: 0.01- 600 s
Enable Limit (V)	Enable Limit	250.7	
Derating Gradient (%/V)	Derating Gradient	21.74% (100% for worst case)	
Parameter adjustment[17]	m/s[18]		

Table 18 – Settings for the P(U) control – Schneider

Voltage values for control	
U/U_n [V]	P/P_{max} [%]
115	100
230	100
250,7	100
251,85	75
253	50
254,15	25
255,3	0

Table 19 – Setting fort he P(U) control – Schneider (2)

Item	Parameter name	Default value for UC1	Comment
Active Power PM Mode	Active Power PM Mode	Rated	
Ramp Up Power	Ramp Up Power (%)	will be varied	Range: 10%- 6000% 100% means 60s 200% means 30s
PM	PM (%)	will be varied	Range: 0% - 100%

4.2.4 Test procedure

This type of control is foreseen in only a very limited number of countries (e.g. since 2016 in Austria [11] and 2016 in Italy [4]) and dedicated testing procedures are fully missing (some indications are given in [4]).

The three tests foreseen for this type of control (chapters 4.1.4.1, 4.1.4.2 and 4.1.4.3) will be performed at full output power.

[17] m: manually / r: remotely / s: with service software
[18] if necessary only

For the test cases TC1 and TC2 (chapters 4.1.4.1 and 4.1.4.2), the inverter will be connected directly to the network simulator (see Figure 7) while for test case TC3 (chapter 4.1.4.3), a network impedance will be added to emulate weak network conditions.

4.2.4.1 UC1-TC1: Characterisation of the control accuracy

The purpose of this test is to evaluate the accuracy of the control. This test will be conducted without any additional impedance between network simulator and EUT.

The voltage will be varied via the network simulator between 1.04 p.u. and 1.13 p.u. via a stair function in steps of 0.2%. The duration of each stair and the response time are chosen to ensure that the steady-state is reached before the next step. To limit the duration of the tests, the inverter will be parametrized as fast as possible.

4.2.4.1.1 Test signals and operating point

The voltage will be varied with the network simulator in 0.2 % steps between 1.04 p.u. and 1.13 p.u. and the response of the inverter will be recorded (active and reactive power).

4.2.4.1.2 Evaluation

The accuracy will be evaluated as the deviation between the expected and the actual active power, normalized to the maximal apparent power (equation (7)). As an example, [4], [5] and [6], [7] specify respectively a maximal deviation of 2.5 %, 2 % and 5 % of the maximal apparent power for the reactive power accuracy (not specifically to the control mode Q(U)).

$$\Delta P = \frac{P_{act} - P_{exp}}{P_{max}} \tag{7}$$

4.2.4.2 UC1-TC2: Characterisation of the time behaviour

The purpose of this test is to characterise the time behaviour of the P(U) control. This test will be conducted without any additional impedance between network simulator and EUT.

The response of the inverter to voltage jumps will be recorded and analysed for the default settings of the P(U) control mode (P(U) curve and response time - see **Table 17** and Table 18).

4.2.4.2.1 Test signals and operating point

The voltage will be varied step-wise at the output of the network simulator (see Figure 13).

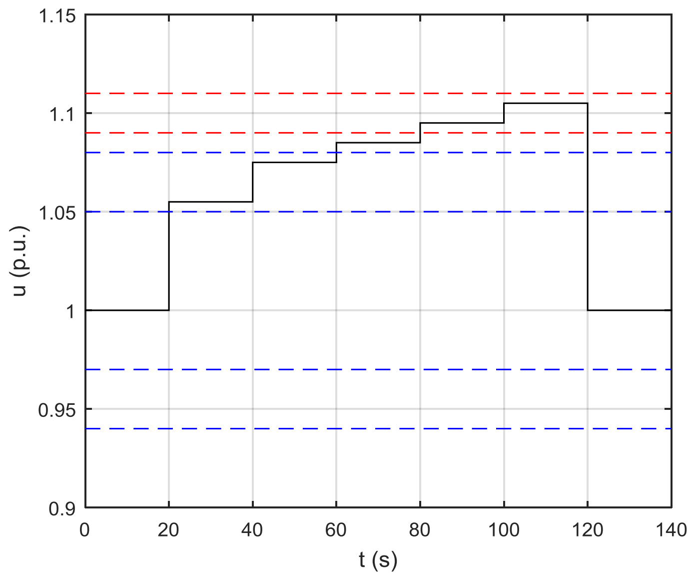

Figure 13 – Test signal for the evaluation of the step response[19]

4.2.4.2.2 Evaluation

The response time will be determined using a tolerance band of ±5 % of the nominal apparent power around the expected value. This value will be compared to the target response time adjusted prior the tests.

4.2.4.3 UC1-TC3: Investigation of the stability under worst-case conditions

The purpose of this test is to evaluate the stability of the control under worst-case conditions. This test will be conducted with an additional impedance between network simulator and EUT, adjusted to represent the worst-case conditions (see below).

Since most of the standards do not specify a default P(U) curve (except [11]), the stability will be evaluated for a worst-case.

4.2.4.3.1 Definition of the worst-case

The purpose of this test is to evaluate the stability of the control under worst-case conditions. The stability of a P(U) control can be handled in a similar way to the stability of the Q(U) control (see chapter 4.1.4.3). The stability of the control is mainly influenced by the following factors:

- Maximal active power compared to the network impedance or short-circuit power at the point of connection
- Slope of the P(U) curve
- Response time of the control
- (unwanted) time delay in the control

A brief discussion on these factors and their selection is given below.

5. **Maximal reactive power compared to the network impedance or short-circuit power at the point of connection**

Since the main purpose of the P(U) control is to avoid the tripping (and the possible disconnection/reconnection cycles) of the over-voltage protection by smoothly reducing the output active power. The resistances to be used will therefore be the same as the reactances given in Table 14.

6. **Slope of the P(U) curve**

The worst case corresponds to steep P(U) curves. While the default P(U) curve (Figure 12) has a droop area over 2 %, the settings will be tuned to obtain the steepest P(U), which might be different for each manufacturer. The width of the droop area should not be larger than 1 % of the nominal voltage for this particular test (without dead-band).

7. **Response time of the control**

The worst-case in terms of response time corresponds to short values (fast response). As for the P(U) control, the response time will be set to the lowest possible value (which should not be greater than 3 s.

8. **(unwanted) time delay in the control**

This delay (or the way of implementing the voltage measurement) is usually not adjustable.

[19] The duration of each step is set to 20 s which allows to reach the steady-state between each step.

4.2.4.3.2 Test signals and operating point

The test signal to be used is shown on Figure 14. However, the signal will be adapted to the new values for the Q(U) and P(U) curve which are set in the worst case scenario.

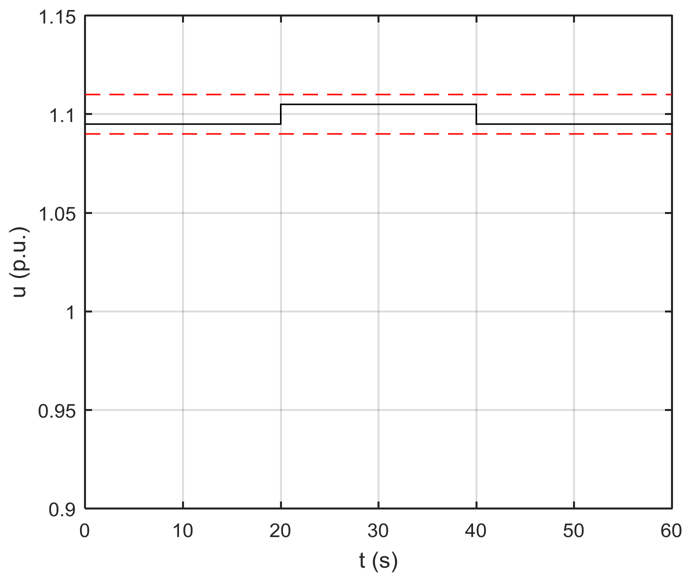

Figure 14 – Test signal for the evaluation of the stability under worst-case conditions

4.2.4.3.3 Evaluation

The response of the P(U) control to the voltage step will be analysed. If (damped) oscillations are visible (underdamped systems), the damping ratio will be evaluated using the logarithmic decrement according to (5) and (6), where ζ is the damping ratio, δ the logarithmic decrement and q_1 and q_2 two successive amplitudes (valid only for underdamped systems only).

4.3 UC3: Smart EV charging

4.3.1 Control function to be tested

The function to be tested under UC3 is a reduction of the charging power to 50 % of e-vehicles in case of network constraints. This behaviour can be triggered by:

a) Under-frequency (function implemented locally – default threshold: 49.9 Hz). A reset/restart after f > 49.9Hz for 5 minutes is included according to CEZ Distribuce requirements.
b) Under-voltage (function implemented locally – default threshold: 95 % of the nominal voltage = 380 V, reset when the voltage has remained for at least 5 minutes above the threshold)
c) Request from the DSO (function requiring a communication interface (ripple control for the demonstration))

For all these functions, the proper functioning of the system will be verified by analysing the PWM signal at the output of the charging station (going into the charging emulator) and by measuring the charging power (from the emulated e-vehicle).

4.3.2 Purpose

The purpose of these tests is to verify the proper functioning of the charging restriction in both local and remote mode.

4.3.3 Activated function(s) and test conditions

The thresholds to be used for the (local) functions a) and b) in chapter 4.3.1 are:

- 49.9 Hz for the under-frequency threshold, with a cancellation of the reduction after 5 minutes with a frequency above this threshold
- 380 V for the under-voltage threshold (phase to phase voltage), with a cancellation of the reduction after 5 minutes with a voltage above this threshold.

For both cases, symmetrical conditions will be assumed.

For the remote control, the ripple control receiver will be emulated (with relays) and the rest of the system will be tested.

The settings will be adjusted via a webbrowser (Siemens) or via a dedicated software.

4.3.4 Test procedure

4.3.4.1 Characterisation of the accuracy for the reduction of the charging power in case of under-frequency or under-voltage

The purpose of this test is to evaluate the accuracy of the control. This test will be conducted without any additional impedance between network simulator and EUT.

The value activating the reduction (activation value) will be evaluated by reducing the frequency or the voltage slowly via the network simulator from nominal values (50 Hz and 400 V respectively) in steps of 10 mHz or 0.5 V) and the steps will be slow enough to ensure that the control system has time to react on time (e.g. 5 s per step).

4.3.4.1.1 Test signals and operating point

The charging station will be operated at full power under normal conditions and a test signal will be applied to the frequency or the voltage of the AC network simulator.

The frequency or voltage will follow the test signal shown on Figure 15 and Figure 16 respectively. On the lower part of the figures, the expected response is shown (without considering the time behaviour).

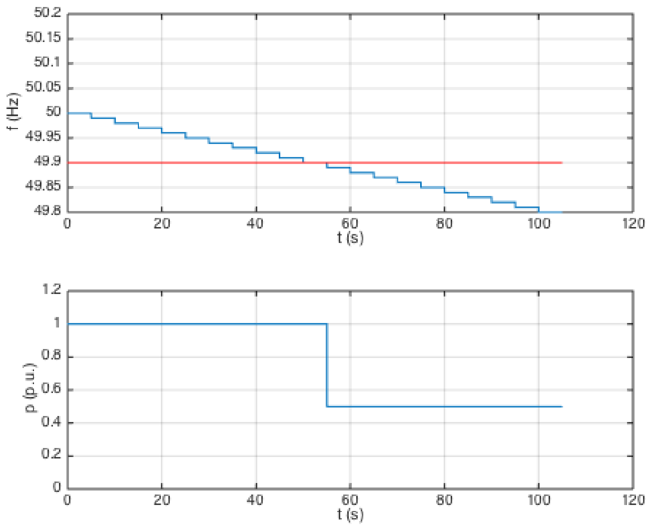

Figure 15 – Test signal for the evaluation of the accuracy of the reduction of the charging power in case of under-frequency

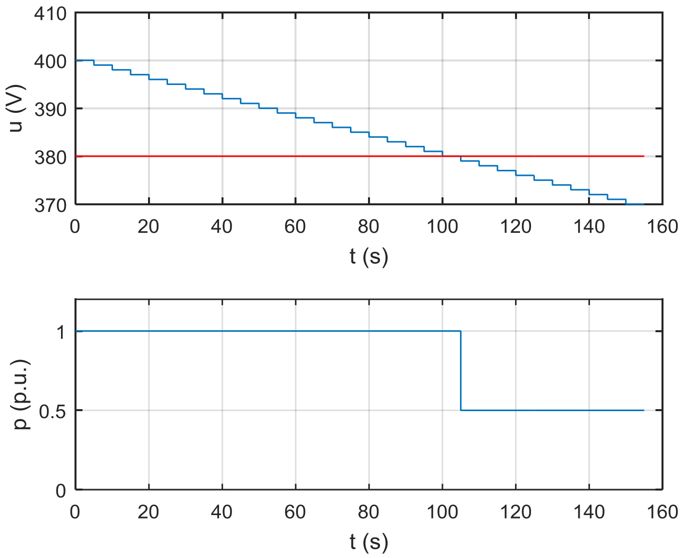

Figure 16 – Test signal for the evaluation of the accuracy of the reduction of the charging power in case of under-voltage

The accuracy of the threshold of reconnection will be evaluated by operating the unit with a frequency or voltage just below or just above (0.5 V or 10 mHz) of the activation value determined previously during at least 5 min, following the approach specified in [14].

4.3.4.1.2 Evaluation

The accuracy will be evaluated as the deviation between the activation setting and the actual activation value power, normalized to the nominal value (equation (8)). As an example, [15] and [14] specify a maximal deviation of 1 % for the voltage and 0.1 % for the frequency.

$$\Delta V = \frac{V_{act} - V_{set}}{V_{nom}} \tag{8}$$

The accuracy of the power control will be evaluated by specifying the difference between the actual power level and the target power after reduction (50 %), given in % of the nominal power

4.3.4.2 Functional validation of the remote limitation of the charging power

The purpose of this test is to verify the proper operation of the remote limitation of the charging power via ripple control.

4.3.4.2.1 Test signals and operating point

The charging station will be operated at full power under normal conditions and a test signal will be applied to input of the RTU which is in reality directly connected to the ripple control receiver (see Figure 2 and Figure 3).

4.3.4.2.2 Evaluation

The accuracy of the power control will be evaluated by specifying the difference between the actual power level and the target power after reduction (50 %), given in % of the nominal power.

4.4 UC4: Smart energy storage

4.4.1 Control function to be tested

The function to be tested under UC4 include local and remote control of the battery system (see chapter 2.4.1).

4.4.2 Purpose

The purpose of these tests is to verify the proper functioning of the charging/discharging behaviour in both local and remote mode.

4.4.3 Activated function(s) and test conditions

The thresholds to be used for the (local) in chapter 2.4.1 are:

- Permanent limitation of the power surplus injected into the network to 50 % of the nominal power of the PV generation.
- Under-frequency stage 1 (function implemented locally – default threshold: 49.9 Hz): stop the charging of the battery. The charging can restart if the frequency is above 49.9 Hz for at least 5 minutes
- Under-frequency stage 2 (function implemented locally – default threshold: 49.85 Hz): discharge of the battery at 100 % of nominal power until the min. allowed SoC (70 %) of the battery is reached or the frequency exceeds 50.1 Hz
- Under-voltage stage 1 (function implemented locally – default threshold: 95 % of the nominal voltage = 380 V): stop the charging of the battery. The charging can restart if the frequency is above 380 V for at least 5 minutes
- Under-voltage stage 2 (function implemented locally – default threshold: 92.5 % of the nominal voltage = 370 V): discharge of the battery at 100 % of nominal power until the min. allowed SoC (70 %) of the battery is reached or the voltage exceeds 420 V
- Remote functions: As in UC3, a remote control is included: the PV + storage system must allow the discharge at 100 % of the nominal power of battery system after activation via ripple control from DSO until the min. allowed SoC (70 %) of the battery is reached.

For all cases, symmetrical conditions will be assumed. Additional tests could be performed with unsymmetrical conditions.

For the remote control, the ripple control receiver will be emulated (with relays) and the rest of the system will be tested.

Information to be provided by Schneider and Fronius on how to adjust the settings (if necessary).

4.4.4 Test procedure

4.4.4.1 Characterisation of the accuracy for the under-frequency control (stage 1 and stage 2)

The test will follow the approach specified for UC3 (see chapter 4.3.4.1).

4.4.4.2 Characterisation of the accuracy for the under-voltage control (stage 1 and stage 2)

The test will follow the approach specified for UC3 (see chapter 4.3.4.1).

4.4.4.3 Functional validation of the remote control of the storage system

The purpose of this test is to verify the proper operation of the remote limitation of the storage system via ripple control.

4.4.4.3.1 Test signals and operating point

The storage system will be operated in idle state, as well as charging and discharging mode at full power, and a test signal will be applied to input of the RTU which is in reality directly connected to the ripple control receiver.

4.4.4.3.2 Evaluation

The accuracy of the power control will be evaluated by specifying the difference between the actual power level and the target power given in % of the nominal power.

5 Analysis and documentation of the results

The results will be analysed (post-processing) in details during and after the lab tests and summarised in a dedicated internal report, which can be used for deliverable D6.1.

Literature

[1] IEC, ‘IEC TR 61850-90-7:2013 Communication networks and systems for power utility automation - Part 90-7: Object models for power converters in distributed energy resources (DER) systems’. 21-Feb-2013.

[2] ‘Generating Plants Connected to the Medium-Voltage Network’, Jun. 2008.

[3] E-CONTROL, ‘Technische und organisatorische Regeln für Betreiber und Benutzer von Netzen. Teil D: Besondere technische Regeln. Hauptabschnitt D4: Parallelbetrieb von Erzeugungsanlagen mit Verteilernetzen’. 2013.

[4] CEI, ‘CEI 0-21 - Reference technical rules for the connection of active and passive users to the LV electrical Utilities’. Jul-2016.

[5] CENELEC, ‘CLC/TS 50549-1:2014-10 Requirements for the connection of a generating plant to a distribution system - Part 1: Connection to a LV distribution system and above 16A’. Oct-2014.

[6] ENEDIS, ‘Principe et conditions de mise en oeuvre d’une régulation locale de puissance réactive pour les Installations de Production raccordées au Réseau Public de Distribution HTA’. 01-Mar-2017.

[7] CENELEC, ‘EN 50438:2013 Requirements for micro-generating plants to be connected in parallel with public low-voltage distribution networks’. 2013.

[8] F. Andren, B. Bletterie, S. Kadam, P. Kotsampopoulos, and C. Bucher, ‘On the Stability of local Voltage Control in Distribution Networks with a High Penetration of Inverter-Based Generation’, *IEEE Trans. Ind. Electron.*, pp. 1–1, 2014.

[9] B. Bletterie, A. Gorsek, A. Abart, and M. Heidl, ‘Understanding the effects of unsymmetrical infeed on the voltage rise for the design of suitable voltage control algorithms with PV inverters’, in *Proc. 26th European Photovoltaic Solar Energy Conference and Exhibition*, Hamburg, 2011, pp. 4469–4478.

[10] VDE-FNN, ‘VDE-AR-N 4105:2011-08 Power generation systems connected to the low-voltage distribution network’. Aug-2011.

[11] E-CONTROL, ‘Technische und organisatorische Regeln für Betreiber und Benutzer von Netzen. Teil D: Besondere technische Regeln. Hauptabschnitt D4: Parallelbetrieb von Erzeugungsanlagen mit Verteilernetzen’. 22-Feb-2016.

[12] FNN - Forum Netztechnik/Netzbetrieb im VDE, ‘VDE-AR-N 4110 Technische Regeln für den Anschluss von Kundenanlagen an das Mittelspannungsnetz und deren Betrieb (TAR Mittelspannung)’. Mar-2017.

[13] UL, ‘UL 1741 - Standard for safety - Inverters, converters, controllers and Interconnection System Quipment for Use With Distributed Energy Resources’. 07-Sep-2016.

[14] VDE V 0124-100, ‘Grid integration of generator plants – Low-voltage – Test requirements for generator units to be connected to and operated in parallel with low-voltage distribution networks’. Jul-2012.

[15] ‘VDE-AR-N 4105:2011-08 - Power generation systems connected to the low-voltage distribution network - Technical minimum requirements for the connection to and parallel operation with low-voltage distribution networks’. .

Annex 6.5

Project InterFlex
WP6 CZ Demo

Lab test results

UC1: Increase the DER hosting capacity of LV distribution networks by combining smart PV inverter functions (demonstration of Q(U) and P(U))

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Revison	Date	Author	Change
0.5	7.12.17	Stefanie Kaser	First version with test results
1.0	11.12.17	Stefanie Kaser	Update of the chapters
2.0	13.12.17	Stefanie Kaser, Friederich Kupzog	Update with comments

Content

1 Documents

The tests were conducted according to the “Test procedure for the lab tests” (chapter 4.1. and 4.2 for Use Case 1) for the project InterFlex CZ Demo. The test procedures are described in detail in this document. In this report, the test procedures are only summarized.

2 Testing infrastructure

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

3 Equipment under test

Table 1 – EUT for UC1

	Fronius	**Schneider**
Model	- Symo Hybrid 5.0-3-S	- Conext RL 3000 E - External hardware for P(U)
AC nominal output (kW)	5.0	3.0
AC nominal apparent power (kVA)	5.0	3.0
Grid connection	3~NPE 400 V	1~NPE 230 V
Power factor range	0.85	0.80

3.1 Settings – Q(U)

The overview of the available parameters for the Q(U) function is provided in Table 2 and Table 3 for both manufacturers.

Table 2 – Settings for the Q(U) control - Fronius

Item	**Parameter name**	**Default value for UC1**	**Comment**
Reactive Power Mode	Q/U	Q/U	
Time constant (s)	Ch Q (U) TimeC.	5 s (0.01 s for worst case)	Range: 0.01- 60 s
Active power above which Q(U) is activated	Ch Q (U) P-LockI	0	
Active power below which Q(U) is deactivated	Ch Q (U) P-LockOut	0	
Minimal power factor	Ch Q (U) Cos. φ Min.	0	For a rectangular PQ-diagram
X-coordinate Point 0 (%)	0-0 (x)	94 (96.5 for worst case)	
Y-coordinate Point 0 (%)	0-1 (y)	43	
X-coordinate Point 1 (%)	1-0 (x)	97	
Y-coordinate Point 1 (%)	1-1 (y)	0	
X-coordinate Point 2 (%)	2-0 (x)	105	

Y-coordinate Point 2 (%)	2-1 (y)	0	
X-coordinate Point 3 (%)	3-0 (x)	108 (105.5 for worst case)	
Y-coordinate Point 3 (%)	3-1 (y)	-43	
Parameter adjustment[1]	m/s[2]		

Table 3 – Settings for the Q(U) control – Schneider

Item	Parameter name	Default value for UC1	Comment
React. P. Mode	Reactive Power Mode	Q of U cntrl	
Time constant / Response time (s)	Response Time	10s	Range: 10- 60 s
Active power above which Q(U) is activated	Lock-in Power	0	
Active power below which Q(U) is deactivated	Lock-out Power	0	
Qmax (%)	Upper	44	
Qmin (%)	Lower	-44	
Vmax (V)	Vmax	248.4 (242.65 for worst case)	
Vmin (V)	Vmin	216.2 (221.95 for worst case)	
Upper(V2) (V)	Upper(V2)	241.5	
Lower(V1) (V)	Lower(V1)	223.1	
Parameter adjustment[3]	s		

3.2 Settings – P(U)

The overview of the available parameters for the P(U) function is provided in Table 4 to Table 6 for both manufacturers.

Table 4 – Settings for the P(U) control - Fronius

Item	Parameter name	Default value for UC1	Comment
Voltage Dependent Power Reduction Mode	GVDPR On/Off	On	
Change Time Constant (s)	Change Time Constant	5 s (0.01 s for worst case)	Range: 0.01- 600 s
Enable Limit (V)	Enable Limit	250.7	
Derating Gradient (%/V)	Derating Gradient	21.74 % (100 % for worst case)	
Parameter adjustment[4]	m/s[5]		

[1] m: manually / r: remotely / s: with service software
[2] if necessary only
[3] m: manually / r: remotely / s: with service software
[4] m: manually / r: remotely / s: with service software
[5] if necessary only

Table 5 – Settings for the P(U) control – Schneider

Voltage values for control	
U/Un [V]	P/Pmax [%]
115	100
230	100
250.7	100
251.85	75
253	50
254.15	25
255.3	0

Table 6 – Setting fort he P(U) control – Schneider (2)

Item	**Parameter name**	**Default value for UC1**	**Comment**
Active Power PM Mode	Active Power PM Mode	Rated	
Ramp Up Power	Ramp Up Power (%)	will be varied	Range: 10%- 6000% 100% means 60 s 200% means 30 s
PM	PM (%)	will be varied	Range: 0% - 100%

4 Results

4.1 Reactive Power Control - Q(U)

The three tests foreseen for this type of control were be performed for two levels of output power.

- 80 % of the nominal apparent power
- 100 % of the nominal apparent power

For the test cases 1 and 2, the inverter is connected directly to the network simulator while for test case 3, a network impedance was added to emulate weak network conditions. The tests were conducted accordingly to the “Test procedure for the lab tests” (chapter 4.1) for the Project InterFlex CZ Demo.

4.1.1 Test Case 1

The voltage was varied via the network simulator between -10 % and + 10 % of the nominal voltage via a stair function (step height of 0.5 % U_n). The duration of each stair was chosen to be 40 s so that the system reaches a steady state before the next step. To limit the duration of the tests, the inverter will be parametrized as fast as possible.

The accuracy was evaluated as the deviation between the expected and the actual reactive power, normalized to the maximal apparent power (equation (1)).

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

4.1.1.1 Fronius Symo Hybrid 5.0-3-S

4.1.1.1.1 Output power at 100 % of nominal apparent power

The detailed results of the test are listed in Table 7. The voltage given in the table is the average of the phases L1-L3 as the inverter is connected to all three phases. All values in the table represent a 5 s-average during the steady state. It can be seen that the measured reactive power (Q_{act}) does not reduce completely to 0 but stays at a value of approximately 17 VAr at minimum. The Q(U) function of the inverter shows small deviations from the expected curve (maximum of 4.7 % deviation). As the voltage of the grid simulator is not measured directly at the inverter, some minor changes of the voltage from the measurement point to the internal measurement of the inverter are possible. However, this will not account for the full 4.7 %.

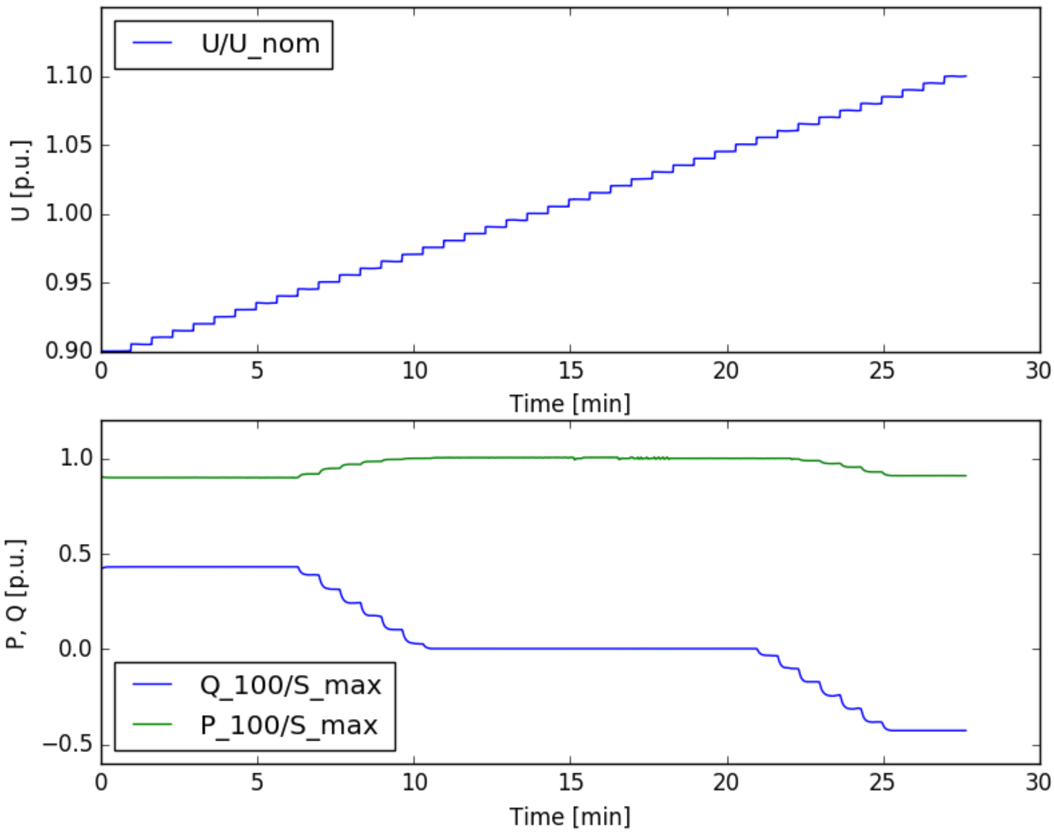
Table 7 – Results for Test Case 1 with Fronius Symo Hybrid at output power of 100 % nominal apparent power

$U[V]$	$Q_{act}[VAr]$	$Q_{exp}[VAr]$	$P_{act}[W]$	$\Delta Q = \frac{Q_{act} - Q_{exp}}{S_{max}}$
207.05	2158.2	2150.0	4493.5	0.002
208.14	2158.4	2150.0	4493.7	0.002
209.36	2158.5	2150.0	4494.2	0.002
210.43	2158.4	2150.0	4494.2	0.002
211.59	2158.1	2150.0	4494.4	0.002
212.80	2158.2	2150.0	4494.0	0.002
213.96	2158.4	2150.0	4495.9	0.002
215.08	2158.1	2150.0	4493.9	0.002
216.23	2158.1	2140.8	4490.3	0.003
217.38	1949.3	1781.7	4589.4	0.034
218.59	1571.0	1404.1	4735.5	0.033
219.75	1214.3	1045.0	4840.9	0.034
220.88	875.0	692.5	4915.9	0.037
222.00	514.6	343.4	4970.2	0.034
223.22	141.8	0.0	4997.1	0.028
224.37	17.3	0.0	5015.5	0.003
225.50	17.2	0.0	5013.4	0.003
226.68	17.2	0.0	5016.4	0.003
227.75	17.1	0.0	5017.5	0.003
228.89	17.0	0.0	5016.5	0.003
230.04	17.0	0.0	5018.0	0.003
231.19	17.1	0.0	5019.7	0.003
232.39	17.3	0.0	5018.3	0.003
233.49	17.3	0.0	5021.2	0.003
234.69	16.6	0.0	4996.0	0.003

235.86	16.8	0.0	4992.1	0.003
236.95	16.6	0.0	4989.1	0.003
238.09	17.0	0.0	4997.6	0.003
239.23	17.2	0.0	4997.8	0.003
240.41	17.1	0.0	4997.1	0.003
241.59	17.1	-27.4	4997.5	0.009
242.76	-165.9	-393.7	4997.7	0.046
243.88	-504.9	-742.4	4983.9	0.047
244.96	-850.3	-1078.0	4936.8	0.046
246.11	-1209.6	-1437.6	4861.7	0.046
247.22	-1547.0	-1783.6	4769.6	0.047
248.37	-1898.5	-2140.3	4645.1	0.048
249.53	-2126.4	-2150.0	4543.9	0.005
250.65	-2126.5	-2150.0	4544.4	0.005
251.79	-2126.4	-2150.0	4544.2	0.005
252.94	-2126.3	-2150.0	4544.5	0.005

The recording of the measurement can be seen in Figure 1. In the areas of maximum reactive power (+/-43 % of nominal apparent power) it can be seen that the active power has to be reduced (to approximately 4494 W) to not exceed the maximum apparent power.

Figure 1 – Measurement of Test Case 1 with Fronius Symo Hybrid at output power of 100 % nominal apparent power



4.1.1.1.2 Testing at 80 % of nominal apparent power

The detailed results of the test are listed in Table 8. The voltage given in the table is the average of the phases L1-L3 as the inverter is connected to all three phases. All values in the table represent a 5 s-average during the steady state. It can be seen that the measured reactive power (Q_{act}) does not reduce completely to 0 but stays at a value of approximately 12 VAr at minimum. The Q(U) function of the inverter shows small deviations from the expected curve (maximum of 5.1 % deviation). As the voltage of the grid simulator is not measured directly at the inverter, some minor changes of the voltage from the measurement point to the internal measurement of the inverter are possible. However, this will not account for the full 5.1 %.

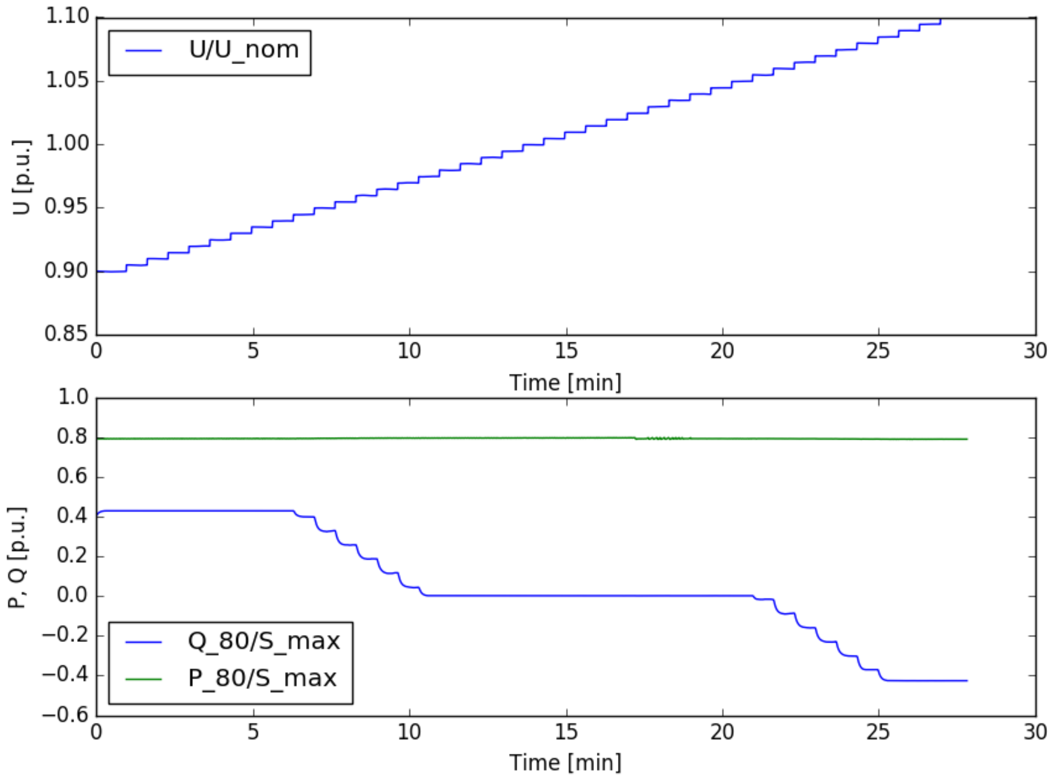
Table 8 – Results for Test Case 1 with Fronius Symo Hybrid at output power of 80 % nominal apparent power

$U[V]$	$Q_{act}[VAr]$	$Q_{exp}[VAr]$	$P_{act}[W]$	$\Delta Q = \frac{Q_{act} - Q_{exp}}{S_{max}}$
206.91	2154.2	2150.0	3972.0	0.001
208.05	2154.4	2150.0	3974.0	0.001
209.21	2154.1	2150.0	3974.5	0.001

210.32	2154.1	2150.0	3974.0	0.001
211.54	2154.2	2150.0	3975.2	0.001
212.65	2154.2	2150.0	3976.0	0.001
213.85	2154.2	2150.0	3975.7	0.001
214.93	2154.0	2150.0	3977.1	0.001
216.09	2154.4	2150.0	3975.1	0.001
217.26	2001.1	1819.8	3977.6	0.036
218.40	1644.5	1466.0	3981.2	0.036
219.51	1294.7	1118.9	3985.3	0.035
220.65	945.0	762.9	3987.1	0.036
221.81	585.6	401.9	3988.3	0.037
223.01	218.5	28.5	3987.5	0.038
224.17	12.5	0.0	3989.9	0.003
225.26	12.5	0.0	3990.8	0.003
226.40	12.3	0.0	3991.2	0.002
227.58	12.3	0.0	3990.9	0.002
228.74	12.0	0.0	3991.7	0.002
229.87	12.6	0.0	3992.5	0.003
230.99	12.1	0.0	3991.5	0.002
232.14	12.5	0.0	3992.5	0.003
233.29	12.3	0.0	3994.6	0.002
234.44	12.1	0.0	3994.8	0.002
235.59	11.7	0.0	3972.5	0.002
236.82	12.1	0.0	3977.5	0.002
237.93	12.3	0.0	3974.4	0.002
239.07	12.2	0.0	3974.2	0.002
240.20	12.4	0.0	3973.9	0.002
241.42	12.4	0.0	3973.8	0.002
242.51	-74.5	-314.7	3974.4	0.048
243.65	-435.0	-671.4	3973.1	0.047
244.86	-795.8	-1045.6	3971.2	0.050
245.98	-1154.4	-1395.4	3969.7	0.048
247.15	-1511.4	-1759.5	3967.0	0.050
248.25	-1850.3	-2103.1	3963.5	0.051
249.44	-2129.5	-2150.0	3961.5	0.004
250.57	-2129.6	-2150.0	3961.7	0.004
251.76	-2129.6	-2150.0	3961.7	0.004
252.82	-2129.6	-2150.0	3961.4	0.004

The recording of the measurement can be seen in Figure 2. In contrast to the measurement at an output power of 100 % of the nominal apparent power, this time the active power does not have to be reduced by the inverter but stays constantly at 80 % of the nominal apparent power.

Figure 2 - Measurement of Test Case 1 with Fronius Symo Hybrid at output power of 80 % nominal apparent power



4.1.1.2 Schneider Context RL 3000 E

4.1.1.2.1 Testing at 100 % of nominal apparent power

The detailed results of the test are listed in Table 9. The voltage given in the table only represents the value of phase L1 as the inverter is connected to this single phase. All values in the table represent a 5 s-average during the steady state. It can be seen that the measured reactive power (Q_{act}) does not reduce completely to 0 but stays between values from approximately -8 VAr to 5 VAr at minimum. The Q(U) function of the inverter shows small deviations from the expected curve (maximum of 6.9 % deviation). As the voltage of the grid simulator is not measured directly at the inverter, some minor changes of the voltage from the measurement point to the internal measurement of the inverter are possible. However, this will not account for the full 6.9 %.

The Q(U) function was implemented in a way that reactive power was released in the wrong direction by the manufacturer during the Test Cases 1 and 2 (reactive power in the expected amount but with the wrong sign). Therefore, the signs of the expected values are also opposite to the signs of the expected values of the tests with the Fronius inverter (cf. chapter

4.1.1.1). The Q(U) function of the inverter was corrected by the manufacturer during Test Case 3.

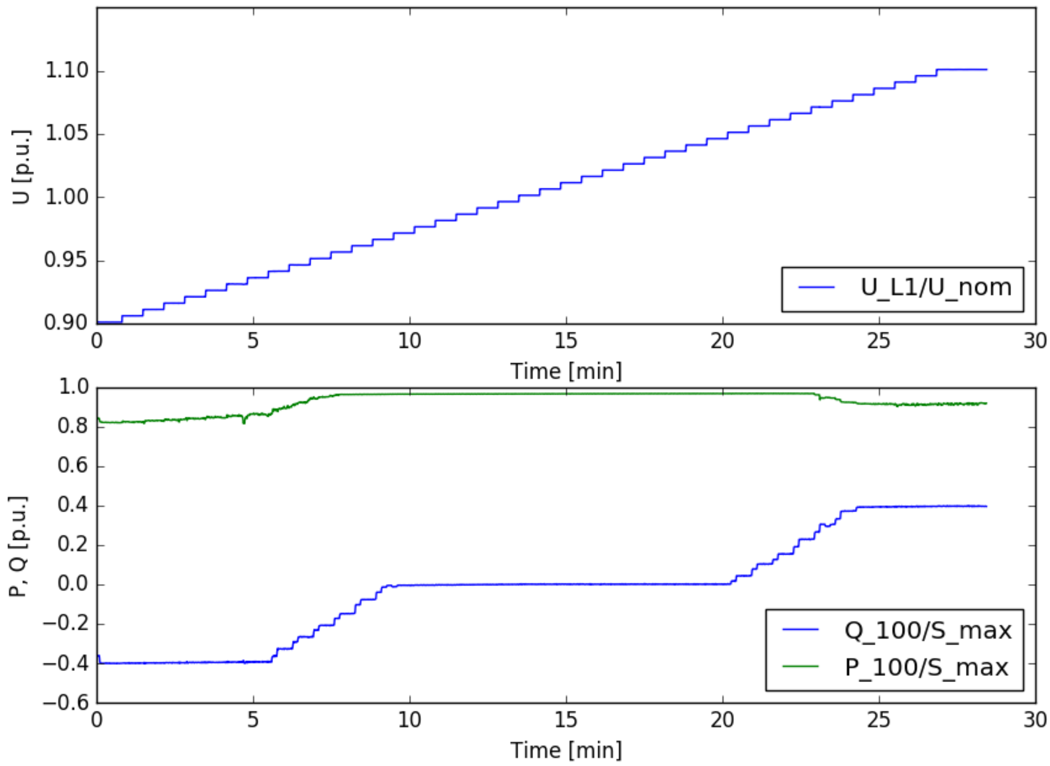
Table 9 - Results for Test Case 1 with Schneider Context RL 3000 E at output power of 100 % nominal apparent power

$U[V]$	$Q_{act}[VAr]$	$Q_{exp}[VAr]$	$P_{act}[W]$	$\Delta Q = \frac{Q_{act} - Q_{exp}}{S_{max}}$
207.28	-1196.9	-1320.0	2458.7	-0.025
208.45	-1193.3	-1320.0	2472.1	-0.025
209.60	-1190.1	-1320.0	2490.4	-0.026
210.75	-1187.7	-1320.0	2506.5	-0.026
211.90	-1183.4	-1320.0	2523.1	-0.027
213.07	-1181.4	-1320.0	2530.7	-0.028
214.17	-1176.8	-1320.0	2476.7	-0.029
215.38	-1173.1	-1320.0	2586.6	-0.029
216.56	-975.4	-1320.0	2680.1	-0.069
217.69	-794.5	-1035.0	2765.1	-0.048
218.87	-620.6	-809.2	2850.4	-0.038
220.05	-442.0	-583.5	2886.4	-0.028
221.20	-227.6	-363.5	2888.4	-0.027
222.35	-13.7	-143.5	2890.2	-0.026
223.49	-11.4	-74.6	2891.7	0.017
224.63	-8.4	0.0	2892.3	0.002
225.26	-6.6	0.0	2892.7	0.001
226.93	-2.8	0.0	2893.3	0.001
228.07	-1.0	0.0	2893.9	0.000
229.21	1.9	0.0	2894.5	0.000
230.36	4.2	0.0	2895.3	-0.001
231.51	5.4	0.0	2895.9	-0.001
232.66	5.8	0.0	2896.4	-0.001
233.80	3.3	0.0	2896.9	-0.001
234.94	4.5	0.0	2897.2	-0.001
236.09	5.1	0.0	2897.9	-0.001
237.24	4.7	0.0	2897.7	-0.001
238.39	5.2	0.0	2898.2	-0.001
239.52	5.1	0.0	2898.7	-0.001
240.66	5.0	0.0	2899.8	-0.001

241.82	131.9	61.2	2899.8	-0.014
242.98	311.1	283.1	2900.7	-0.006
244.12	463.2	501.2	2900.8	0.008
245.27	686.3	721.2	2900.1	0.007
246.41	885.4	939.3	2840.1	0.011
247.53	1115.0	1153.6	2767.9	0.008
248.68	1176.2	1373.6	2742.6	0.039
249.82	1179.2	1320.0	2742.8	0.028
250.95	1183.1	1320.0	2729.3	0.027
252.11	1186.6	1320.0	2737.9	0.027
253.25	1190.8	1320.0	2734.9	0.026

The recording of the measurement can be seen in Figure 3. In the areas of maximum reactive power (+/-44 % of nominal apparent power) it can be seen that the active power has to be reduced (to approximately 4494 W) to not exceed the maximum apparent power.

Figure 3 - Measurement of Test Case 1 with Schneider Context RL 3000 E at output power of 100 % nominal apparent power



4.1.1.2.2 Testing at 80 % of nominal apparent power

The detailed results of the test are listed in Table 10. The voltage given in the table only represents the value of phase L1 as the inverter is connected to this single phase. All values in the table represent a 5 s-average during the steady state. It can be seen that the measured reactive power (Q_{act}) does not reduce completely to 0 but stays between values from approximately -8 VAr to 7 VAr at minimum. The Q(U) function of the inverter shows small deviations from the expected curve (maximum of 5.5 % deviation). As the voltage of the grid simulator is not measured directly at the inverter, some minor changes of the voltage from the measurement point to the internal measurement of the inverter are possible. However, this will not account for the full 5.5 %.

The Q(U) function was implemented in a way that reactive power was released in the wrong direction by the manufacturer during the Test Cases 1 and 2 (reactive power in the expected amount but with the wrong sign). Therefore, the signs of the expected values are also opposite to the signs of the expected values of the tests with the Fronius inverter (cf. chapter 4.1.1.1). The Q(U) function of the inverter was corrected by the manufacturer during Test Case 3.

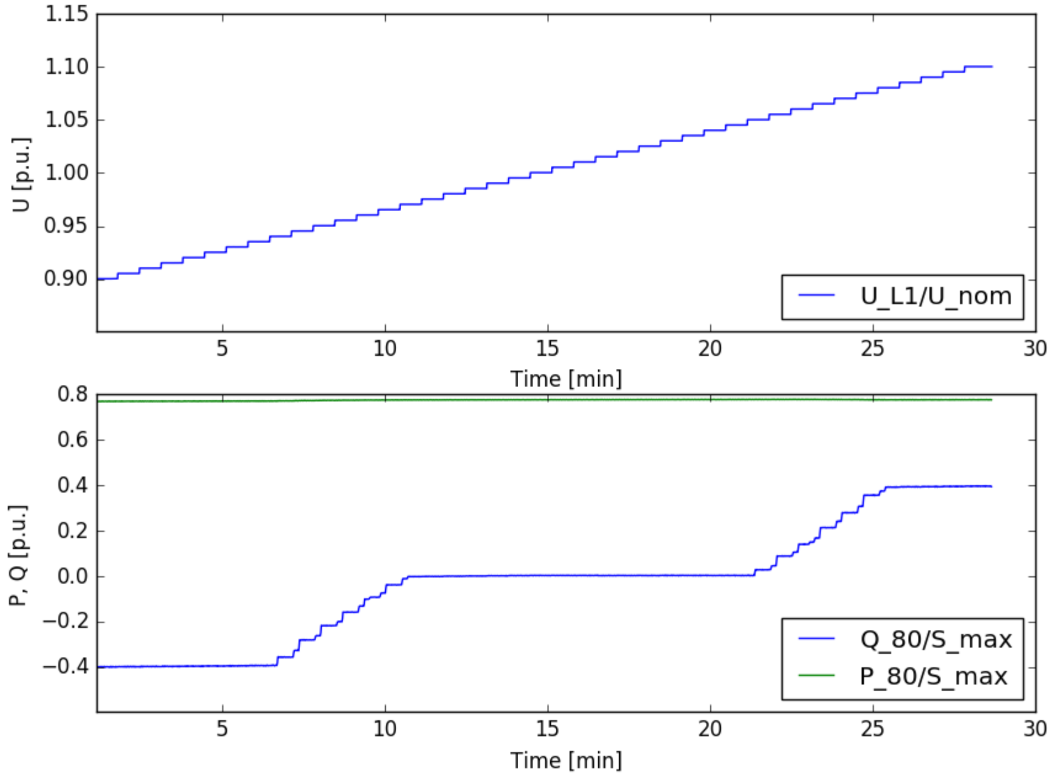
Table 10 - Results for Test Case 1 with Schneider Context RL 3000 E at output power of 80 % nominal apparent power

$U[V]$	$Q_{act}[VAr]$	$Q_{exp}[VAr]$	$P_{act}[W]$	$\Delta Q = \frac{Q_{act} - Q_{exp}}{S_{max}}$
207.08	-1201.7	-1320.0	2310.2	-0.024
208.23	-1199.5	-1320.0	2310.9	-0.024
209.37	-1197.0	-1320.0	2311.6	-0.025
210.52	-1196.2	-1320.0	2311.5	-0.025
211.67	-1194.3	-1320.0	2312.5	-0.025
212.82	-1191.3	-1320.0	2312.5	-0.026
213.97	-1187.6	-1320.0	2313.6	-0.026
215.12	-1184.7	-1320.0	2312.8	-0.027
216.27	-1073.7	-1320.0	2316.6	-0.049
217.43	-845.6	-1084.7	2320.5	-0.048
218.58	-657.4	-864.7	2323.5	-0.041
219.75	-478.1	-640.9	2325.4	-0.033
220.90	-279.8	-420.9	2327.3	-0.028
222.05	-117.6	-200.9	2328.8	-0.017
223.21	-8.1	-21.0	2328.4	0.006
224.35	-6.3	0.0	2328.8	0.001
225.50	-2.8	0.0	2329.9	0.001
226.65	-0.2	0.0	2330.6	0.000
227.79	2.6	0.0	2330.7	-0.001

228.93	5.9	0.0	2331.1	-0.001
230.08	7.0	0.0	2330.7	-0.001
231.24	7.5	0.0	2331.8	-0.002
233.53	7.4	0.0	2332.2	-0.001
234.67	5.4	0.0	2332.6	-0.001
235.82	6.1	0.0	2332.2	-0.001
236.97	5.4	0.0	2332.5	-0.001
238.12	6.9	0.0	2333.6	-0.001
239.25	6.8	0.0	2333.8	-0.001
240.40	7.2	0.0	2333.7	-0.001
241.56	6.9	11.5	2334.5	0.001
242.71	82.7	231.5	2334.9	0.030
243.86	263.6	451.5	2334.8	0.038
245.01	425.8	671.5	2335.1	0.049
246.17	638.7	893.4	2333.2	0.051
247.32	836.3	1113.4	2332.1	0.055
246.92	1068.5	1036.4	2331.4	-0.006
248.49	1176.2	1337.2	2330.7	0.032
249.63	1179.7	1320.0	2330.8	0.028
250.77	1181.3	1320.0	2330.6	0.028
251.92	1185.1	1320.0	2331.4	0.027
253.06	1188.1	1320.0	2331.8	0.026

The recording of the measurement can be seen in Figure 4. In contrast to the measurement at an output power of 100 % of the nominal apparent power, this time the active power does not have to be reduced by the inverter but stays constantly at 80 % of the nominal apparent power.

Figure 4 - Measurement of Test Case 1 with Schneider Context RL 3000 E at output power of 80 % nominal apparent power



4.1.2 Test Case 2

The purpose of this test is to characterise the time behaviour of the Q(U) control. This test was conducted without any additional impedance between network simulator and EUT. The response of the inverter to voltage jumps was recorded and analysed.

The voltage was varied step-wise (each step was decided to be 40 s) in both directions (over-voltage and under-voltage) at the output of the network simulator between

- the nominal voltage and a voltage in the droop area close to the droop start
- a voltage in the droop area close to the droop start and a voltage in the droop area close to the droop end
- a voltage in the droop area close to the droop end and the nominal voltage

The beginning of the response time was determined by using a tolerance band of ± 1 % of the nominal voltage around the average of the voltage in the steady state (end of the step). The end of the response time was determined using a tolerance band of ± 5 % of the maximum reactive power around an average of 5s of the expected value (steady state at the end of the step).

4.1.2.1 Fronius Symo Hybrid 5.0-3-S

The maximum reactive power used for the tolerance band was determined to be 2015.8 VAr regarding the tests done in Chapter 4.1.1.1. The time constant was chosen to be 5 s.

4.1.2.1.1 Testing at 100% of nominal apparent power

The detailed results of the test are listed in Table 11. The voltage in the table is the average of the phases L1-L3 as the inverter is connected to all three phases. All values in the table represent a 5 s-average during the steady state.

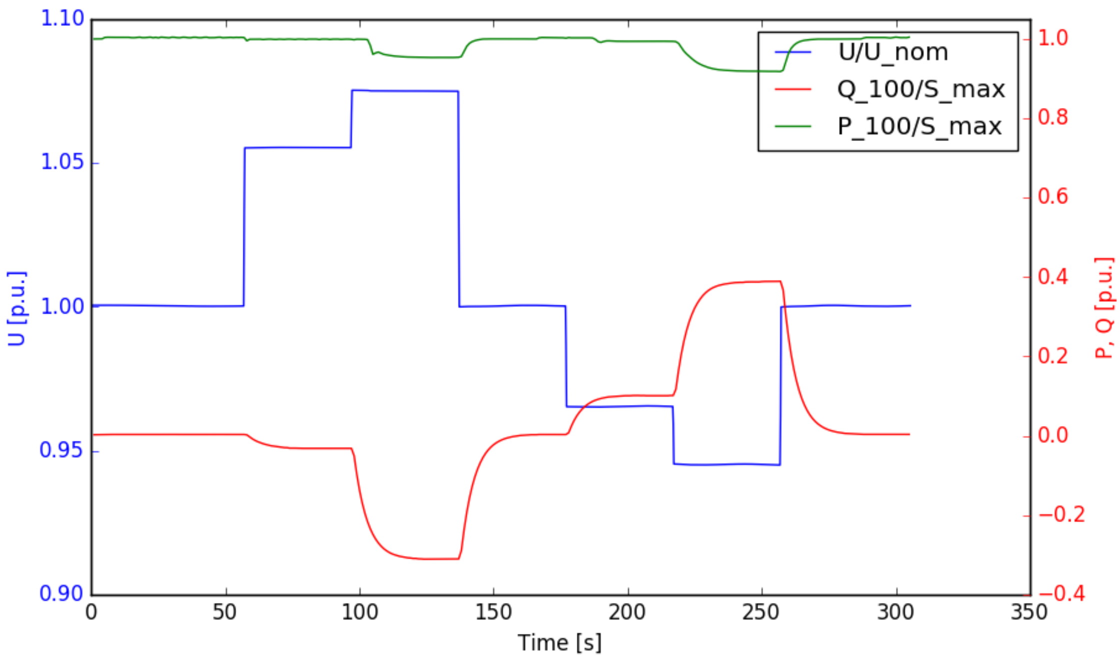
Table 11 - Results for Test Case 2 with Fronius Symo Hybrid at output power of 100 % nominal apparent power

$U[V]$	242.73	247.25	230.10	222.07	242.73	230.06
$Q[VAr]$	-158.0	-1555.4	16.5	505.2	1942.3	18.2
$P[W]$	4997.0	4766.9	5018.3	4971.0	4592.6	5017.2
$\Delta t[s]$	4.0	14.0	14.0	9.0	13.8	15.0

The recording of the measurement can be seen in Figure 5. At high over-voltage (247.25 V) or high under-voltage (222.07 V) it can be seen that the active power reduces again not to exceed the maximum possible apparent power.

The measurement shows that the Q(U) control of the inverter reacts nearly immediately to the voltage step and then slowly approximates to a stable value. For larger voltage steps, this process takes about 14 s-15 s, for smaller steps, values under 10 s are possible, depending strongly on the height of the step.

Figure 5 - Measurement of Test Case 2 with Fronius Symo Hybrid at output power of 100 % nominal apparent power



4.1.2.1.2 Testing at 80 % of nominal apparent power

The detailed results of the test are listed in Table 12. The voltage given in the table is the average of the phases L1-L3 as the inverter is connected to all three phases. All values given in the table represent a 5s-average during the steady state. As the step in the reactive power was really small in the beginning of the droop area at over-voltage (242.73 V), the tolerance band had to be adjusted. For this single step, a tolerance band of +/-1 % of the maximum reactive power was therefore used.

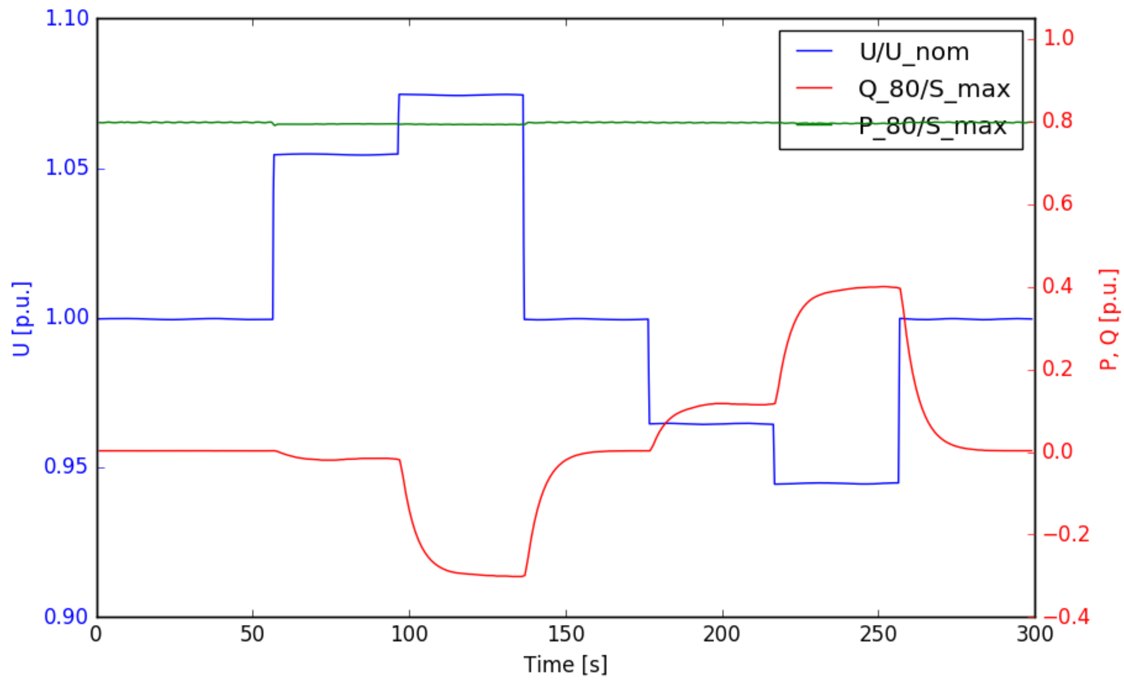
Table 12 - Results for Test Case 2 with Fronius Symo Hybrid at output power of 100 % nominal apparent power

$U[V]$	242.53	247.16	229.86	221.87	217.26	229.91
$Q[VAr]$	-77.0	-1502.5	14.19	573.9	2000.2	15.5
$P[W]$	3974.2	3966.9	3991.9	3988.4	3979.6	3992.0
$\Delta t[s]$	6.4[6]	13.4	14.4	9.4	14.4	15.4

The recording of the measurement can be seen in Figure 6. The active power was set to 80 % of the nominal apparent power during this test, therefore it did not have to reduce at high over- or under-voltage due to the Q(U) control.

The measurement shows again that the Q(U) control of the inverter reacts nearly immediately to the voltage step and then slowly approximates to a stable value. For larger voltage steps, this process takes about 13-15 s, for smaller steps, values under 10 s are possible, depending strongly on the height of the step.

Figure 6 - Measurement of Test Case 2 with Fronius Symo Hybrid at output power of 80 % nominal apparent power



[6] A tolerance band of +/- 1% of the maximum reactive power was chosen around the expected value as this step was too small for a higher tolerance band.

4.1.2.2 Schneider Context RL 3000 E

The maximum reactive power used for the tolerance band was determined to be 1200 VAr regarding the tests done in Chapter 4.1.1.2. The time constant was chosen to be 10 s (which is the lowest possible value for the device).

4.1.2.2.1 Testing at 100% of nominal apparent power

The detailed results of the test are listed in Table 13. The voltage given in the table only represents the value of phase L1 as the inverter is connected to this single phase. All values given in the table represent a 5 s-average during the steady state.

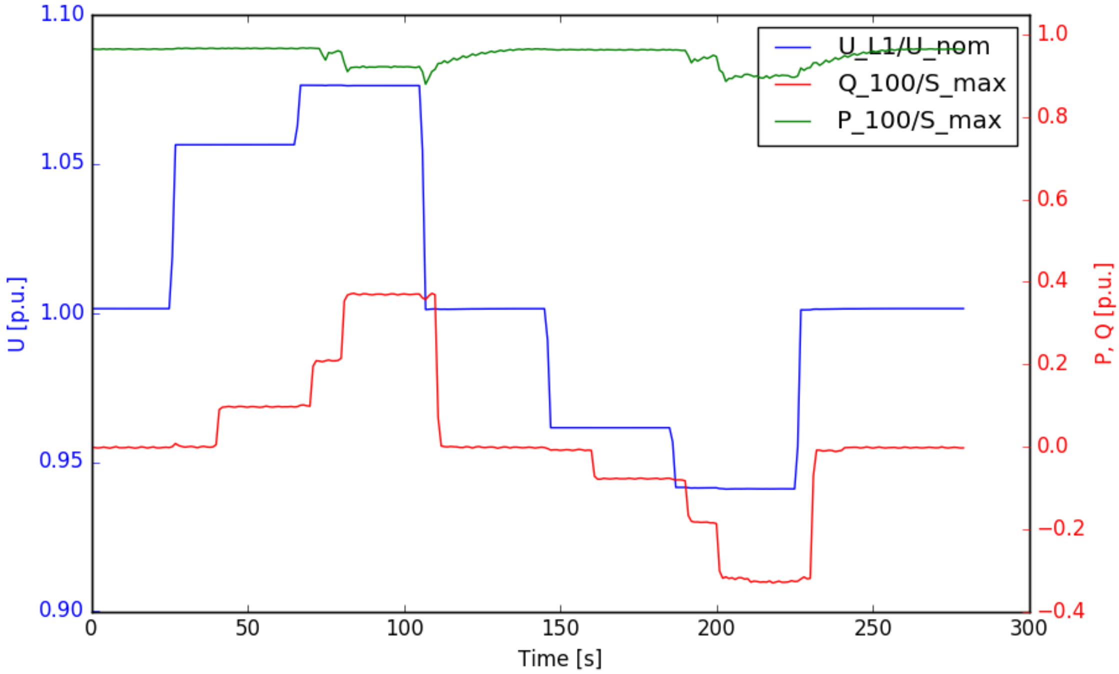
The Q(U) function was implemented in a way that reactive power was released in the wrong direction by the manufacturer during the Test Cases 1 and 2 (reactive power in the expected amount but with the wrong sign). The Q(U) function of the inverter was corrected by the manufacturer during Test Case 3.

Table 13 - Results for Test Case 2 with Schneider Context RL 3000 E at output power of 100 % nominal apparent power

$\boldsymbol{U}[\boldsymbol{V}]$	242.95	247.50	230.31	221.14	216.43	230.32
$\boldsymbol{Q}[\boldsymbol{VAr}]$	289.5	1108.5	-6.4	-233.3	-986.0	-8.0
$\boldsymbol{P}[\boldsymbol{W}]$	2901.1	2766.5	2893.7	2890.2	2697.0	2892.3
$\boldsymbol{\Delta t}[\boldsymbol{s}]$	14.4	14.4	4.8	14.4	14.6	4.6

The recording of the measurement can be seen in Figure 7. The Inverter shows a quite different reaction on the voltage change than the Fronius inverter. After a period of dead time (no reaction), the reactive power rises to an intermediate level (with a duration of approx. 10 s which corresponds to the selected time constant) before it rises again to the final value. However, this behaviour cannot be seen during each change of voltage. When the reactive power control becomes active for the first time (steps from nominal voltage to small over-voltage and step from nominal voltage to small under-voltage), no intermediate step can be seen in the reactive power which results in a longer dead time. When the voltage goes back from a high over-voltage or high under-voltage to the nominal value, the reactive power is set to its minimum without intermediate step. This results in a smaller response time in total.

Figure 7 - Measurement of Test Case 2 with Schneider Context RL 3000 E at output power of 100 % nominal apparent power



4.1.2.2.2 Testing at 80 % of nominal apparent power

The detailed results of the test are listed in Table 14Table 13. The voltage in the table only represents the value of phase L1 as the inverter is connected to this single phase. All values in the table represent a 5 s-average during the steady state.

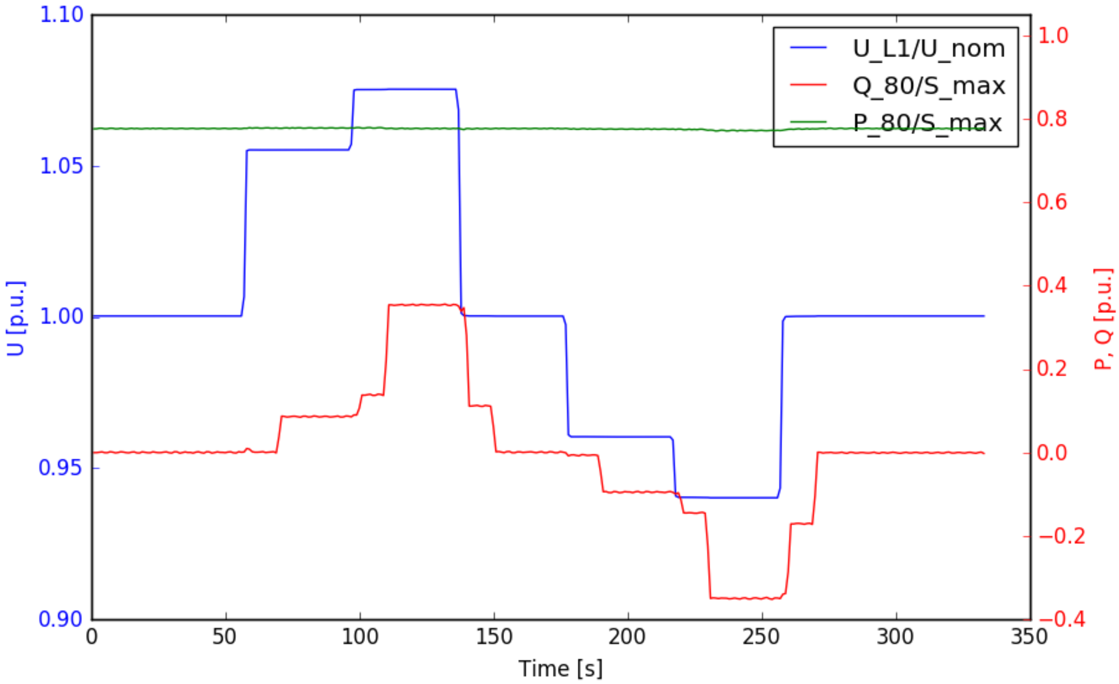
The Q(U) function was implemented in a way that reactive power was released in the wrong direction by the manufacturer during the Test Cases 1 and 2 (reactive power in the expected amount but with the wrong sign). The Q(U) function of the inverter was corrected by the manufacturer during Test Case 3.

Table 14 - Results for Test Case 2 with Schneider Context RL 3000 E at output power of 100 % nominal apparent power

$U[V]$	242.71	247.32	230.07	220.88	216.25	230.08
$Q[VAr]$	259.1	1063.0	3.1	-284.0	-1047.2	-1.0
$P[W]$	2334.3	2331.4	2331.2	2326.5	2315.9	2330.8
$\Delta t[s]$	12.8	13.0	12.8	12.8	12.8	12.8

The recording of the measurement can be seen in Figure 8. Again it can be seen that after a period of dead time (no reaction), the reactive power rises to an intermediate level (with a duration of approx. 10 s which corresponds to the selected time constant) before it rises again to the final value. When the reactive power control is active for the first time (steps from nominal voltage to small over-voltage and step from nominal voltage to small under-voltage), however, no intermediate step can be seen in the reactive power which results in a longer dead time. When the voltage goes back from a high over-voltage or high under-voltage to the nominal value, the inverter behaves different than during the measurement with maximum active output power. This time, the reactive power reduces to an intermediate step before it is set to its minimum value. The response time therefore remains the same for ramp up and ramp down during this test at approximately 13 s for each step.

Figure 8 - Measurement of Test Case 2 with Schneider Context RL 3000 E at output power of 80 % nominal apparent power



4.1.3 Test Case 3

The purpose of this test is to evaluate the stability of the control under worst-case conditions. This test was conducted with an additional impedance between network simulator and EUT, adjusted to represent the worst-case conditions (see below).

The stability of a Q(U) control has been investigated and presented in a number of papers. In one of them[7], a stability criterion has been established and the authors have come to the conclusion that the stability is mainly influenced by the following factors:

- Maximal reactive power compared to the network impedance or short-circuit power at the point of connection
- Slope of the Q(U) curve
- Response time of the control
- (unwanted) time delay in the control

4.1.3.1 Fronius Symo Hybrid 5.0-3-S

The parameters for the worst case scenario were tested separately (Figure 9 to Figure 14) and then all together (In Figure 15 and Figure 16 the final measurement during which all “worst case parameters” were set, can be seen. Only a very small step was made in the total

[7] F. Andren, B. Bletterie, S. Kadam, P. Kotsampopoulos, and C. Bucher, ‘On the Stability of local Voltage Control in Distribution Networks with a High Penetration of Inverter-Based Generation’, *IEEE Trans. Ind. Electron.*, pp. 1–1, 2014.

voltage as the Q(U) curve was set to be very steep (cf. chapter 3.1). The stability of the Q(U) control could be maintained during both measurements (two levels of output power). The voltage on phase L1, where the grid impedance was the largest, did not increase during the measurement due to the Q(U) control. It even slightly decreased while the total voltage increased. The voltage on phase L2 and L3, where a smaller grid impedance was used, did increase and caused a higher total voltage. During the measurement shown in Figure 16, the phase L3 showed some oscillations in the voltage. However, the stability of the Q(U) control was still given.

Figure 15 and Figure 16) for the Fronius device. Each test was performed at two levels of output power: 100 % of the nominal apparent power and 80 % of the nominal apparent power.

Regarding Figure 9 and Figure 10, it can be seen that to inverter now reacts a lot faster to the voltage change due to the changed time constant. The reactive power does not slowly approximate to the final value but jumps nearly directly to it.

Figure 9 - Measurement of Test Case 3 with Fronius Symo Hybrid at output power of 100 % nominal apparent power – time constant set to 0.01 s

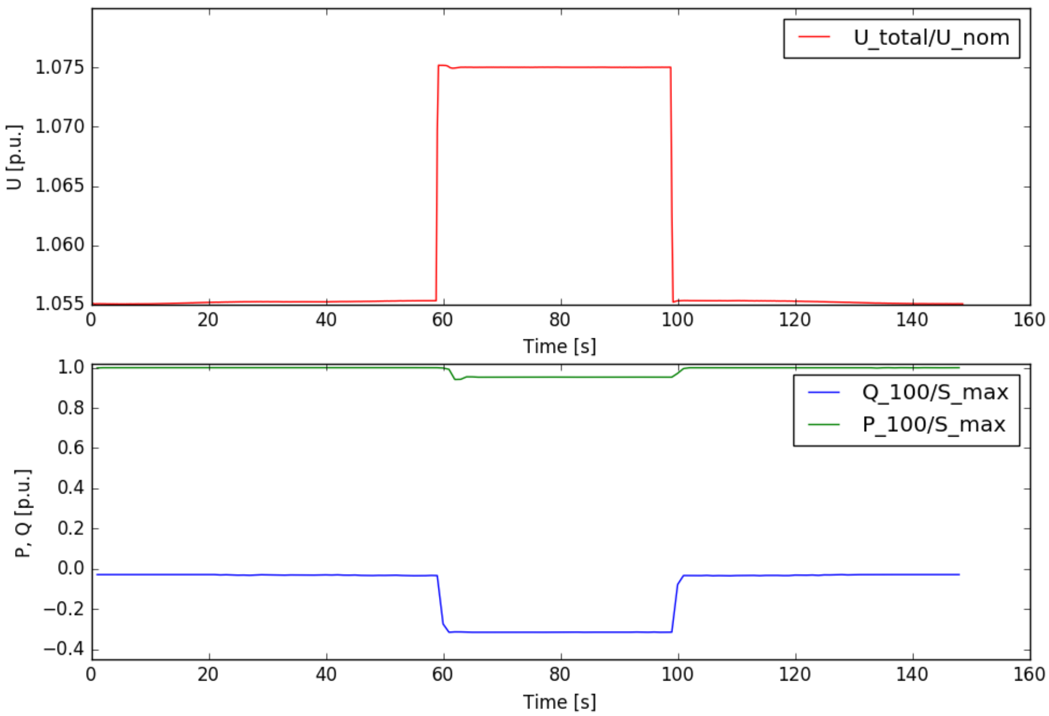
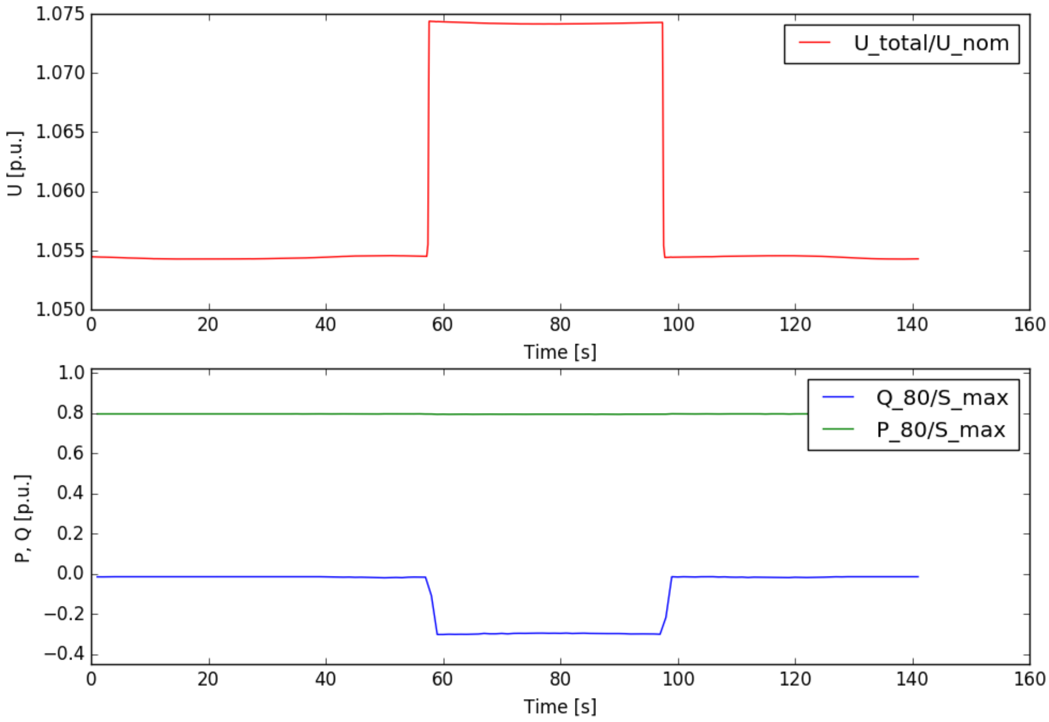


Figure 10 - Measurement of Test Case 3 with Fronius Symo Hybrid at output power of 80 % nominal apparent power – time constant set to 0.01 s



In Figure 11 and Figure 12, the measurement recordings during which the slope of the Q(U) curve was changed (steeper curve) can be seen. Due to the voltage step from approx. 1.55 U_n to 1.75 U_n, the reactive power has to rise to its maximum value (43 % of nominal apparent power in negative direction). This increase remains stable and as the time constant was again set to 5 s, the final value is slowly approximated (as it could be seen in the tests of the time behaviour in chapter 4.1.2.1).

Figure 11 - Measurement of Test Case 3 with Fronius Symo Hybrid at output power of 100 % nominal apparent power – steep Q(U) curve

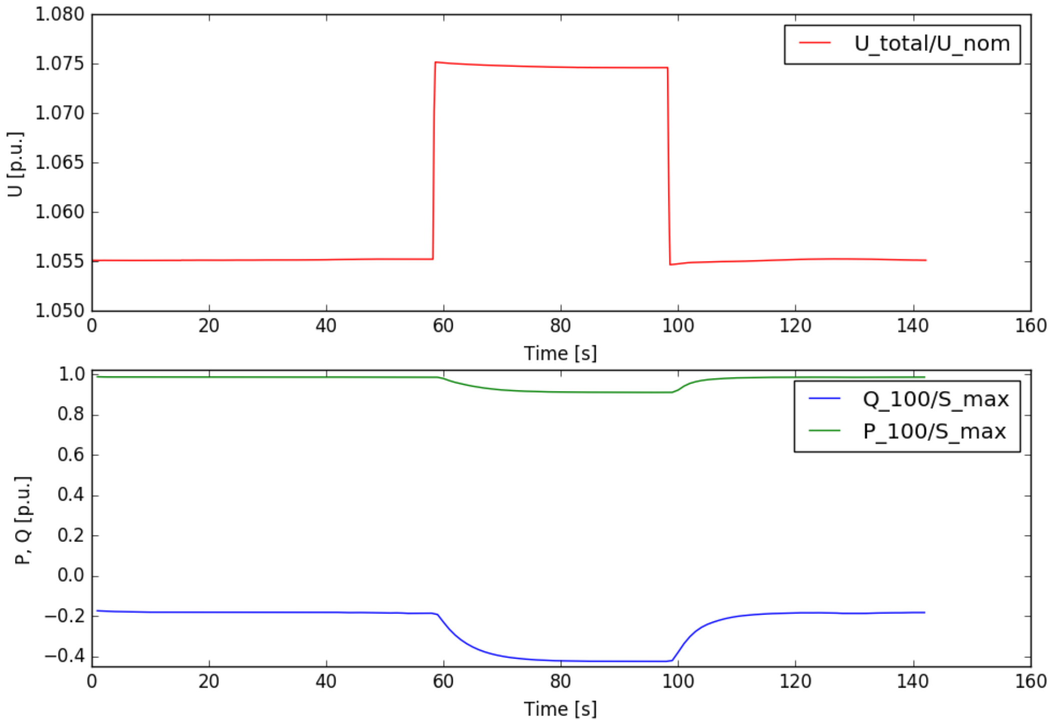


Figure 12 - Measurement of Test Case 3 with Fronius Symo Hybrid at output power of 80 % nominal apparent power – steep Q(U) curve

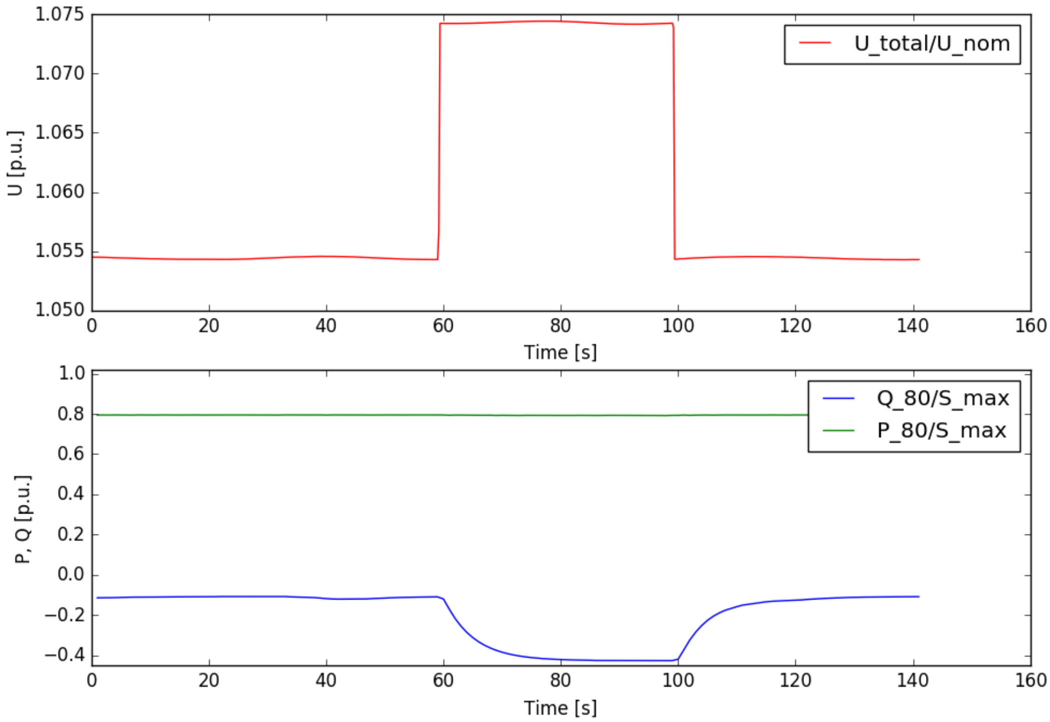


Figure 13 and Figure 14 show the measurement recordings during which an additional grid impedance was used between grid simulator and EUT (all three phases and their average are displayed). The value of the impedance could not be set to the value proposed in the "Test procedure for the lab tests" for the project InterFlex CZ Demo (chapter 4.1.4.3.1), as only particular values can be set.

The impedance that was finally used can be seen in Table 15. As the impedance at phase L1 is larger than on the other phases, the voltage is higher on this phase. The measurement shows that the voltage on phase L1 can be strongly reduced due to the Q(U) control and therefore also the total voltage decreases. The voltage on phase L2 and L3, where only a very small grid impedance is used, remains nearly the same.

Table 15 - Grid impedance for worst case scenario with Fronius Symo Hybrid

L1	(0.996 + 0.919i) Ω
L2	(0.157 + 0.158) Ω
L3	(0.157 + 0.158) Ω
N	(0.096 + 0.102i) Ω

Figure 13 - Measurement of Test Case 3 with Fronius Symo Hybrid at output power of 100 % nominal apparent power – additional grid impedance

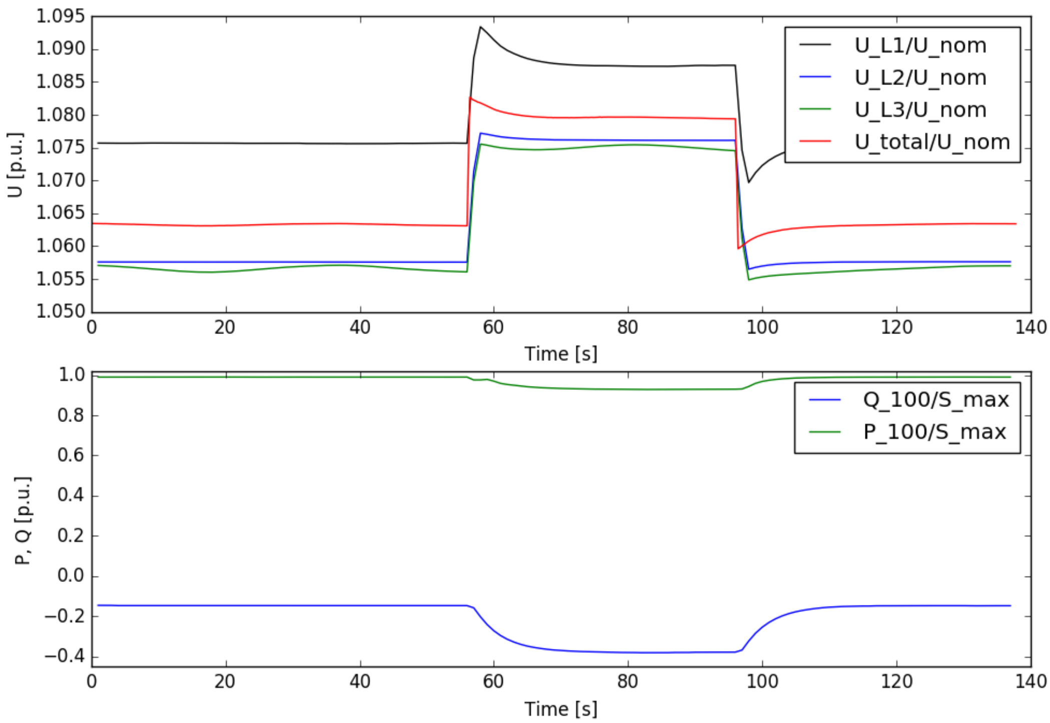
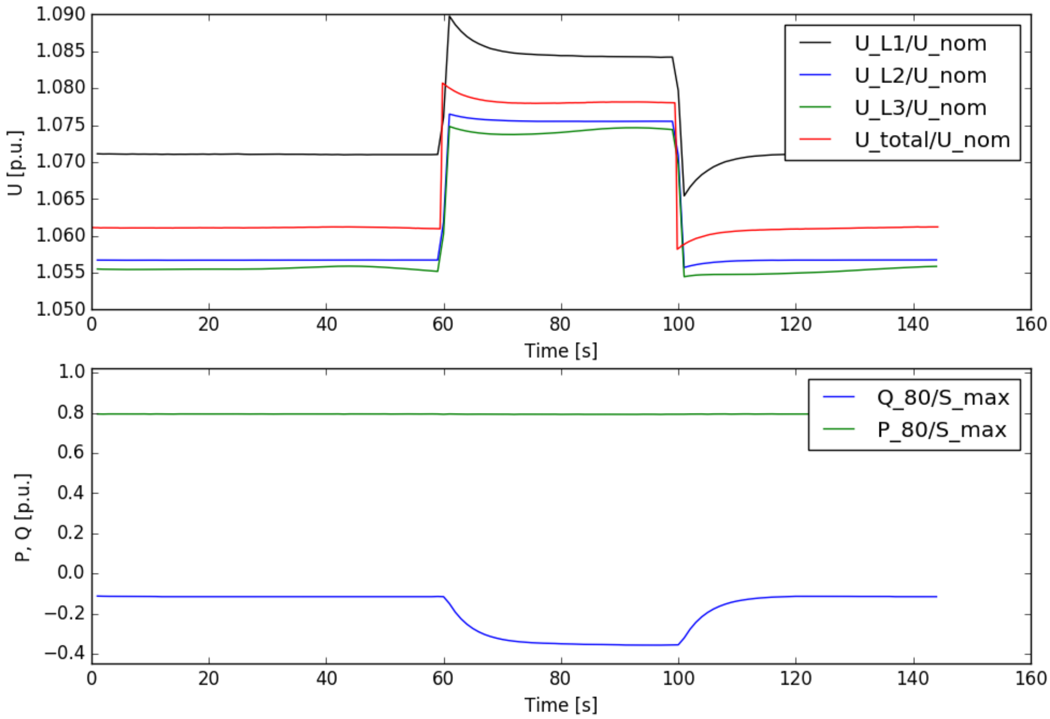


Figure 14 - Measurement of Test Case 3 with Fronius Symo Hybrid at output power of 80 % nominal apparent power – additional grid impedance



In Figure 15 and Figure 16 the final measurement during which all "worst case parameters" were set, can be seen. Only a very small step was made in the total voltage as the Q(U) curve was set to be very steep (cf. chapter 3.1). The stability of the Q(U) control could be maintained during both measurements (two levels of output power). The voltage on phase L1, where the grid impedance was the largest, did not increase during the measurement due to the Q(U) control. It even slightly decreased while the total voltage increased. The voltage on phase L2 and L3, where a smaller grid impedance was used, did increase and caused a higher total voltage. During the measurement shown in Figure 16, the phase L3 showed some oscillations in the voltage. However, the stability of the Q(U) control was still given.

Figure 15 - Measurement of Test Case 3 with Fronius Symo Hybrid at output power of 100 % nominal apparent power – all worst case parameters changed

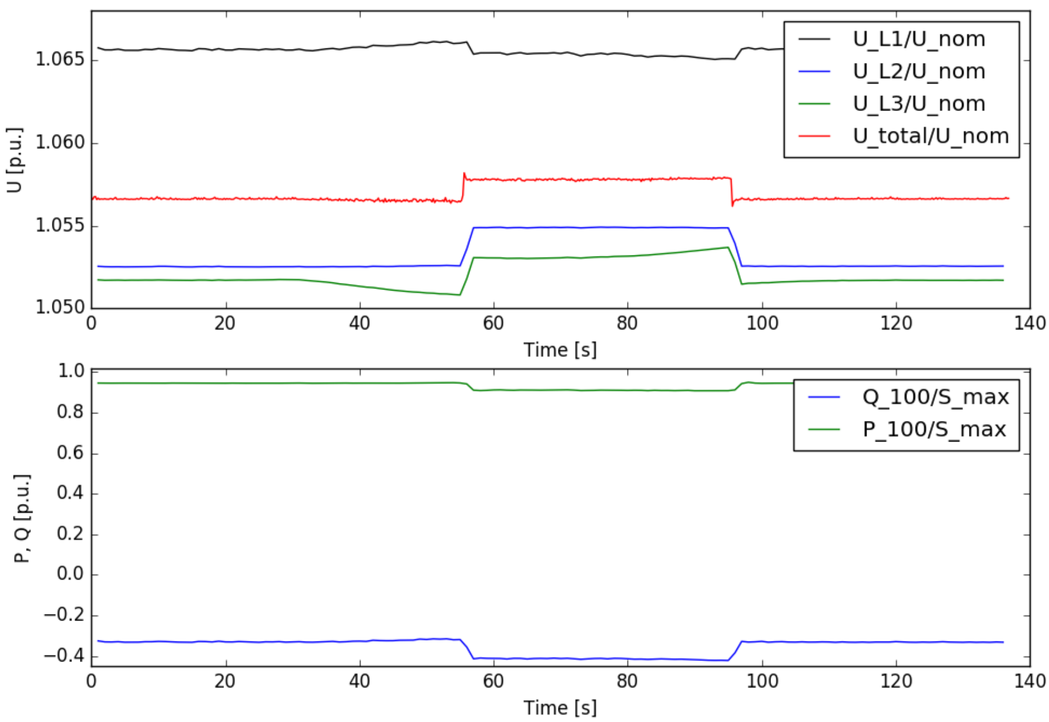
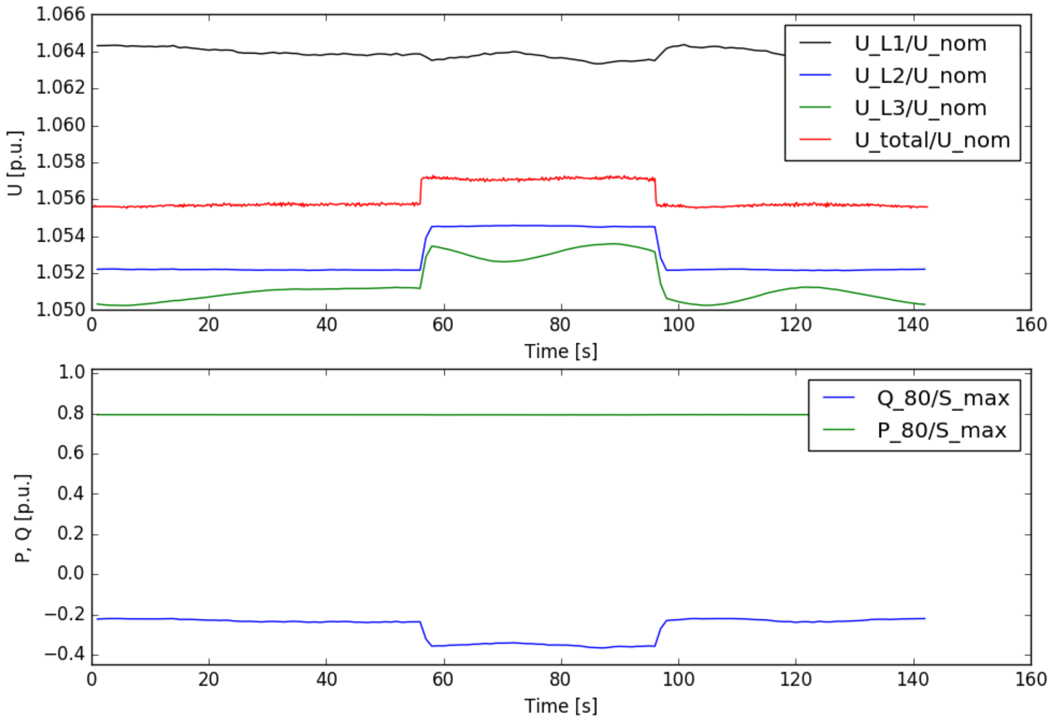


Figure 16 - Measurement of Test Case 3 with Fronius Symo Hybrid at output power of 80 % nominal apparent power – all worst case parameters changed



4.1.3.2 Schneider Context RL 3000 E

For this test, the slope of the Q(U) curve was changed as it is shown in chapter 3.1 (Table 3). Furthermore, an additional grid impedance (Table 16) was used additionally between grid simulator and EUT. The response time was not changed as 10s is already the minimum.

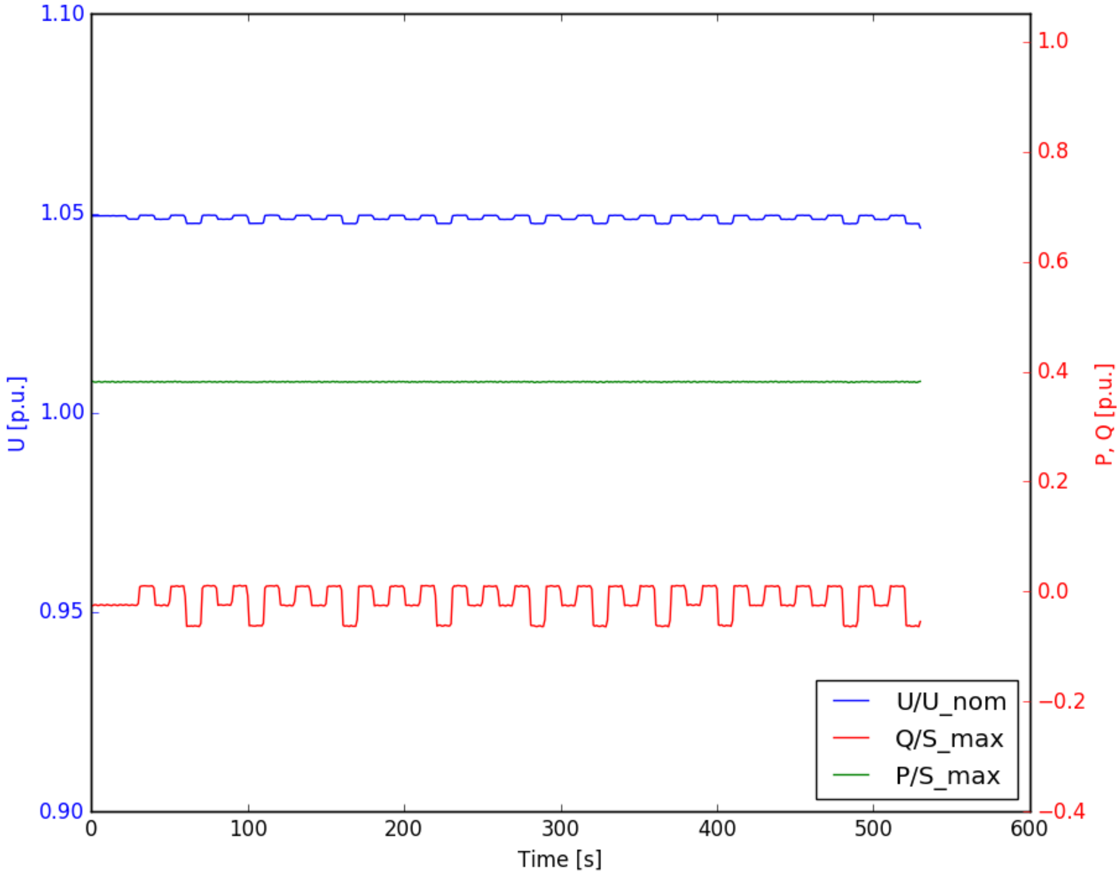
Table 16 – Grid impedance for worst case scenario with Schneider Context RL 3000 E

L1	(0.586 + 0.512i) Ω
N	(0.006 + 0.001i) Ω

The test was performed at three levels of output power: 40 %, 80 % and 100 % of the nominal apparent power. The voltage was either set to a value close to the droop start or close to droop end. Without changing the voltage any further at this point it can be seen that the inverter does not stay at a fixed operating point but begins to oscillate accordingly to the self-induced change in voltage.

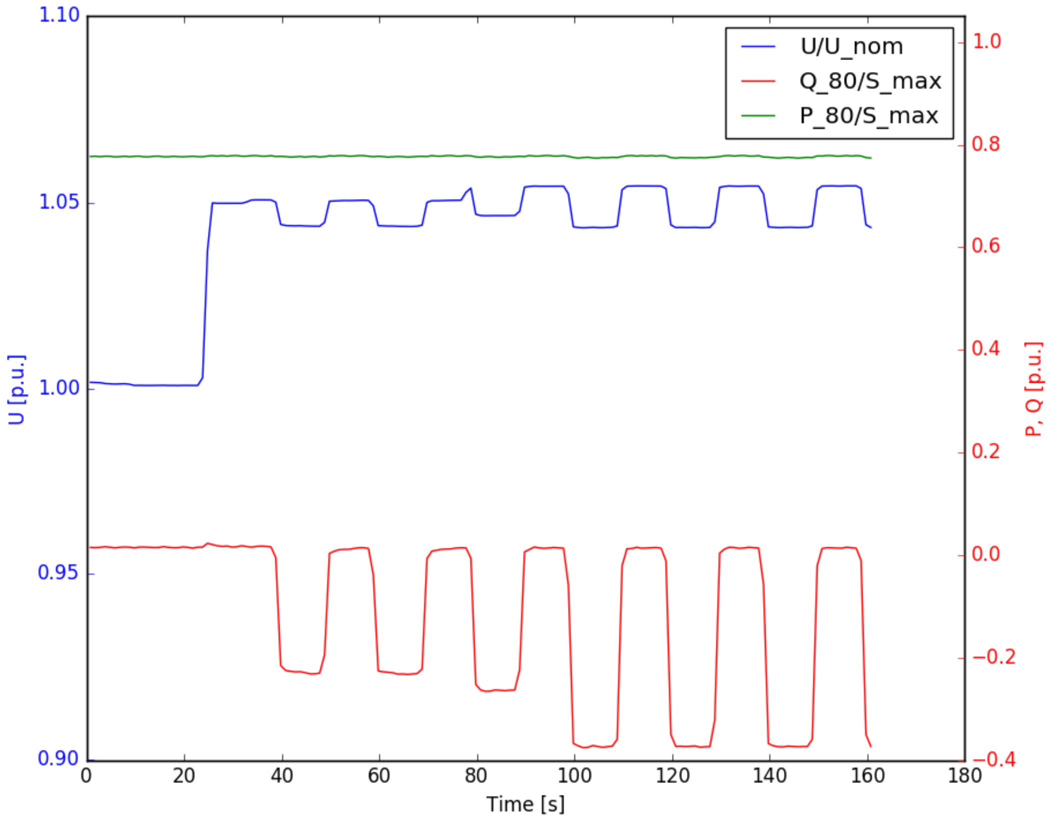
In Figure 17, the measurement at an output power of 40 % of the nominal apparent power can be seen. The voltage is set to 241.2 V which is an over-voltage in the beginning of the droop area of the Q(U) curve. The negative reactive power reduces the voltage which is then in an area outside the droop area (Q = 0). The inverter therefore reduces its reactive power to approx. 35 kVAr which effects again a rise of the voltage and then again an increase of negative reactive power. The steps in the reactive power are about 10 s long. The oscillations do not have the same height each time at this level of output power – the reactive power changes between either approx. -70 kVAr or approx. -185 kVAr.

Figure 17 - Measurement of Test Case 3 with Schneider Context RL 3000 E at output power of 40 % nominal apparent power



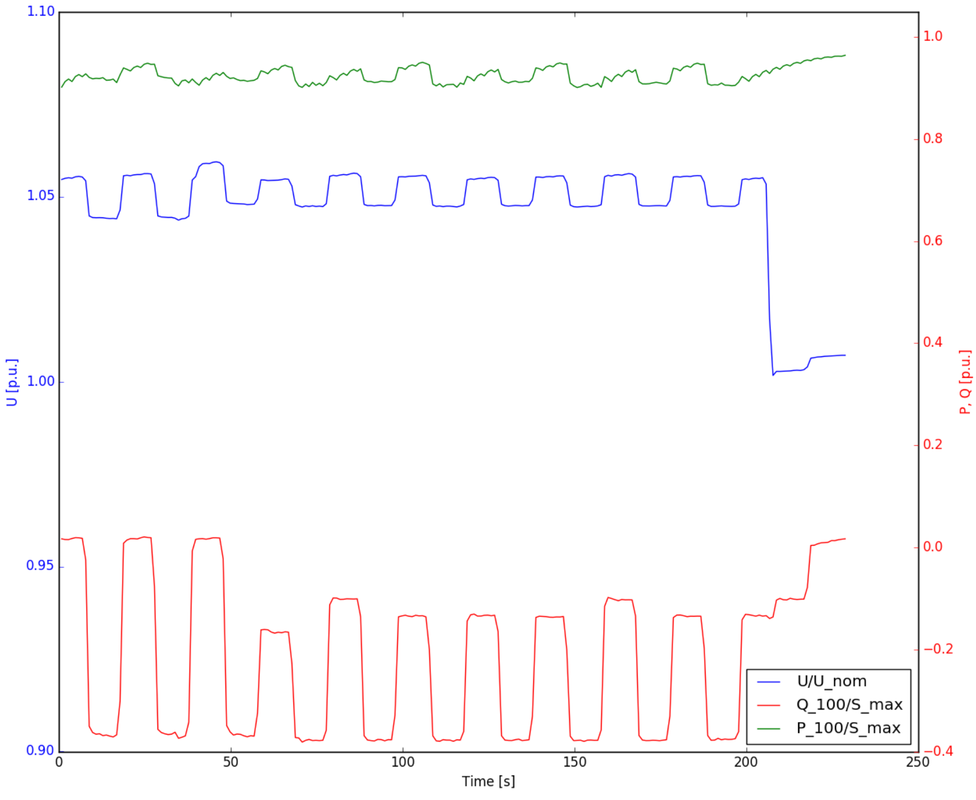
In Figure 18, the measurement at an output power of 80 % of the nominal apparent power can be seen. First of all, the voltage was set to 241.3 V which is a value at the beginning of the droop area. The first three oscillations show a similar behaviour of the inverter as the measurement at an output power of 40 % of the nominal voltage. The steps of the reactive power have a duration of approx. 10s during which the reactive power is not exactly constant but takes a value between -650 to -800 kVAr and then reduces again to a value between 25 and 70 kVAr. Then the voltage was set to approx. 242.1 V which is a value at the end of the droop area of the Q(U) curve. Again, oscillations in the reactive power (and the resulting change of voltage) can be seen. The value of the reactive power within such a step is now more stable and is between 30-50 kVAr and -1100 to -1150 kVAr.

Figure 18 - Measurement of Test Case 3 with Schneider Context RL 3000 E at output power of 80 % nominal apparent power



In Figure 19, the measurement at an output power of 100 % of the nominal apparent power can be seen. Again, the voltage was set to a value near to the end of the droop area of the Q(U) curve. This time it can be seen that also the active power changes due to the reactive power control. Again, oscillations can be seen in the control. After a few oscillations, the reactive power does not reduce to its minimal value but starts oscillating between a value for reactive power corresponding to the middle of the droop area of the Q(U) curve and a value near the maximum of the reactive power.

Figure 19 - Measurement of Test Case 3 with Schneider Context RL 3000 E at output power of 100 % nominal apparent power



4.2 Active Power Control – P(U)

The active power control to be tested under UC1 is a local control of the voltage through a voltage-dependant active power reduction (P(U)). The settings for the P(U) control can be found in Chapter 3.2 for both inverters. As the function Q(U) remained activated during the tests, so the resulting maximum active power was lower than the usually maximum possible value for active power (100 % nominal apparent power). The tests were conducted with the maximum possible value for the active power.

The purpose of these tests is to verify the proper functioning of the reactive power control mode P(U) (also in combination with the Q(U) control) and to characterise the control in terms of:

- Accuracy
- Time behaviour
- Stability under worst-case conditions

For the test cases 1 and 2, the inverter was connected directly to the network simulator while for test case 3, a network impedance was added to emulate weak network conditions.

4.2.1 Test Case 1

The purpose of this test is to evaluate the accuracy of the control. This test was conducted without any additional impedance between network simulator and EUT. The voltage was varied via the network simulator between 1.04 p.u. and 1.13 p.u. via a stair function in steps of 0.2 %. The duration of each stair and the response time was determined to be 40 s to ensure that the steady-state is reached before the next step. The response of the inverter was recorded (active and reactive power).

The accuracy will be evaluated as the deviation between the expected and the actual active power, normalized to the maximal apparent power (equation (2)).

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

4.2.1.1 Fronius Symo Hybrid 5.0-3-S

The detailed results of the test are listed in Table 17. The voltage U_{mean} in the table is the average of the phases L1-L3 as the inverter is connected to all three phases. Furthermore, the maximum voltage is given as it is used for the P(U) control. All values given in the table represent a 5 s-average during the steady state.

Table 17 – Results of Test Case 1 with Fronius Symo Hybrid 5.0-3-S

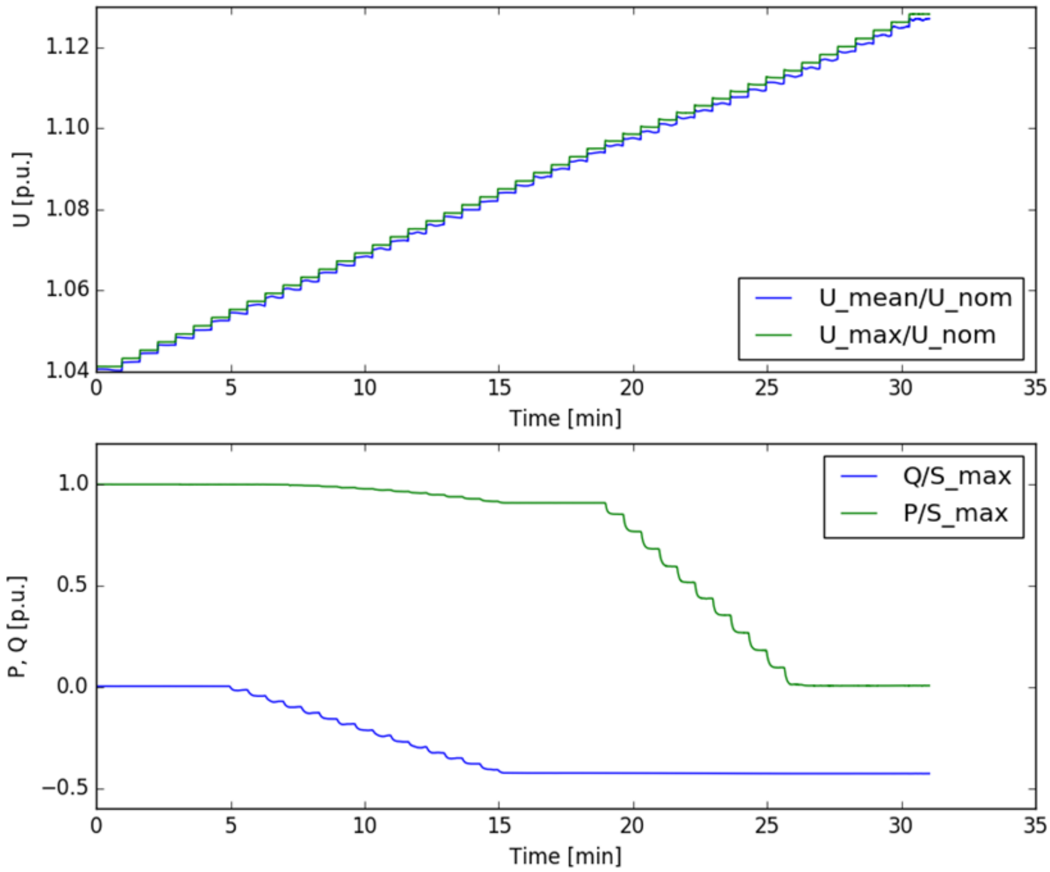
$U\_mean[V]$	$U\_max[V]$	$P_{act}[VAr]$	$P_{exp}[W]$	$Q_{act}[VAr]$	$\Delta P = \frac{P_{act} - P_{exp}}{P_{max}}$
239.23	239.46	4999.7	-[8]	14.1	-
239.72	239.92	4999.6	-	14.6	-
240.22	240.39	4998.6	-	14.6	-
240.68	240.85	4998.9	-	14.5	-
241.07	241.30	4995.4	-	14.3	-
241.53	241.77	4997.5	-	14.4	-
242.07	242.24	4997.7	-	14.5	-
242.45	242.69	4997.5	-	-76.4	-
242.95	243.15	4998.0	-	-228.2	-
243.36	243.61	4996.2	-	-357.4	-
243.81	244.06	4982.3	-	-495.4	-
244.27	244.52	4966.9	-	-639.9	-
244.79	244.98	4945.6	-	-792.8	-
245.19	245.44	4921.3	-	-916.4	-
245.70	245.90	4892.1	-	-1073.3	-
246.10	246.36	4862.9	-	-1206.1	-
246.62	246.82	4823.1	-	-1362.7	-
247.02	247.27	4785.6	-	-1496.5	-
247.49	247.72	4744.4	-	-1629.1	-
247.92	248.18	4698.7	-	-1759.5	-

[8] The maximum possible value is expected which is approx. 5000W but is reduced due to the Q(U) control. As the exact control strategy of the inverter is not given, no expected values are given until the area of the P(U) control where the expected values are known.

248.36	248.64	4644.9	-	-1900.8	-
248.86	249.09	4580.9	-	-2047.5	-
249.33	249.54	4543.9	-	-2128.7	-
249.75	250.00	4543.7	-	-2128.5	-
250.26	250.47	4543.5	-	-2128.6	-
250.70	250.91	4543.5	(4767.7)	-2128.4	(-0.045)
251.16	251.37	4543.8	4266.2	-2128.7	0.056
251.63	251.84	4543.7	3758.0	-2128.9	0.157
252.05	252.26	4262.2	3302.4	-2129.2	0.192
252.40	252.65	3834.1	2878.0	-2130.6	0.191
252.75	253.05	3408.6	2443.2	-2131.7	0.193
253.17	253.47	2974.4	1993.0	-2132.7	0.196
253.62	253.86	2575.7	1559.6	-2133.4	0.203
254.00	254.27	2184.5	1120.5	-2134.7	0.213
254.38	254.67	1771.0	686.2	-2135.8	0.217
254.76	255.07	1335.8	247.3	-2137.9	0.218
255.12	255.46	901.1	0	-2139.6	0.180
255.52	255.86	477.9	0	-2140.9	0.096
255.94	256.26	55.4	0	-2141.7	0.011
256.38	256.71	27.4	0	-2142.1	0.005
256.84	257.18	27.3	0	-2142.0	0.005
257.36	257.63	27.3	0	-2142.1	0.005
257.83	258.09	27.6	0	-2141.7	0.006
258.23	258.56	27.6	0	-2142.2	0.006
258.74	259.02	28.2	0	-2142.0	0.006
259.15	259.48	27.6	0	-2142.5	0.006

The recording of the measurement can be seen in Figure 20. Again, maximum voltage and average voltage (of all three phases) are displayed. First of all, it can be seen that due to the over-voltage and the activated Q(U) function reactive power starts to rise in negative direction following the steps of the voltage (cf. 4.1.1.1). The active power, which is at its maximum in the beginning has to reduce to not exceed the maximum apparent power in total. After the Q(U) control has reached its maximum, the P(U) control becomes active. The inverter shows a really stable curve which reacts quickly to the changes in voltage. It can be seen that the active power control starts at the step of the voltage to 252.3 V which is about 109.7 % of the nominal voltage. The active power is reduced to its minimum at a voltage of 256.7 V which is 111.7 % of the nominal voltage. As there is a large change in the active power for each Volt (21.74 % reduction), the deviation from the expected value is quite high at this measurement although the curve only seems to be shifted a little. Furthermore, as the voltage of the grid simulator is not measured directly at the inverter, some minor changes of the voltage from the measurement point to the internal measurement of the inverter are possible. However, this will not account for the full deviations from the expected value.

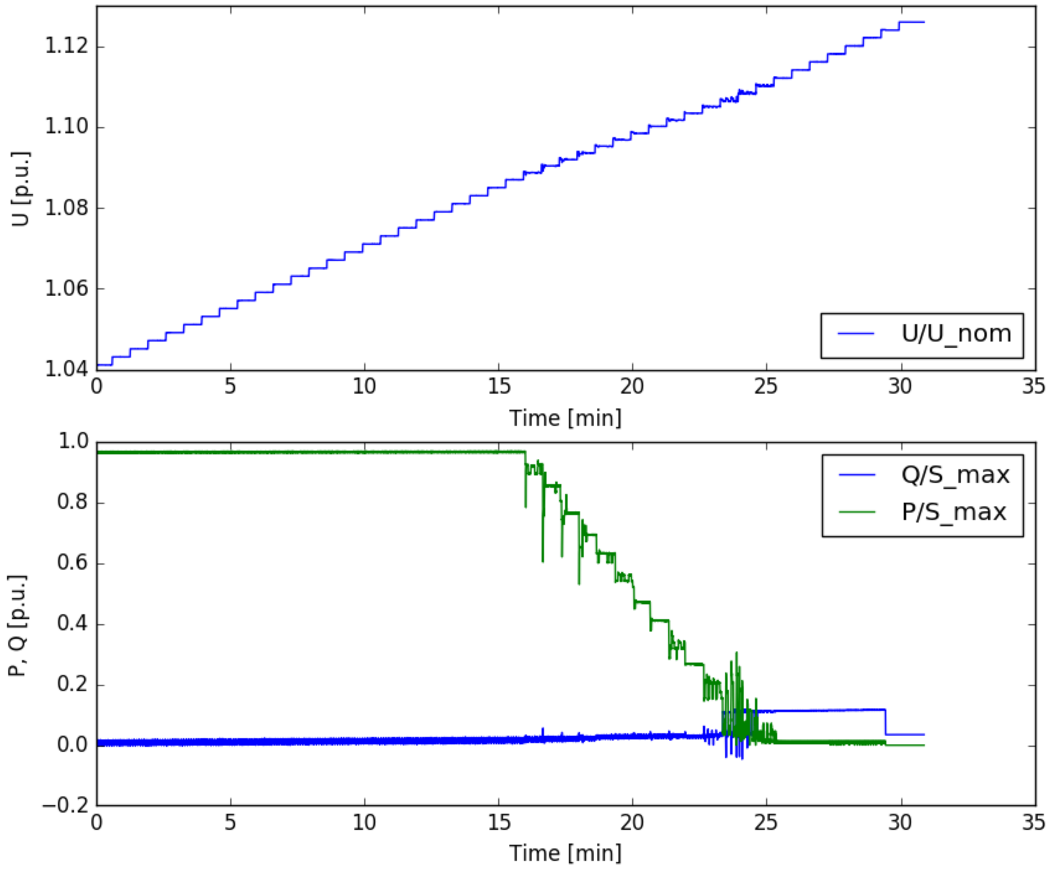
Figure 20 - Measurement of Test Case 1 with Fronius Symo Hybrid



4.2.1.2 Schneider Context RL 3000 E

For the P(U) control, an additional hardware was needed for the Schneider Context RL 3000 E. The test of the P(U) control was done several times with the device, during this time also the Q(U) control remained activated. In the measurements it can be seen that the P(U) control becomes active between 249.7 V to 250 V (108.6 to 108.7 % of the nominal voltage) which corresponds very well with the settings. However, during the first measurement (Figure 21), there was no increase of the reactive power until the very end of the measurement (approx. at 254.4 V). Regarding the reactive power closer at this point it can be seen that it jumps to a value between 330-340 kVAr and back to a smaller value again a few times before the reactive power stays nearly constant at around 340 kVar for the rest of the measurement. Regarding the P(U) it can be seen that the reduction of the active power indeed follows the steps of the voltage. However, for many steps no steady state was reached and in the end the function became even more unstable.

Figure 21 - Measurement of Test Case 1 with Schneider Context RL 3000 E (1)



Because of that, the test was conducted again (with only the part of the voltage stair function where P(U) should be active) and some parameters at the inverter were changed (settings for P(U) und Q(U) as shown in chapter 3.1 and 3.2 remained the same). The measurement recordings are displayed in Figure 22 and Figure 23. This time, also reactive power control became active. Its value showed a lot of noise (jumps up to in the beginning compared to the measurements done in chapter 4.1.1.2 but stayed in average around the maximum reactive power. At 253.6 V (Figure 22) and 253.4 V (Figure 23), there was a slight increase in the reactive power before it dropped again and became unstable. The value then became quite stable at a value around 345 kVAr and afterwards at 103 kVar (both measurements).

Regarding the P(U) function, again it could be seen that the active power follows changes in the voltage quickly. However, not all steps in the active power reached a steady state. In Figure 23, it can be seen that the active power rises in the beginning although the voltage rises.

Figure 22 - Measurement of Test Case 1 with Schneider Context RL 3000 E (2)

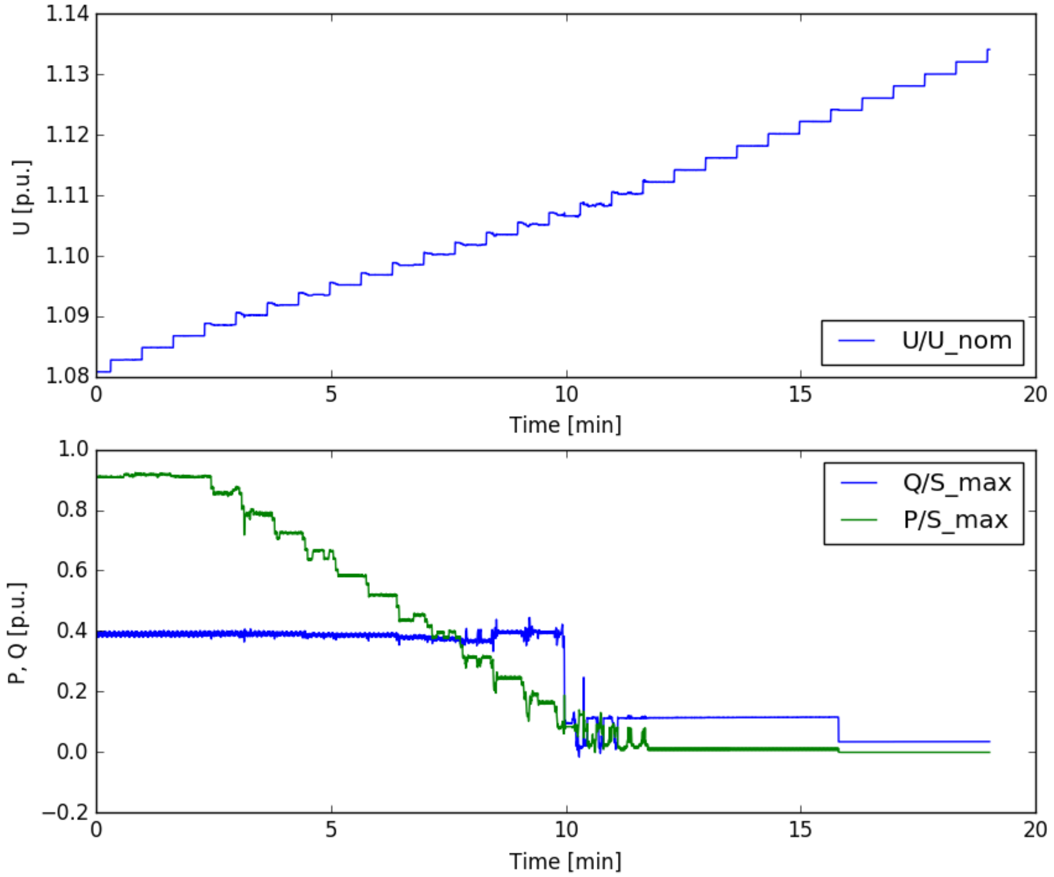
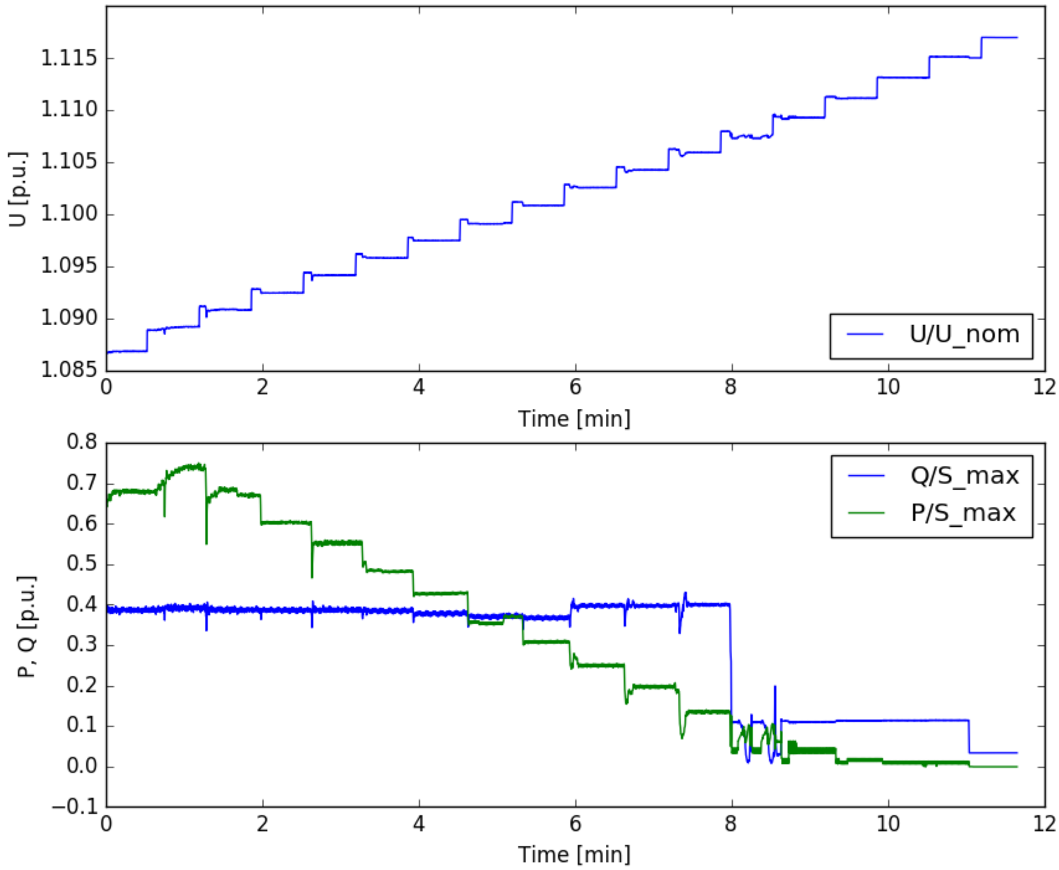
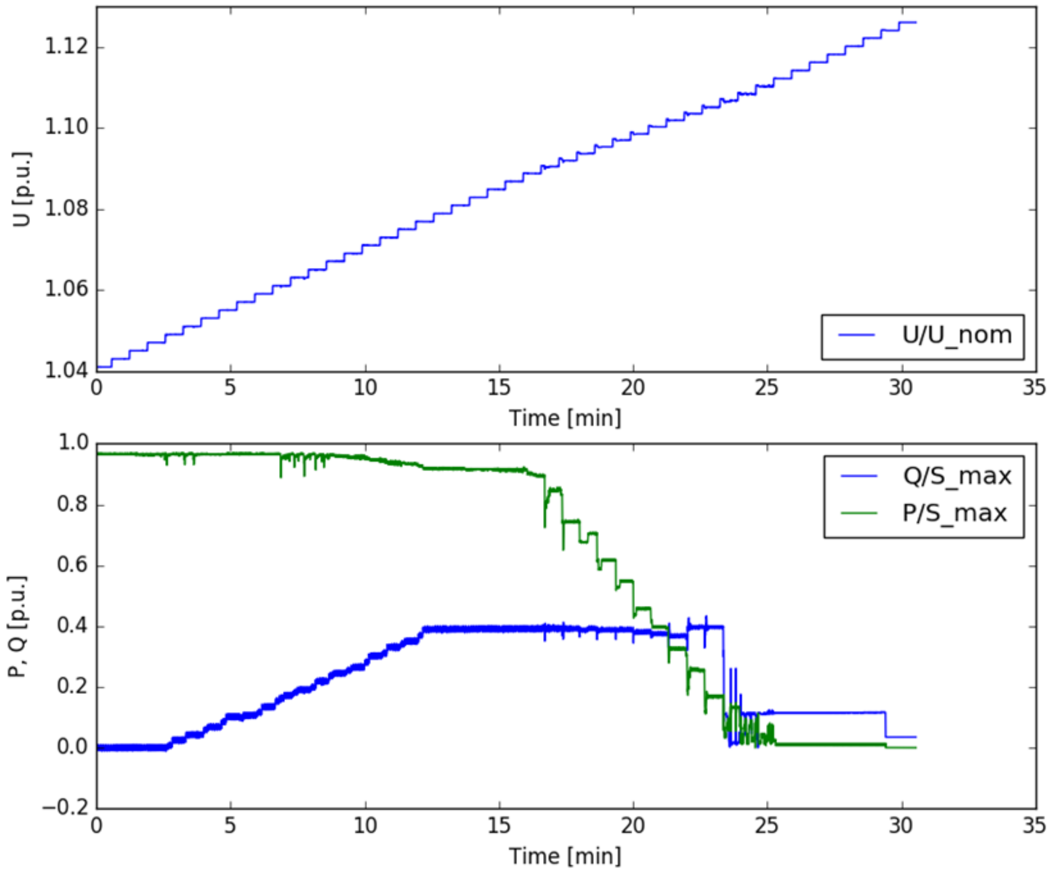


Figure 23 - Measurement of Test Case 1 with Schneider Context RL 3000 E (3)



Some internal parameters of the inverter were adjusted by the manufacturer and the test was done again with the whole testing signal (voltage stair function starts in an area where Q(U) should start to get active). The measurement recording can be seen in Figure 24. The inverter showed a similar behavior as in the measurements before. The Q(U) function became active and followed the steps in the voltage. However, the reactive power had a lot of noise, the steps did not always have the same height and for some steps even no steady state was reached. During the area of voltage where the P(U) is active, the reactive power showed a similar behavior as in the measurements displayed in Figure 22 and Figure 23. The active power again showed no totally stable reduction of power (power drops and rises during the steps irregularly, peaks at the beginning of the steps).

Figure 24 - Measurement of Test Case 1 with Schneider Context RL 3000 E (4)



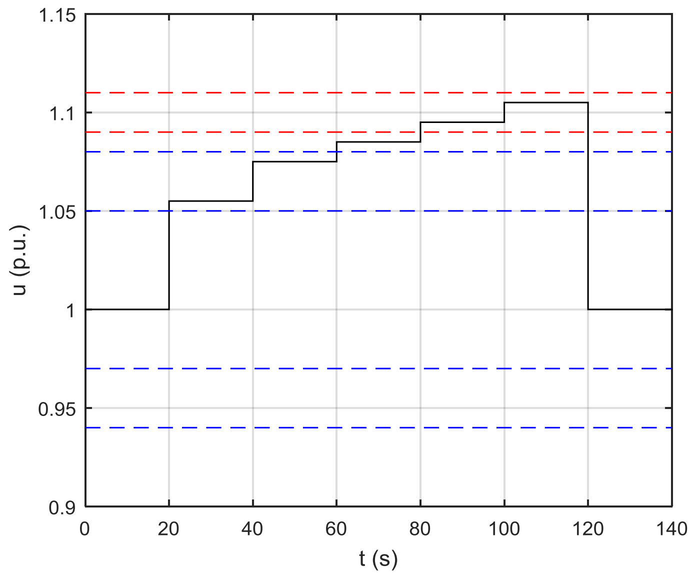
During the measurements, the curve for the P(U) function could be improved. Also, the Q(U) control stayed active while P(U) control was activated. The active power control function became active close to the set point of 109 % of U_n. However, the P(U) control did not deliver reproducible results (some steps where unstable, behavior was slightly different each measurement) and the Q(U) control became really imprecise in comparison to earlier measurements. During the voltage area where P(U) is active, also it did not stay constant the whole time. Therefore it was decided that it is not reasonable to do the detailed analysis as it was done for the Fronius device (chapter 4.2.1.1) but that there will be some improvements of the device and the additional hardware by the manufacturer first. For that reason, also no testing of the time behavior and the behavior in the "worst case" were conducted.

4.2.2 Test Case 2

The purpose of this test is to characterise the time behaviour of the P(U) control. This test was conducted without any additional impedance between network simulator and EUT. The response of the inverter to voltage jumps was recorded and analysed for the default settings of the P(U) control mode (P(U) curve and response time (see chapter 3.1 and chapter 3.2).

The voltage was varied step-wise at the output of the network simulator (see Figure 25). The duration of each step was set to 40 s which allows to reach the steady-state between each step.

Figure 25 - Test signal for the evaluation of the step response



The response time was determined using a tolerance band of ±5 % of the nominal apparent power around the expected value. This value will be compared to the target response time adjusted prior the tests.

4.2.2.1 Fronius Symo Hybrid 5.0-3-S

The detailed results of the test can be found in Table 18. The values represent a 5 s average at the end of each step (steady state). Again, the maximum voltage and an average for the total voltage (L1-L3) is given.

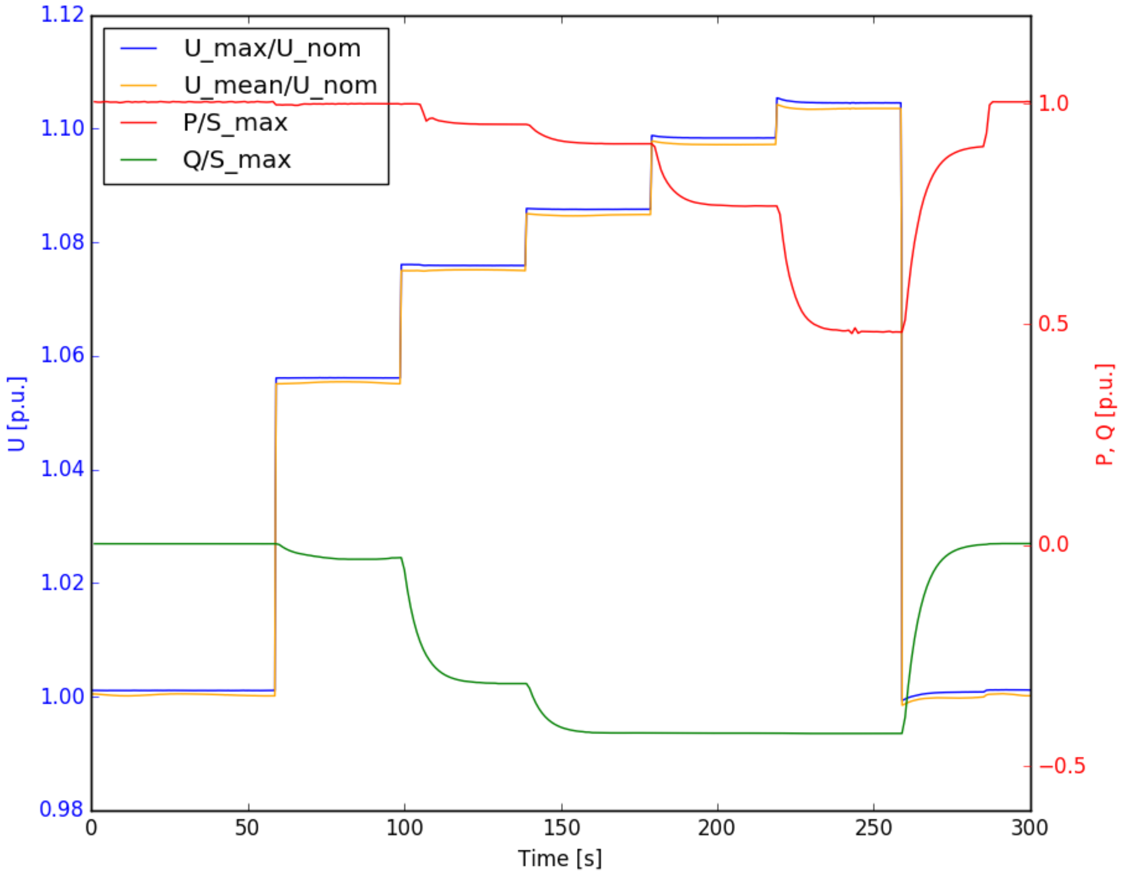
The measurement recording can be seen in Figure 26 – the voltage signal corresponds to the signal shown in Figure 25. The first three steps (242.72 V, 247.28 V and 249.52 V) are in a voltage area where the Q(U) control changes the reactive power of the inverter and the P(U) does not change the active power yet. For the first step it can be seen that the active power remains nearly constant and only reactive power rises in negative direction. Therefore no response time was determined. For the two following steps, reactive power rises again and the active power begins to reduce to not exceed the maximum apparent power (not because of the P(U) control). The response time was determined as the time until the active power reached the tolerance band around the expected value. However, as these steps were really small, the tolerance band was determined to only be ±1 % of the nominal apparent power around the expected value. For the remaining steps the tolerance band of ±5 % of the nominal apparent power was used. The remaining steps were already in a voltage area where the P(U) control reduces the active power. The reaction of the control is nearly immediately when the step in the voltage occurs.

For the step from 253.82 V to 230.11 V it can be seen that the system takes longer than before to reach the expected value. First of all, the active power rises until a value of approx. 4.5 kW simultaneously as the reactive power reduces to a value close to zero (minimum). Then, when the minimum of the reactive power is reached, the active power jumps back to its maximum which results in a response time of 28.2 s.

Table 18 - Results of Test Case 1 with Fronius Symo Hybrid 5.0-3-S

$U\_mean[V]$	242.72	247.28	249.52	252.36	253.82	230.11
$U\_max[V]$	242.91	247.46	249.74	252.63	254.05	230.27
$Q[VAr]$	15.6	-158.7	-1565.0	-2125.8	-2132.3	16.5
$P[W]$	5018.2	4997.5	4764.1	3839.7	2416.4	5019.1
$\Delta t[s]$	Only Q(U)	8.2[9]	9.0[9]	6.0	8.0	28.2

Figure 26 - Measurement of Test Case 2 with Fronius Symo Hybrid



4.2.2.2 Schneider Context RL 3000 E

No tests were conducted (cf. chapter 4.2.1.2).

4.2.3 Test Case 3

The purpose of this test is to evaluate the stability of the control under worst-case conditions. This test was conducted with an additional impedance between network simulator and EUT, adjusted to represent the worst-case conditions (see below).

The stability of a P(U) control can be handled in a similar way to the stability of the Q(U) control (see chapter 4.1.3). The stability of the control is mainly influenced by the following factors:

[9] Power reduction due to Q(U) function not because of P(U) control. As these steps were very small, the tolerance band was set to +/- 1% of the nominal apparent power around the expected value.

- Maximal active power compared to the network impedance or short-circuit power at the point of connection
- Slope of the P(U) curve
- Response time of the control
- (unwanted) time delay in the control

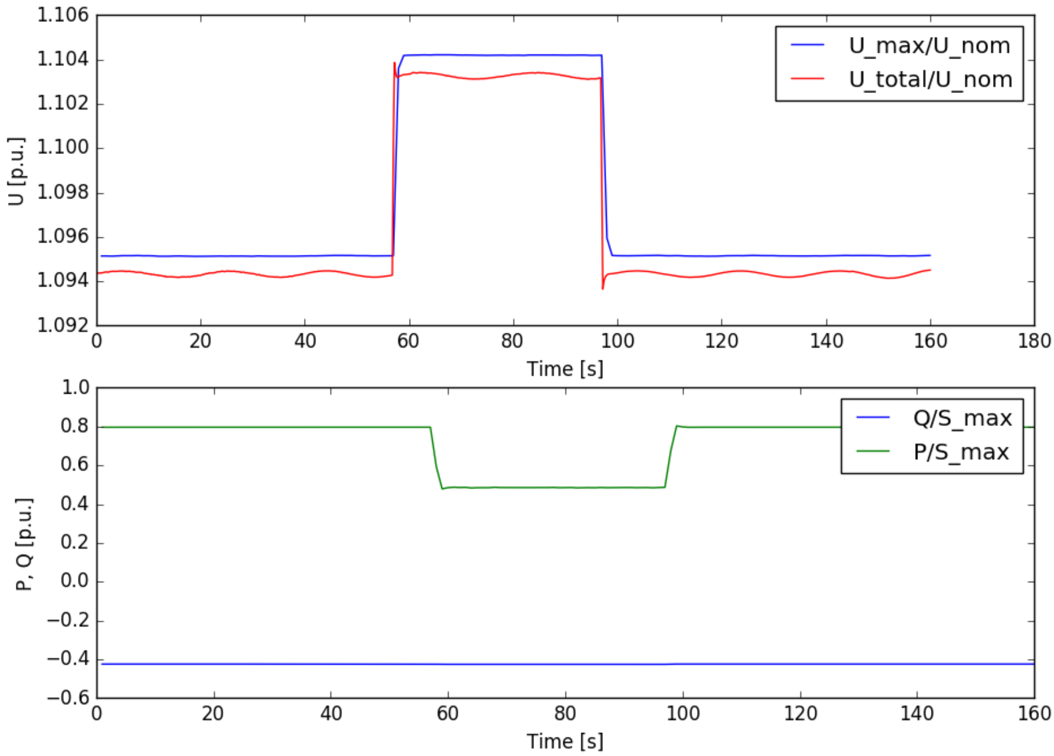
The settings of the Q(U) control and the P(U) control were set for the worst case as it can be seen in Table 2 and Table 4 (chapter 3.1 and 3.2). The response of the P(U) control to the voltage step was analysed.

4.2.3.1 Fronius Symo Hybrid 5.0-3-S

The parameters for the worst case scenario were tested separately (Figure 27 to Figure 29) and then all together (Figure 30) for the Fronius device. During the tests, the reactive power stayed constantly at its maximum in negative direction due to the over-voltage.

During the measurement shown in Figure 27, only the time constant was changed to a smaller value (0.01 s). The active power therefore does not slowly descend to its final value as it could be seen in chapter 4.2.2.1, but jumps really quickly to it. The P(U) control maintained stable during this test. Phase L3 showed some oscillations in the voltage (can also be seen in the resulting average of all three phases) during this test which did not affect the P(U) control.

Figure 27 Measurement of Test Case 3 with Fronius Symo Hybrid – time constant set to 0.01 s



In Figure 28, the additional grid impedance was used (same as in chapter 4.1.3.1, Table 15). The voltage decreases on all phases due to the P(U) control. The highest decrease can be seen on the voltage of phase L1, where the grid impedance is the largest.

Figure 28 - Measurement of Test Case 3 with Fronius Symo Hybrid – additional grid impedance

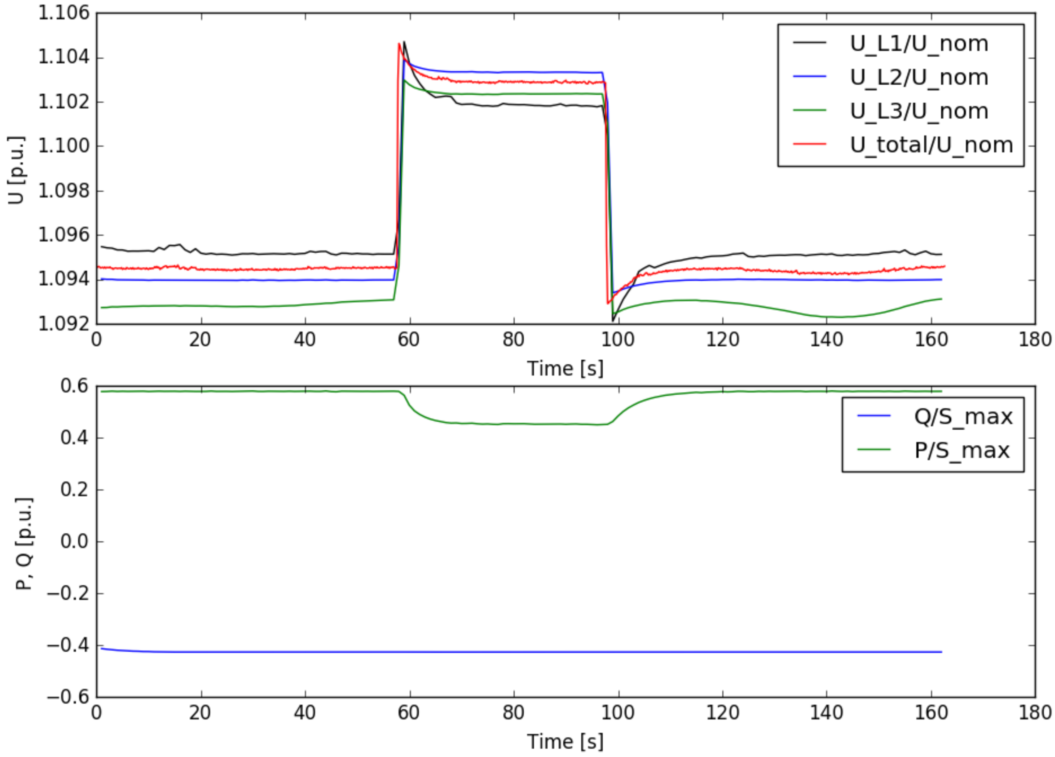


Figure 29 shows the measurement during which the P(U) curve was made steeper. Therefore only a small step in the voltage was necessary to see a large decrease in the active power. Again, the control maintained stable. During this measurement, also the grid impedance was active. Therefore the reaction of the voltage to the P(U) control can be seen very well (slow decrease/rise depending on the active power).

Figure 29 - Measurement of Test Case 3 with Fronius Symo Hybrid – steeper P(U) curve and additional grid impedance

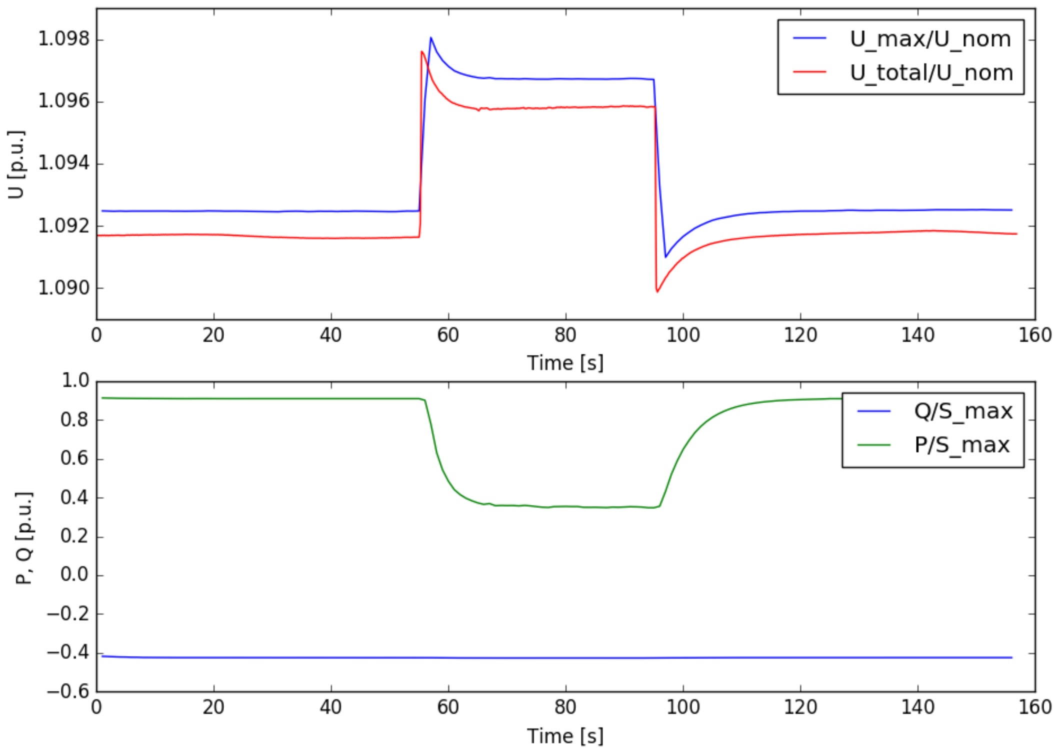
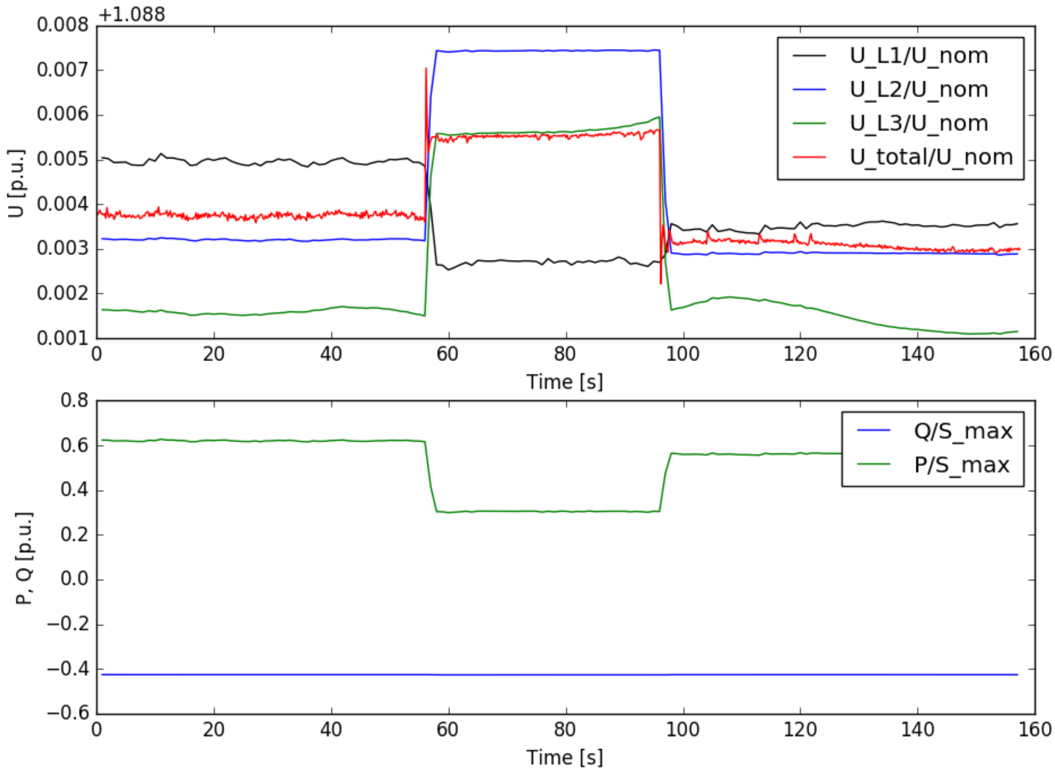


Figure 30 shows the measurement where all “worst case parameters” were set to their value for the worst case. It can be seen that the P(U) control remains stable and reacts quickly to small changes in the voltage by setting the active power to a constant value according to the respective voltage. The voltage on phase L1, where the grid impedance is the largest, can be remarkably reduced due to the P(U) control.

Figure 30 - Measurement of Test Case 3 with Fronius Symo Hybrid – all worst case parameters changed



4.2.3.2 Schneider Context RL 3000 E

No tests were conducted (cf. chapter 4.2.1.2).

5 Conclusion

The tests for InterFlex UC1 showed that the reactive power control is already very well implemented for both devices (Fronius Symo Hybrid 5.0-3-S and Schneider Context RL 3000 E). Only small deviations from the given Q(U) curve settings could be seen in the demonstration.

Regarding the response time, both inverters show a different behavior. The Fronius device reacts nearly immediately to changes in voltage and then slowly increases reactive power to its final value. The Schneider device shows a longer dead time und then increases reactive power to an intermediate value before it is then again increased to its final value in form of a step function. In some cases, the intermediate step could not be seen.

In the worst case scenario, the Schneider device did not stay at a fixed operating point but changed its reactive power every 10 seconds. The Fronius device stayed at a constant value depending on the current voltage.

The P(U) function is already working very well for the Fronius device. The inverter reacts very fast to a change in voltage and then slowly decreases active power to its final value. The stability could also be maintained during worst case conditions.

For the Schneider device there was an additional hardware necessary for the P(U) control. Therefore some instabilities in the control function could be seen. However, there will be some further improvements by the manufacturer.