D8.6: Tallinn extra-urban area UC-5 complete solution description

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T8.4: Superfast charging systems for European Corridors – Tallin Area

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Technical References

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[1] PU = Public

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CO = Confidential, only for members of the consortium (including the Commission Services)

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Document history			
V	Date	Partner(s)	Action
V0.0	06/04/22	CIRCE	Table of Content available for WP7 and WP8 deliverables
V0.1	20/06/23	EESTI, CIRCE	First Draft.
V0.2	23/06/23	CIRCE	First Technical Revision
V0.3	27/06/23	EESTI, CIRCE	First Consolidated version of D8.6.
V0.4	30/06/23	CIRCE	First Quality Review
V0.5	12/07/23	EESTI, CIRCE	Second Consolidated Version of D8.6
V1.0	21/07/23	CIRCE	Final Quality Review

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0 EXECUTIVE SUMMARY

This document is the deliverable "D8.6 – Use case solutions modelling, simulation, engineering and equipment development according to demo-site" of the H2020 project INCIT-EV (project reference: 875683).

The main objective of this deliverable is to collects the main conclusions reached after finalizing the modelling, basic and detail engineering, and equipment development activities before the deployment of the UC-5.

The UC-5 represents the Super-Fast Charger (SFC) system and 200 kW DC chargers development to provide for EV users the fast charging experience in Tallinn peri-urban area. Additionally SFC system with SCADA and VPP platform enables to provide ancillary pservices for DSO and TSO.

The delivery of this deliverable is done in accordance with the description in the Grant Agreement Annex 1 Part A with no time deviation and no content deviation from the original planning.

Table of content

INCIT-EV

List of figures

NO TABLE OF FIGURES ENTRIES FOUND.

List of tables

ACRONYM LIST

Table 1 Acronym List

Acronym	Definition
SFC	Super-Fast Charging
DSO	Distribution System Operator
CPO	Charging Point Operator
VPP	Virtual Power Plant
SCADA	Supervisory Control and Data Acquisition
AFE	Active Front End
AC	Alternative Current
CCS	Combined Charging System
DC	Direct Current
EV	Electric Vehicle
EMC	Electro Magnetic Compatibility
V2G	Vehicle to Grid
RTU	Remote Terminal Unit
THD	Total Harmonic Distortion
ZVS	Zero Voltage Switching

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1 INTRODUCTION

INCIT-EV aims to demonstrate an innovative set of charging infrastructures, technologies, and associated business models, ready to improve the EV users experience beyond early adopters, thus, fostering the EV market share in the EU. The project will seek the emergence of EV users' subjective expectations. 5 demo environments at urban, peri-urban, and extra-urban condition will be ready for the deployment of 7 use cases addressing:

- UC1: Smart and bi-directional charging optimized at different aggregation levels – Amsterdam – Utrech Area
- UC2: Dynamic wireless charging lane in urban areas - Paris
- UC3: Dynamic wireless charging for long distances -Versailles
- UC4: Charging Hub in a Park & Ride facility – Torino
- UC5: Superfast charging systems for EU corridors - Tallin
- UC6: Low power DC bidirectional charging infrastructure for EVs, including two-wheelers.
- UC7: Opportunity wireless charging

1.1 Contribution to INCIT-EV Objectives

WP7 and WP8 "Use Cases deployment and demonstration in urban and extra-urban areas" of the INCIT-EV project aims to model, design and develop the use cases to be demonstrated in all areas with aim of collecting real data from the field. The specific objectives are:

- To elaborate a plan for the successful deployment of the innovative use cases to be demonstrated (D7.1 and D8.1)
- To model, design and develop the different solutions addressing to be implemented in the project
- To commission all the developed equipment and prepare the field for the demonstration activities.
- To carry out the demonstration activities of the use cases, monitoring the defined KPIs for its ulterior contrast and analysis.
- To analyse the medium and long-term impacts of the use cases evaluating their techno-economic, environmental, regulatory and social aspects.

This deliverable collects the main conclusions reached after finalizing the modelling, basic and detail engineering, and equipment development activities before the deployment of the UC-5.

1.2 Contribution from partner table

Table 1 - Contribution table

Partner	Contribution
24. EESTI ENERGIA	• **Leading UC 5 project** • Defining the charger specifications • Setting up the VPP and SCADA platforms • Designing the charger externally • Planning the chargers installation procurement • **Grid works**
1. CIRCE	• Design of the AC/DC and DC/DC power electronics modules used in SFC design • AC/DC and DC/DC modules test • SFC electrical design • SFC assembly and test

1.3 Relation to other project activities table

Table 2 - Relation to other project activities table

Task	Relation to other project activities
T3.1 - Cost-effective low and medium Power DC-DC bidirectional chargers	Theorical modelling of the solution
T3.2 - Superfast conductive charging systems improvement	Theorical modelling of the solution
T4.2 - Grid services enabled by charging infrastructure and ESS deployment	Theorical modelling of the solution
T8.5 - Evaluation and impacts assessment	Short-term impacts

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2 UC5 OBJECTIVES

The main consideration behind UC5 is to give additional value to Mode 4 chargers as defined by IEC 61851-1. From the technical point of view, such chargers have active front end (AFE) power converters on the utility grid side, which are known for their ability of four-quadrant operation, meaning bidirectional active and reactive power exchange capabilities.

The main objective is to develop an innovative Super-Fast Charging (SFC) system with two 200 kW DC super-fast chargers that provide ancillary services and EV charging service for EV users at Tallinn peri-urban area gas stations. The partners involved in UC5 are Eesti Energia and CIRCE.

This technology will contribute to reducing range anxiety, that is one of the major concerns of users on long-range trips. In this sense, taking for example a 40-kWh battery, it will only take 12 minutes to fully charge the EV using this super-fast charger.

Moreover, these SFCs, that are generally seen as a burden for electricity distribution grids since they consume high amounts of energy in short timeframes requiring expensive investments in strengthening the grid to cover the peak load of their systems, could serve a dual purpose. In this sense, they will act as load leveling devices that support the stability of the power system during time periods when it is idle from charging electric vehicles.

Furthermore, due to the growing number of RES such us solar panels and wind generators that have been recently added to the grid, it is necessary to increase the voltage level on their inverters or create a phase shift in the voltage. Thus, if many of these independent generators and converters are connected to the grid, there might be problems with the stability and quality of the energy supply. In this vein, HPC will be used in the power grid as reactive power compensator in addition to charging the car. For example, if there is a voltage swell in the power grid, the charger is set to behave as an inductive load, in case of voltage dips the behavior is more capacitive. Hence, public V2G electric car chargers will act as controlled electronic inverters, communicating with each other over the same platform and keeping their power quality on good level, thus leading to a reliable, intelligent, robust power grid.

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3 UC5 COMPLETE SOLUTION

Services provided / Problem solved

The high power 200 kW DC chargers are ready to provide grid services. It will be controlled by specified software to use its power electronics to assist the grid according to DSO needs when no electric vehicles are connected to the charger.

Fig. 1 shows the communication scheme via DSO, VPP and Enefit Volt platforms between charger and the stakeholders as DSO, TSO and EV-drivers.
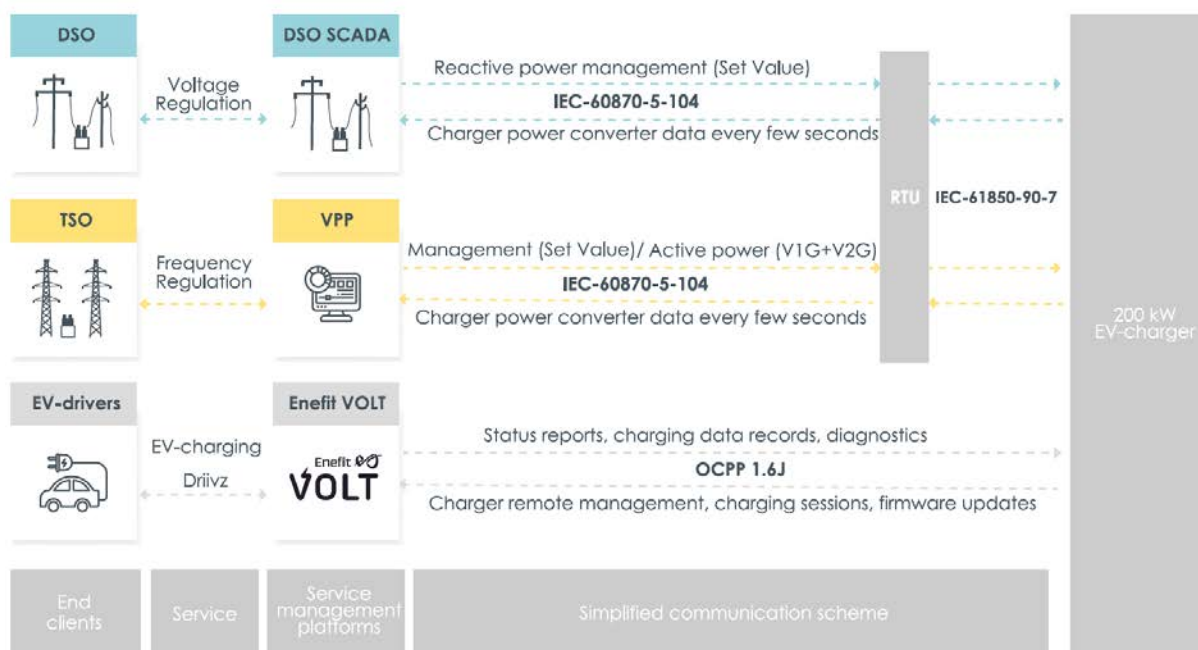

Fig. 1 Defined solution

The following services have been identified for its testing within INCIT-EV:

1. At the end of long low-voltage feeders (locations with limited power), where unpredictable loads are more prone to tamper line voltage. Unpredictable and rapid high loads at the end of long feeders can cause voltage drops that will affect all connected devices/customers. Such voltage drops can cause current surges and malfunction or permanent damage to customer devices. In such cases Super-Fast charger shall act as either:

   a) remotely controlled load

   b) static reactive compensator with high response time to avoid voltage drops that will cause power failure

2. Near energy generators and, especially renewable energy sources. High volumes of low voltage distributed energy resources affect the power quality in many ways: Unpredictable generation will tamper the local voltage level and the grid must respond to it. In the case of high-RES generation level, the local grid voltage will rise and can cause severe damage to customers and OT assets. By installing bidirectional charger to the grid, it can respond to the generation by controlling the production/consumption.
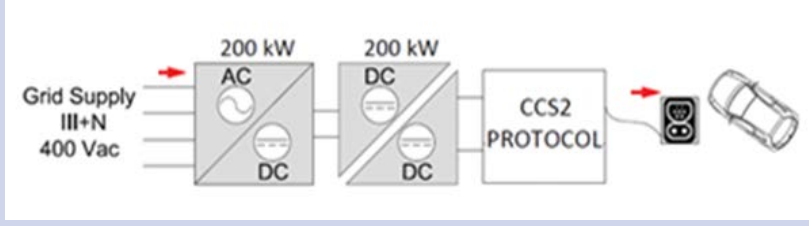
Final design

To achieve a 200-kW active power output for EV charging, power electronics modules with a rating of 50 kW have been developed. This development includes an AC/DC module and a galvanically isolated DC/DC module.

The specifications of the 50 kW AFE module need to be designed to operate at an AC voltage of 400 Vac, with voltage variations as required by the standard, and a variable DC voltage between 700V and 800 V. The current on the grid should have a THD lower than 3%. The equipment's efficiency must exceed 95%. Additionally, it has been determined that the switching frequency should be 48 kHz to ensure that the third harmonic is below the typically measured conducted emissions range of 150 kHz to 30 MHz, as per the standard.

The DC/DC module should have a continuous input voltage ranging from 700 V to 800 V, and a variable output voltage between 250 V and 1000 V, which corresponds to the vehicle battery voltage it will be connected to. The maximum current per module is limited to 62.5 A, resulting in a total current of 250 A for the system. A minimum efficiency of 95% is also defined. The working frequency of the resonant tank will vary depending on the transformer inductance and capacitors. According to initial calculations, the working frequency will range between 48 kHz and 65 kHz, depending on the operating point.

In the next table 4. the technical specifications of the SFC are presented.

Table 3 – SFC specification

Specification	Description
Block diagram:	
Power rated:	400 Vac / 50 Hz / 200 kVA 3-phase System + Neutral (III+N) CCS 2 DC Connector 250 A / 250 – 1000 V

Main characteristics:	4-Leg AC/DC converter DC/DC Converter: DC/AC-HF Converter + AC-HF/DC Converter Galvanic isolation High frequency switching SiC semiconductors technology Low harmonic current Accurate operation
Main functionalities:	Power factor variable in function of needs Reactive power balance CCS2 charger

Number of charging points / power /technology used

For UC5 demonstration, two locations were selected in Tallinn peri-urban area as indicated by "☆"   in Figure 2. The location selection was made based on next arguments:

1) Ease of access from the main highway;

2) nearby a petrol station with a small shop or cafe;

3) nearby a transformer substation;

4) ease of transformer station and cabling upgrade;

5) renewable (solar) electricity producers nearby;
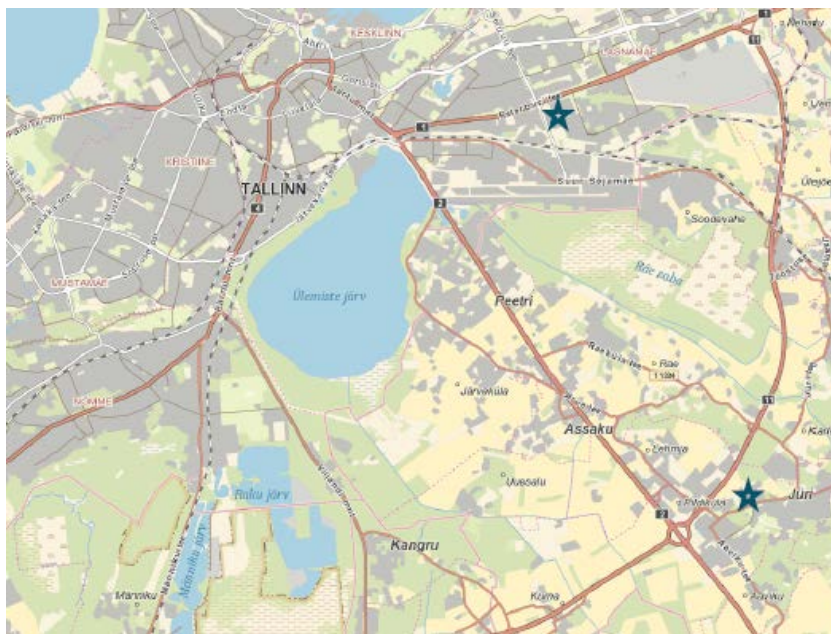
6) cooperation willingness of the landowners.

Fig. 2 Defined locations

Table 4 – Measured reactive power at defined locations

Location	Average reactive power
Jüri	2060 kvar inductive
Tallinn- Lasnamäe	603 kvar inductive/ 517 kvar capacitive

The grid works are done – increasing the ampacity in the substation and new substation installation.

In Fig.3 there is shown that the AFE inside the SFC is principally a voltage source converter (VSC) with an LCL-filter on the AC side, enabling both active and reactive power control in a bidirectional manner. Whereas bidirectional reactive power control is an inherent AFE property, active power injection into utility grid requires either long-term electricity storage elements to be installed into the power conversion chain or vehicle-to-grid capabilities of electric vehicle to be charged.
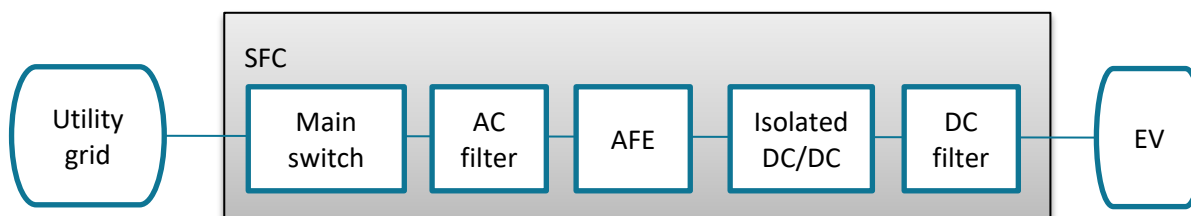

Fig. 3 Filters in the SFC

3.1 UC5 Final modelling and engineering results

Electrical design

Fig. 4 below shows the electrical diagram of the SFC. It is composed of 4 AFE and 4 isolated 50kW DC/DC converters each.
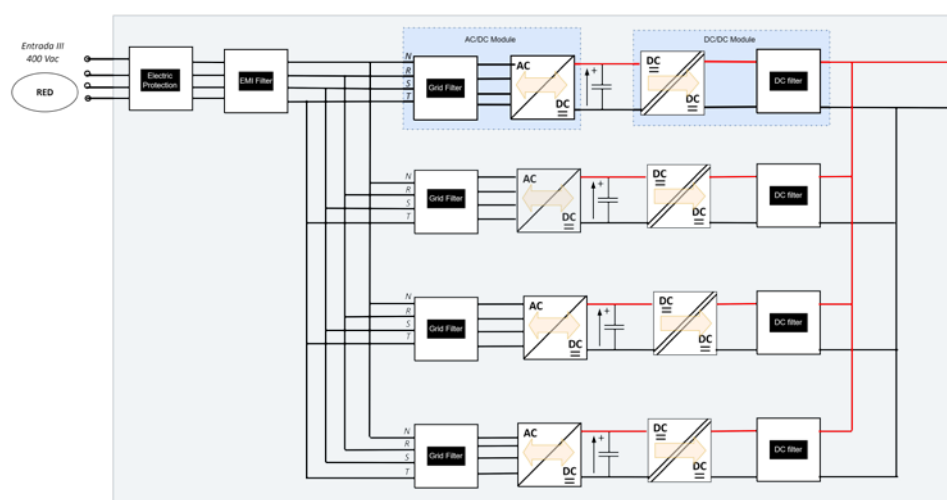

Fig. 4 Electrical diagram of SFC

For the assembly in the electrical cabinet, it has been decided to design the modules with rack dimensions of 19" with a length of 60 cm and 5U so that it is easily usable for other designs that is required for a lower or higher power by parallelizing the modules.

The electrical scheme of the AFE design is shown below in Fig. 5. It is formed by 3 branches of SiC technology mosfets, to be able to increase the working frequency and reduce the power filter.
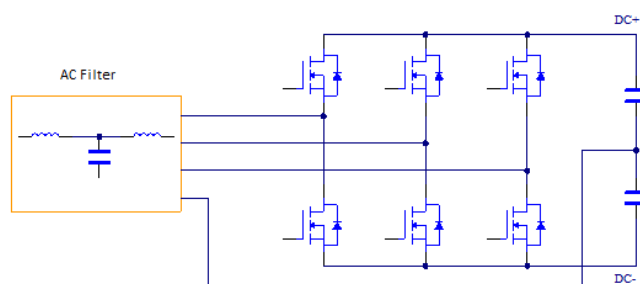

Fig. 5 The electrical scheme of AFE

In the design of the AFE rack size module, coupled with the inclusion of the AC filter, a clear demarcation has been established between the control part and power part by means of an aluminum plate. This demarcation serves the purpose of preventing potential interference that could adversely impact the functioning of the control. Within the control segment, the Switched-Mode Power Supplies (SMPS) are incorporated to provide the requisite voltage levels. Additionally, a control card, equipped with a Texas Instruments Digital Signal Processor (DSP), undertakes the task of overseeing the management of power electronic control. Conversely, the electronic power component is comprised of two contactors within the SFC. The first contactor, characterized by lower power capacity, is responsible for initiating preloading of the DC bus by utilizing a resistor. The primary contactor, on the other hand, establishes the connection between the SFC and the grid. The AC/DC converter part and filter is formed by several PCBs where the Mosfet SiC are welded with the trigger and control drivers, the necessary measures are also made for the control and another filtering PCB along with the three inductances that can be observed. In Fig. 6 below, the final mounting of the AFE rack is represented.
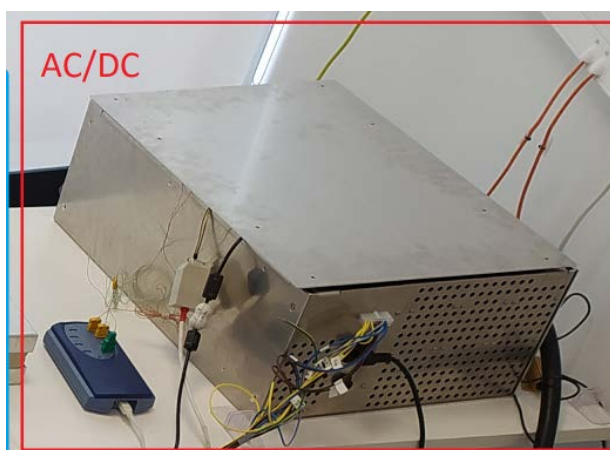

Fig. 6 AC/DC module

The electrical scheme of the DC/DC is shown below in Fig. 7. The design is composed of two H-bridges, one primary and one secondary composed of SiC technology mosfets modules, a transformer with relation 1:1 with a leakage inductance designed to work in resonance with defined capacitors. The system works in ZVS to minimize the switching losses and increase equipment efficiency. A DC filter has been calculated on the secondary side.
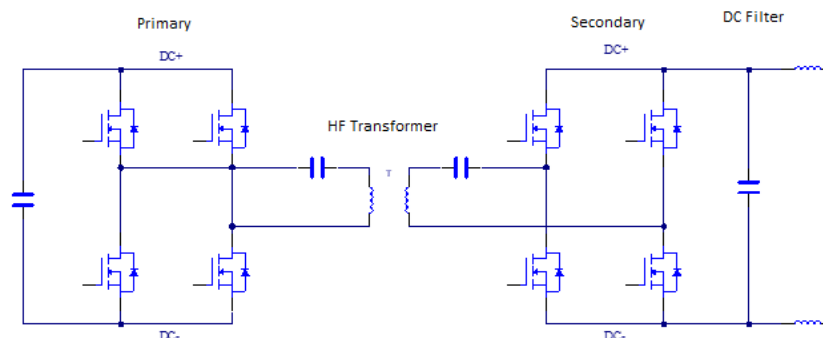
Fig. 7 DC/DC electrical scheme

The design of the DC/DC module, just as the design of the AC/DC module has been designed in a rack size of 19" are a length of 60 cm and 5U.

In this development, the control part is located at the top of the equipment. It consists of the control PCB, which includes a Texas Instruments DSP and power supplies. At the bottom, there are two power cards, each equipped with an H-bridge (primary and secondary), mounted on heatsinks. The mosfet modules with thermal paste and HF transformer are also placed on the heatsinks. The DC filter is designed on the secondary PCB. The final assembly can be seen below in Fig. 8.

Fig. 8 DC/DC module

Below are the waveforms obtained in the developed equipment.
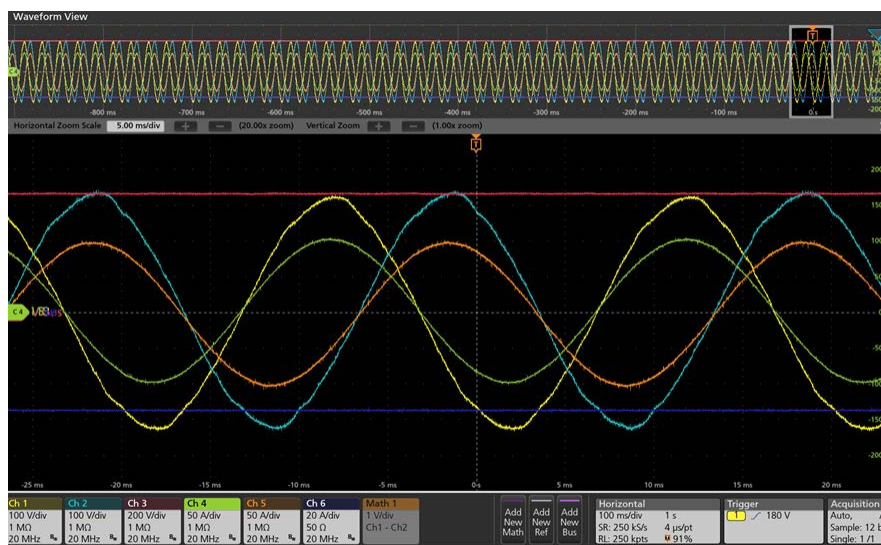

Fig. 9 Waveforms obtained.

Fig. 9 shows the waveforms of two-phase voltages of the electrical grid (yellow and blue) and its two-phase currents (green and orange) during a test with a power consumption of 50 kW. Visible is also the voltage of the continuous bus (red).
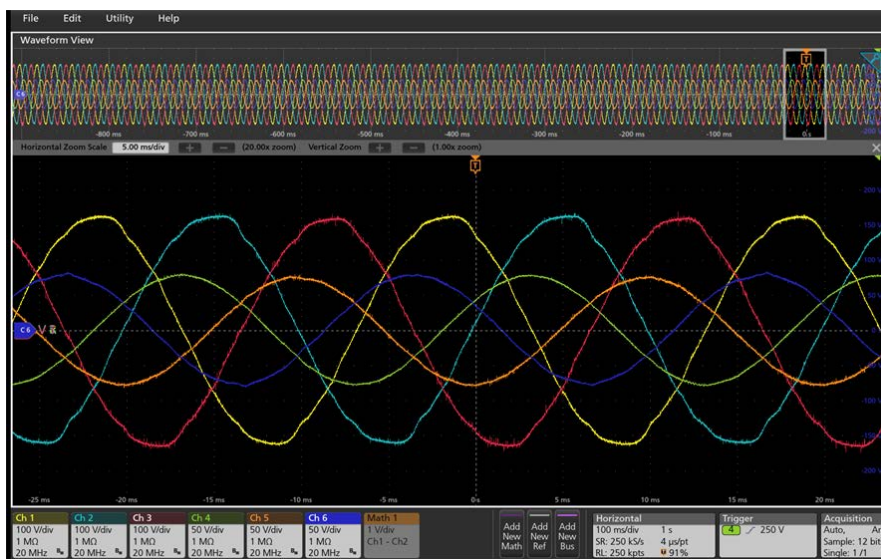

Fig. 10 Waveforms of two-phase voltages and two–phase currents during the 50-kW power consumption test

Fig.10 shows the waveforms of the three phase voltages of the electrical grid (yellow, blue and red) and their currents, delayed 90º (green, orange and blue) because we are working as a purely inductive load of 37.5 kVAr.

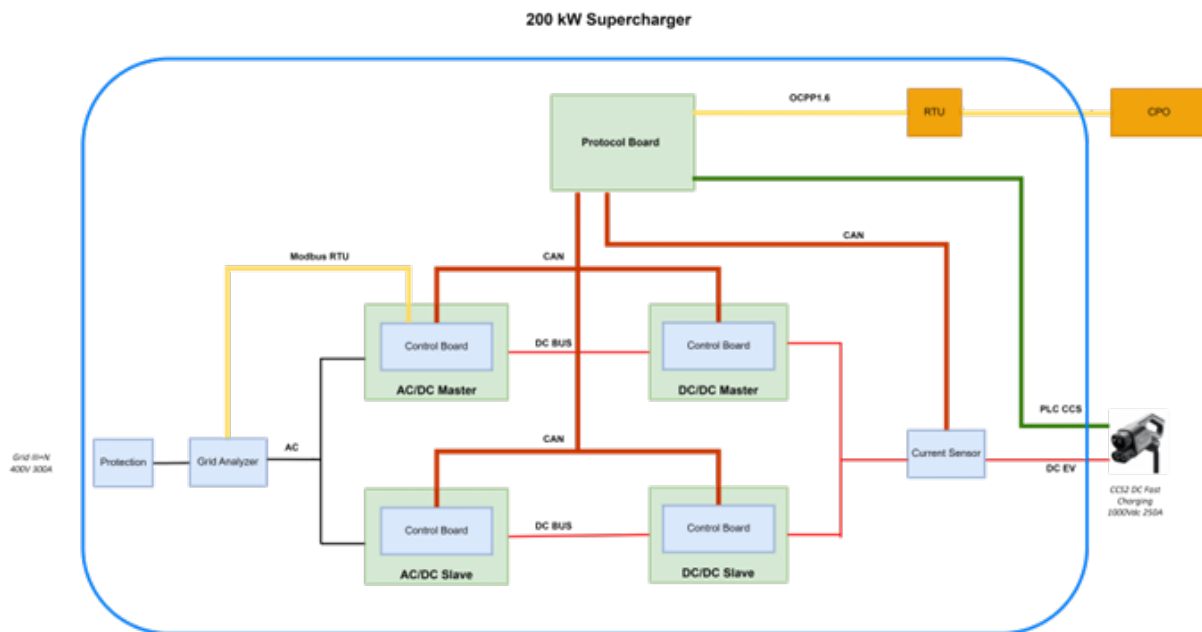The following Fig. 11 shows the communication scheme between all elements of the system.

Fig. 11 The communication scheme in SFC

- CAN communication. Ring Protocol Board with power electronics modules.

CAN communication is used between all power electronics modules. A DC/DC module is the master, this module is responsible for communication with the protocol card, so it manages the other modules. The AC/DC master module handles the pushbuttons and LEDs of the SFC.

- CAN communication. Protocol board with current sensor.

A SFC current sensor has been installed, this current is the sum of the currents of all modules, in addition it also performs the voltage measurement. This sensor carries a CAN communication and is managed by the protocol board.

- Modbus RTU. Grid Analyzer with AC/DC module master.

The grid analyzer performs all the measurements of the electrical network, and the AC/DC master module asks you for the measures needed for the management of the SFC. All these measures are sent to the protocol board for the CPO to be informed.

- PLC CCS communication.

It is the communication protocol CCS2 Combo, performed by a Raspberry Pi integrated in the protocol Board.

- OCPP1.6. Protocol Board communication with RTU

Mechanical design

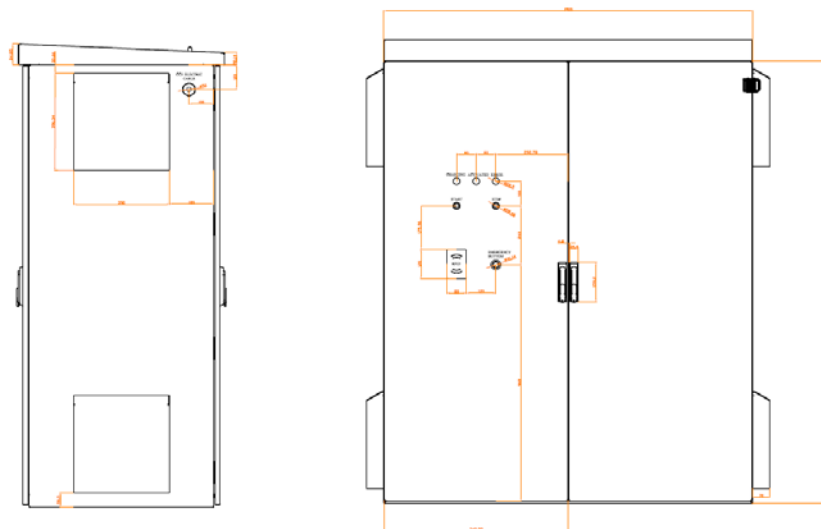Fig. 12 shows the final design of the SFC power cabinet.

Fig. 12 Design of the SFC cabinet

The following equipment has been placed on the front of the cabinet:

- 2 push buttons. Push button and stop button.
- 3 leds. Equipment in error (red), equipment with voltage on the bus (yellow), equipment running (green).
- Emergency button.
- Reader RFID

The size of the SFC has been designed with dimensions of 1800 x 1500 x 800 mm.

Inside the cabinet there are two 19" rack racks and a height of 38 U each frame, the frame depth can be adjusted up to a maximum of 80cm, allowing you to assemble the 8 power electronics modules.

The minimum IP grade required is IP 55, the cabinet has a higher IP grade but when adding forced ventilation, the final IP is IP55.

The thermal calculations for SFC have been performed with a minimum temperature of -30ºC and a maximum of 35ºC, the absolute maximum and minimum temperatures recorded in Tallinn-Harku during 1991-2020 are -29.4ºC and 34.3ºC [1]. Heating power necessary of 1492W, it has decided place two heaters

of 750W. With this heating power we ensure that the internal temperature of the SFC is greater than 2ºC. Loss of equipment while in operation has not been considered in calculating the required power.

- It has been calculated that the flow necessary to keep the SFC internally below 60 ºC is 1095 m3/h, two IP55 fans have been installed with a flow of 630 m3/h each.

Below are the cabinet images before installing the power electronics modules.

Fig. 13 SFC cabinet before installing

In the development of AC/DC and DC/DC modules, thermal tests have been performed to see the performance of the equipment.

Below are the following tests performed with the AC/DC module with different working instructions. (Blue-heatsink, red-coil case, green-coil winding)

- 50 kW of active power for 40 minutes.
- 37,5 kW of active power for 1 hour
- 37,5 kVAr capacitive for 3 hours
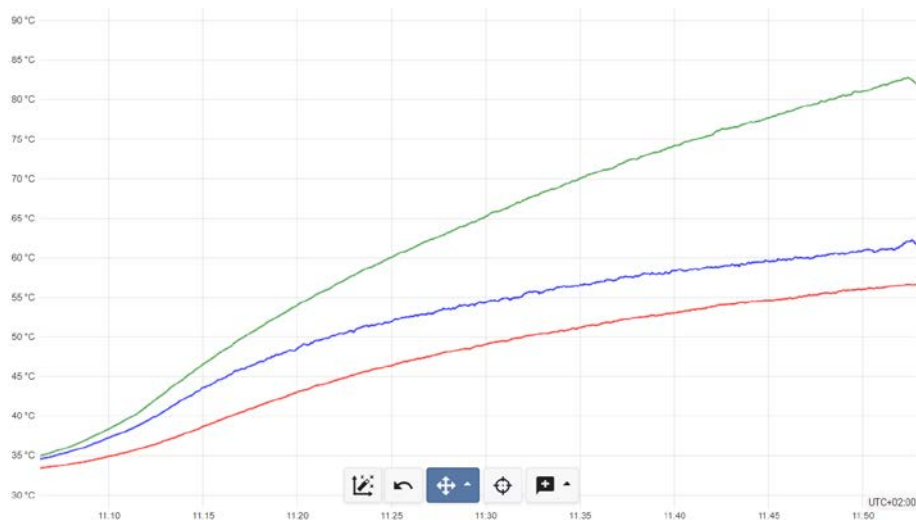- 37,5 kVAr inductive for 4 hours

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Fig. 14 AC/DC module test with 50 kW of active power for 40 minutes
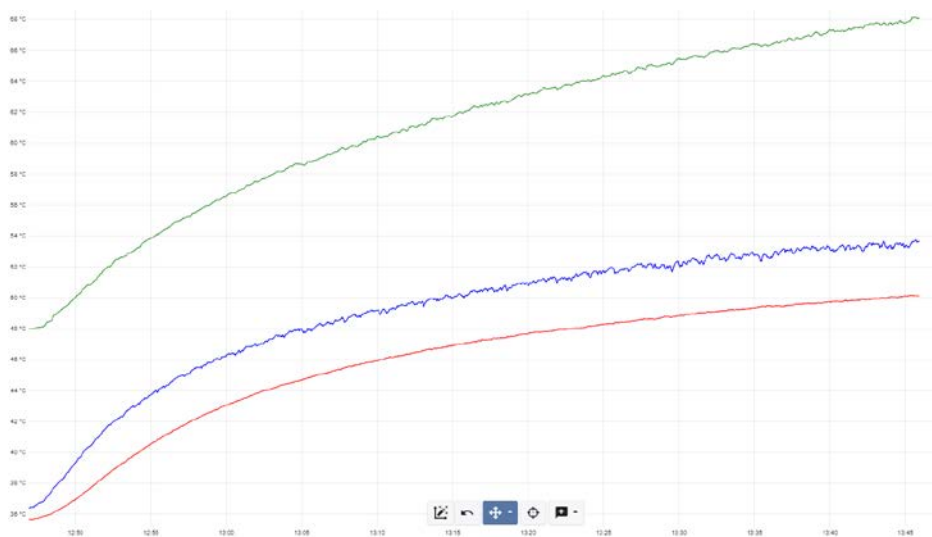

Fig. 15 AC/DC module test with 37.5 kW of active power for 1 hour
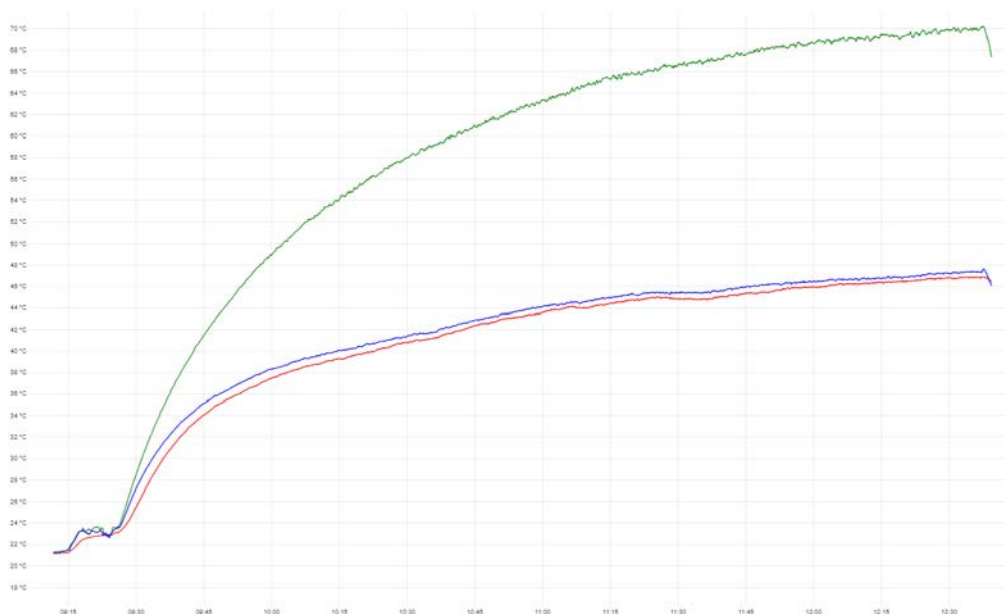
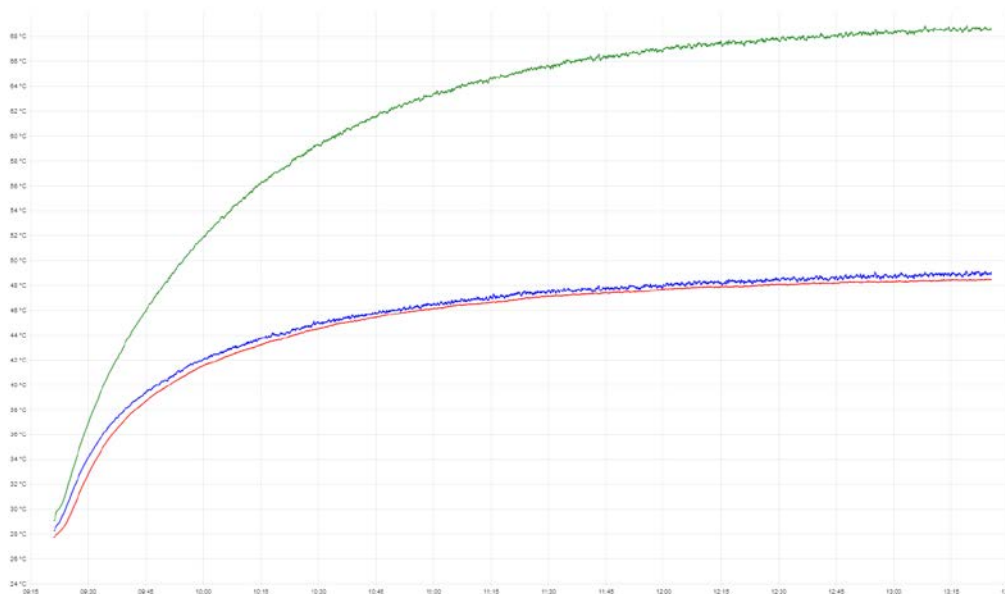*Fig. 16 AC/DC module test with 37,5 kVAr capacitive for 3 hours*

Fig. 17 AC/DC module test with 37,5 kVAr inductive for 4 hours

In Fig. 18 is a test with DC/DC module with a bus voltage of 700 V and a battery voltage of 700 Vdc, the battery charge setpoint is 62 A, therefore, we are delivering a charging power of 43.4 kW. A test of 1 hour with constant power has been performed.
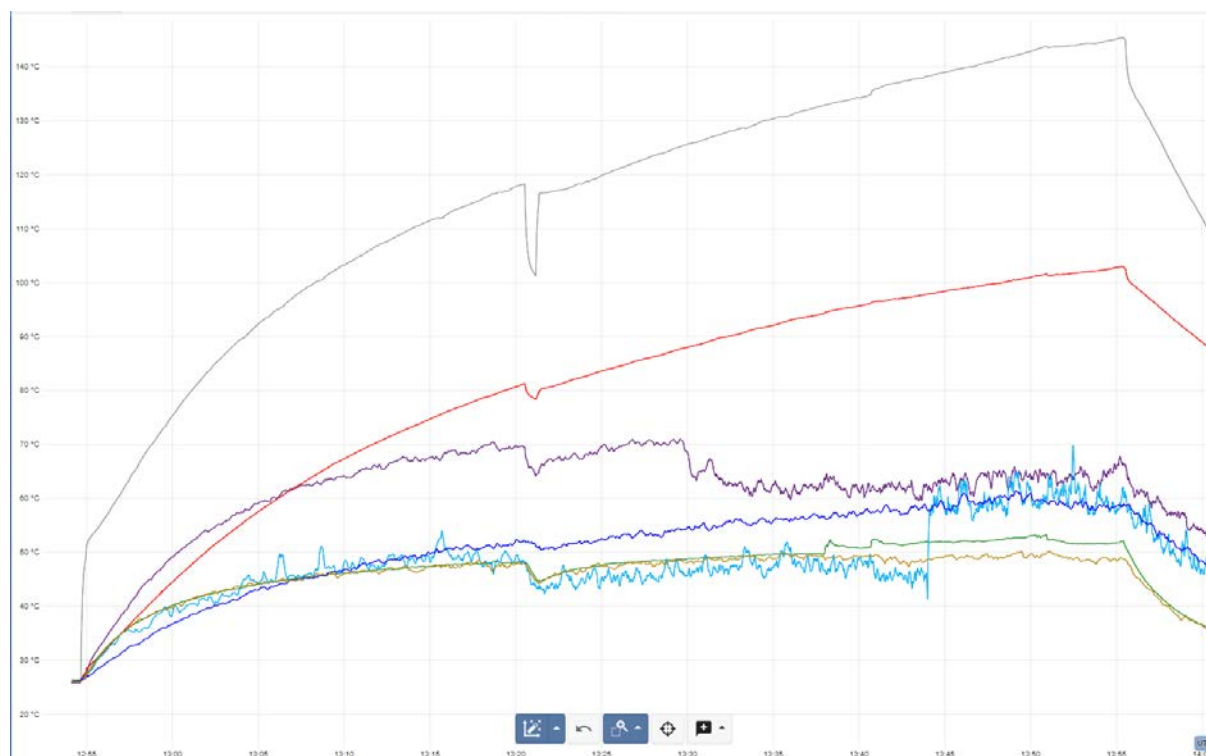
Fig. 18 DC/DC module test with a bus voltage of 700 V and a battery voltage of 700 Vdc

The following thermal measurements are shown in the figure:

- Transformer Case   Light blue
- Transformer primary winding 1   Dark blue
- Primary coil winding   Red
- Transformer primary coil winding 2   Grey
- Transformer secondary coil winding   Purple
- Primaries heatsink   Yellow
- Secondary heatsink   Green

In the test phase, network quality measurements were also carried out where we obtained the current THD.

With a nominal current of 72 A the harmonic distortion of each phase is:

- THD L1 = 0,34 %
- THD L2 = 0.41 %
- THD L3 = 0.43 %

These values are well below the values allowed by the UNE Standard -EN 61000-3-12:2012.

The tests of conducted emission measurements are pending, these tests will be carried out in the CIRCE facilities.

During the power electronics module debugging process, we encountered various issues, which can be divided into two categories:

•   Problems with radiated and conducted emissions caused by the switching of SiC MOSFETs, due to high dV/dt, resulting in interference with different electronic equipment. These issues have been resolved by reducing the dV/dt through modifications in the gate resistance of the MOSFETs and analyzing the C snubber. Signal and equipment shielding have also been improved.

•   Heating of magnetic components. These issues have been addressed by making minor modifications to the design of these components and enhancing their ventilation.

Main conclusions of engineering phase.

• Complete control of power factor, allowing for improved operation of electrical lines through the injection or consumption of reactive power.
• Adjustment of active power consumption based on the limitations imposed by the DSO at that moment.
• A lower current THD has been achieved, improving the harmonic content of the connected electrical grid.
• Design of 50 kW AC/DC and DC/DC power electronics modules, enabling the development of chargers with different power ratings through parallelization.
• Mechanical rack-size design, facilitating easy installation in standard electrical cabinets.
• Development of an internal CAN communication matrix to parallelize AC/DC and DC/DC power modules, enabling module shutdown and startup based on desired power, heating, errors, etc.

3.2 UC5 Expected data to be collected.

The success of the UC-5

The success of the UC-5 is assessed after the grid & chargers tests.

EV user KPI:

• Charging time reduction

Charger KPIs:

• Efficiency
• Threshold

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DSO KPI:

- Reactive power management and reduction in DSO grid

TSO KPI:

- SFC system support through the flexibility offering for TSO.

The information that will be collected:

EV user

The signals between the SFC and the DSO's SCADA system are logged cyclically with timestamps, which allows mapping with data from upstream and neighboring grid nodes, like district MV distribution substation and renewable sources in the neighborhood. In order not to overload the data communication channels and the database, the 1 s cycle length is sufficient.

Power quality data collection

The running grid parameters are recorded and estimated by using the measurement apparatuses inside the SFC, transformer and district substations. Inside substations, measurements are done by state-of-the-art feeder terminals, which can acquire enough grid parameters.

For more thorough analysis, portable power quality analyzers were procured to be installed into the nodes of interest. These analyzers record timestamped and synchronized data to be collated for finding correlations between grid parameters' changes during the SFC operation. Moreover, it is mandatory to make sure a SFC causes no interference in the utility grid which may negatively affect the functionality of DSO's operational assets.

The tentative dataset of monitored signals is shown in Table 1. These signals can be divided into following signals:

1) references (setpoints) from the DSO;

2) acknowledgments from the SFC – conditioned setpoints considering internal limitations;

3) feedbacks – how well does the SFC's internal control follow the acknowledged setpoints;

4) other grid values;

5) internal DC values;

6) charging voltage and current.

DC charging voltage and current monitoring is necessary to characterize various vehicles and their charging limitations as well as to estimate SFC's efficiency at different power levels.

Data collection

From TSO sight - data mediated with VPP

1. Data from SFC to VPP

a. Up flex capacity - how much active power can be increased in a given moment.

b. down flex capacity – how much active power can be decreased in a given moment.

2. Data from VPP to charger

a. Active power setpoint and period.

i. Option 1: Start time, end time, active power setpoint

ii. Option 2: Initially active power setpoint will be given, and later a new message with new setpoint or end of control will be sent.

From DSO sight - DSO signals and collected data

Table 5 – DSO signals from and to the SFC

Voltage	Current	Power	Energy
Grid voltage L1-N	Grid current L1	Grid sum active power	Active energy from the grid
Grid voltage L2-N	Grid current L2	Grid sum reactive power	Active energy to the grid
Grid voltage L3-N	Grid current L3	Active power reference	Reactive energy from the grid
Grid voltage L1-L2		Active power acknowledgment	Reactive energy to the grid
Grid voltage L2-L3		Reactive power reference	
Grid voltage L3-L1		Reactive power acknowledgment	
DC charging voltage	DC charging current		

3.3 UC5 Innovation

The main novelties related to UC5 are:

1) Linking a SFC to the DSO's control center and virtual power plant platform in addition to standard CPO backend. Thus, a SFC can contribute to grid control, including flexibility services.

2) Enhanced utilization of the built-in AFE converter present in SFC, enabling voltage stabilization in nodes where otherwise grid must be reinforced for sufficient hosting capacity, especially when distributed electricity resources are present in the given grid segment.

3) Silicon carbide technology has been employed to achieve a mitigation in switching losses, thereby enabling operation at a frequency of 100 kHz. The utilized module corresponds to a United Sic cascode configuration.
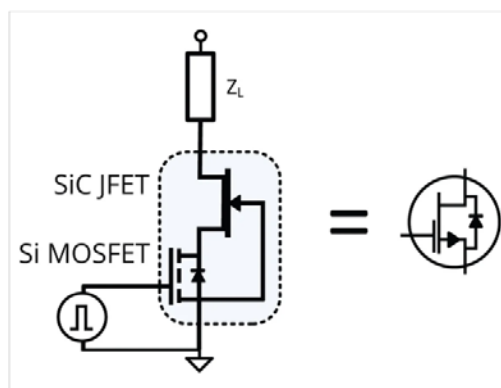

Fig. 19 Low-voltage MOSFET controls a high voltage JFET. Image from United Sic.

4) Development of a 50 kVA transformer that meets the defined requirements. Challenges have been encountered in the transformer development process due to overheating issues.

3.4 UC5 Risks

Five main risks are present, related to technology, location, and market development.

1. Technology risks concern malfunctions caused by design or installation errors, both in hardware and software. Among them are electromagnetic interferences negatively affecting the DSO's or customers' operational assets and communication failures between the SFC, DSO and CPO.

2. As for location, tradeoffs had to be made between the reactive power need, proximity to main roads and site owners' willingness for cooperation. From the end-user's viewpoint, the selected locations would be unattractive when there are other SFCs more conveniently accessible. With marginal charging events, there would not be sufficient data to be collected and analyzed.

3. The risks related to market development can be derived from the two previous ones. Most of the commercially available EVs have a 400 V voltage class battery onboard, meaning they can only recharge with 100 kW with the 250 A charging current as designed. To reduce the risk, influence the special info about charging speed will be added to the charger to give some knowledge for EV drivers.

4. 200 kW is not the highest

5. data collection – to lower the risk the price of charging session will be option, to get more data.

4 CONCLUSIONS

The UC-5 main technical details are defined in this report from the platform, communication, and engineering side before the deployment of the UC-5.

From the solution part, the platform and communication canals are selected in the SFC system where the VPP and SCADA platforms communicate with the charger through RTU, and the Enefit Volt Platform communicates with the SFC through OCPP 1.6J protocol.

From the engineering part, the design of 50 kW AC/DC and DC/DC power electronics modules are defined that enable the development of chargers. Also, the development of an internal CAN communication matrix is selected for SFC to parallelize AC/DC and DC/DC power modules, enabling module shutdown and startup based on desired power, heating, errors, etc. From engineering testing results, an achievement is complete control of the power factor and a lower current THD. In addition, the adjustment of active power consumption based on the limitations imposed by the DSO at that moment.

From the preparation for the charger installations, the grid works are done at the selected locations.

The next steps are

- assemblying fully two superfast chargers and testing them with high power and EV car;
- finishing the charger branding;
- charger installation and maintenance;
- electricity offer and grid connection;
- carrying out electricity quality measurements;
- system monitoring and testing.

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5 REFERENCES

[1] Estonian Environment agency; Climate normals; Temperature |Estonian Environment Agency

Weather Services (ilmateenistus.ee); 30.06.2023