D8.4: Versailles extra-urban area UC-3 complete solution description

Date of document – 06/2023 (M42)

D8.4: Versailles extra-urban area UC-3 complete solution description

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Technical References

Project Acronym	INCIT-EV
Project Title	Large demonstration of user centric urban and long-range charging solutions to boost an engaging deployment of electric vehicles in Europe
Project Coordinator	CIRCE Miguel Zarzuela - mzarzuela@fcirce.es
Project Duration	01/2020 – 06/2024

Deliverable No.	D8.4 - Paris extra-urban area UC-3 complete solution description
Dissemination level [1]	PU
Work Package	WP 8 – Use cases deployment and demonstration in peri-urban and extra-urban areas
Task	T 8.4 – Versailles extra-urban area UC-3 complete solution description
Lead beneficiary	3. VEDECOM
Contributing beneficiary(ies)	3. VEDECOM; 10. CIRCE, 8. ENEDIS
Due date of deliverable	June 2023, M42
Actual submission date	June 2023, M42

[1] PU = Public

PP = Restricted to other programme participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

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Document history			
V	Date	Partner(s)	Action
V0.0	20/09/22	CIRCE	Table of Content available for WP7 and WP8 deliverables
V0.1	14/06/23	VEDECOM	Table of Content and first Drafting
V0.2	29/06/23	VEDE, CIRCE, ENEDIS, UGE	First Consolidated Version
V0.4	30/06/23	ENEDIS	Technical contribution
V0.5	11/07/23	UGE	Review by P.Hornych
V0.6	13/07/23	CIRCE	Technical contribution
V0.7	24/08/23	VEDECOM	Final Consolidated version
V1.0	28/08/23	CIRCE	Final Quality Review

Disclaimer of warranties

0 EXECUTIVE SUMMARY

This document is the deliverable "D8.4 – Versailles extra-urban area UC-3 complete solution description" of the H2020 project INCIT-EV (project reference: 875683).

The main objective of this deliverable is to collect the main conclusions reached after finalizing the modelling, basic and detailed engineering, and equipment development activities before the deployment of UC-3.

In this document, the complete solution of UC-3 for the wireless charging lane in Versailles is described. The system, architecture and integration aspect are presented, to explain how the final solution will operate on the demo site.

The delivery of this report is done in accordance with the description in the Grant Agreement Annex 1 Part A.

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Table of contents

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List of figures

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List of tables

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ACRONYM LIST

Table 1 Acronym List

Acronym	Definition
AC	Alternating Current
BOM	Bill Of Materials
DC	Direct Current
DWPT	Dynamic Wireless Power Transfer
EMC	Electromagnetic Compatibility
EMF	Electromagnetic Field
EV	Electric vehicle
LQI	Line Quality Indicator
LCP	Liquid Cold Plates
PLC	Packet Loss Concealment
PWM	Pulse-width modulation
VMA	Vector Network Analyser

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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. Five demo environments, in urban, peri-urban, and extra-urban locations 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 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 ulterior analysis.
- To analyze 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 detailed engineering, and equipment development activities before the deployment of UC-3.

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1.2 Contribution from partners table

Table 1 - Contribution table

Partner	Contribution
10. CIRCE	Design, engineering and performance tests on coils and inverters
4. UGE	Numerical simulation on coils and asphalt pavement. Solar energy generation.
3. VEDECOM	Task leader
7. Eurovia	Ground coils integration and civil works
8. Enedis	Grid connection and power quality measurements

1.3 Relation to other project activities table

Table 2 - Relation to other project activities table

Task	Relation to other project activities
T3.4 – Dynamic Wireless Power Transfer. Urban and extra-urban charging	Theoretical modelling of the solution
T8.5 - Evaluation and impacts assessment	Short term impacts

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2 UC3 OBJECTIVES

Versailles extra-urban UC3 will demonstrate a Dynamic Wireless Power Transfer (DWPT) technology to recharge electrical vehicles in motion in an extra-urban scenario. This scenario is characterized by higher speeds compared with the urban use case and by a lack of city constraints like pedestrians, bicycles and other systems installed around. It changes the specifications of the dynamic charging system, partly reducing the difficulties and costs of the technical solution.

Therefore, the objective of the UC3 is to demonstrate a dynamic charging system for a long-range application taking into account the specificities of the scenario and the interoperability capabilities. This implies the following aspects:

- **Interoperability:**
    - **Between vehicles**: As for UC2, three different vehicles will be adapted in two different power levels (30kW and 90kW). A utility vehicle and two passenger cars will be adapted, the first one with three 30kW coils to reach the 90kW power.
    - **Systems and use cases**: The vehicles will be able to recharge using three different system concepts and in very different conditions. The same vehicle will be charging at two urban areas: UC7 in Zaragoza for static wireless charging at 30 kW, UC2 in Paris for dynamic charging at low speed (30km/h) and one extra-urban demonstration (UC3 in Versailles) reaching 90 km/h at the same power (30kW and 90kW). The secondary and primary systems for the UC2 case are developed by VEDECOM.
- **Power grid integration**: The charging system will be connected to the AC grid provided by ENEDIS via an AC/DC with Power Factor Converter. Charging power available will be set at 120 kVA. Eurovia partner will do the civil engineering work.
- **Communication system**: The charging station operation will be assured by a common communication system developed by VEDECOM and based on the ISO 15118 standard.
- **Lane keeping assist system**: A keep lane assistant will be used in the vehicles to assist the driver to reach the best alignment condition between the vehicle and the ground integrated coils.
- **High speed scenario**: The system will be installed and tested in the Fabric Lane at VEDECOM's facilities for a speed up to 90km/h.

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3 UC3 COMPLETE SOLUTION

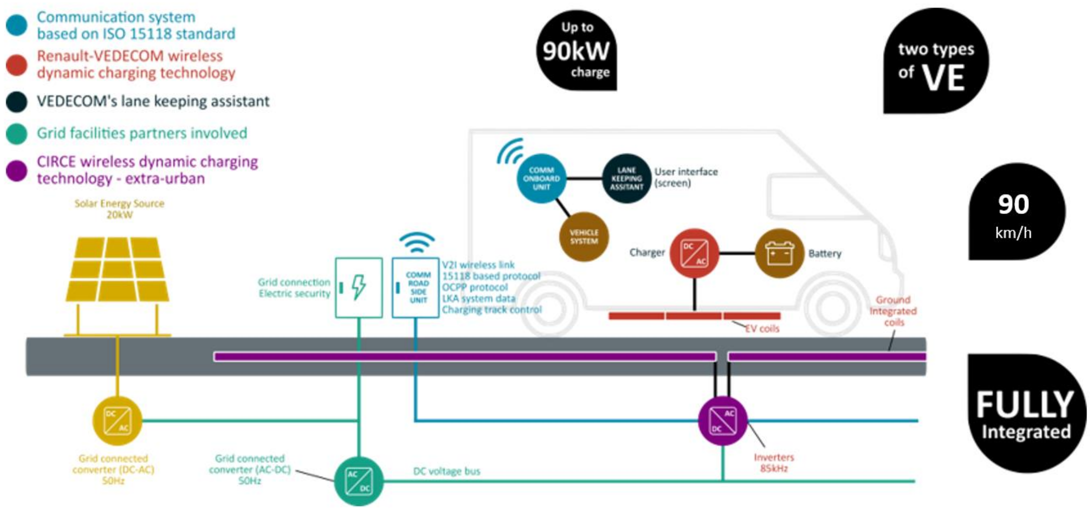
The UC3 experimentation aims to quantify the efficiency of dynamic wireless power transfer. The overall solution is based on the design principles outlined in D3.9 "Update of DWPT Reference Charger Models," but incorporates modifications that have been identified as improvements during the activities conducted under task 8.3 "Dynamic wireless charging for European corridors (M14-M48) – Paris area."

At its current stage, the system retains the innovative concept of employing a primary coil longer than the secondary coil. This design approach eliminates the need for ferrite sheets and aluminum shielding on the ground side, leading to a significant reduction in costs compared to alternative dynamic charging systems.

The key design parameters of the solution described in this document are listed below:

- The resonant topology has been redefined as an LCC topology.
- Misalignment range is defined as ± 7 m respects to the coil's ends in x-direction and ± 0.2 m in y-direction.
- Air gap range defined as 0.23-0.26 m
- Shielding design according to ICNIRP 2010
- Ground system interoperable with Zoe and Master secondary systems
- Power control performed by the secondary side. Communication between charging station and vehicle is not required, but vehicle detection must be implemented.
- Maximum speed of the vehicles set at 90 km/h

Figure 1: UC3 descriptive scheme



The UC3 ground system is based on the next general structure:

- The charging track is formed by eight primary coils of 10 m length, covering 80-90 m.
- The power electronics stages, which main function is generating the high frequency AC current needed to supply the coils, are distributed in five cabinets:
    - A grid cabinet, which contains the AC/DC stage.

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- Four coils' cabinets, with two DC/AC stages per cabinet, and one DC/AC stage per coil.

Figure 2: UC3 general structure.

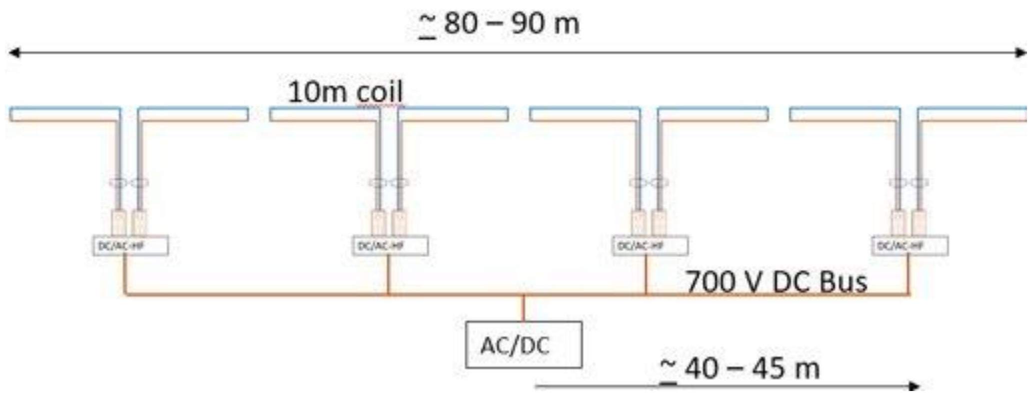
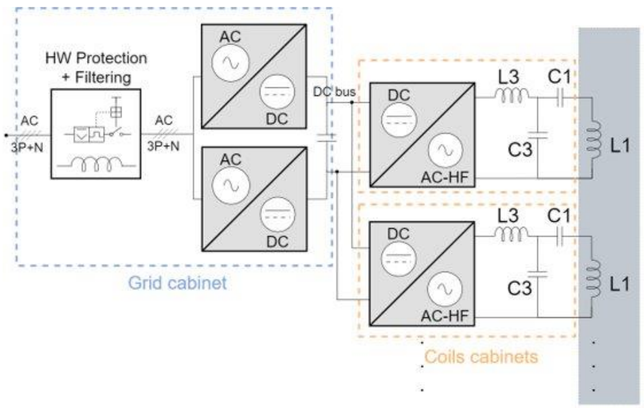


Figure 3 shows the block diagram of the main electronic stages and circuits that constitutes the UC3 ground system:

Figure 3: UC3 block diagram.



3.1.1 Demo-site

The demo-site is situated at Versailles – Satory inside VEDECOM's facilities. A testing lane that was previously built in the Fabric European project will be used to install and test the system. The final solution will occupy 80 meters of the 120 meter long available lane. Some adaptations will be necessary to correctly connect the coils and converters and for the grid connection.

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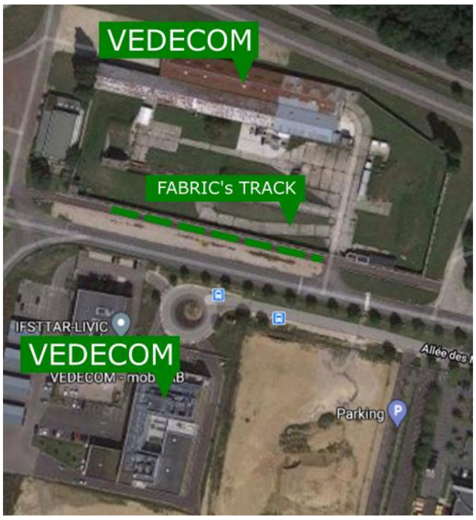
Figure 4: Fabric's track location at VEDECOM's facilities - Versailles, Satory



Given the final positioning of the UC3 demonstrator and the objective of minimizing the separation between the track and the cabinets, the system installation scheme depicted in Figure 5 is proposed. The proposed arrangement entails a symmetrical configuration in relation to the grid cabinet, with the cabinets positioned near the road.

Figure 5: UC3 demonstrator basic scheme

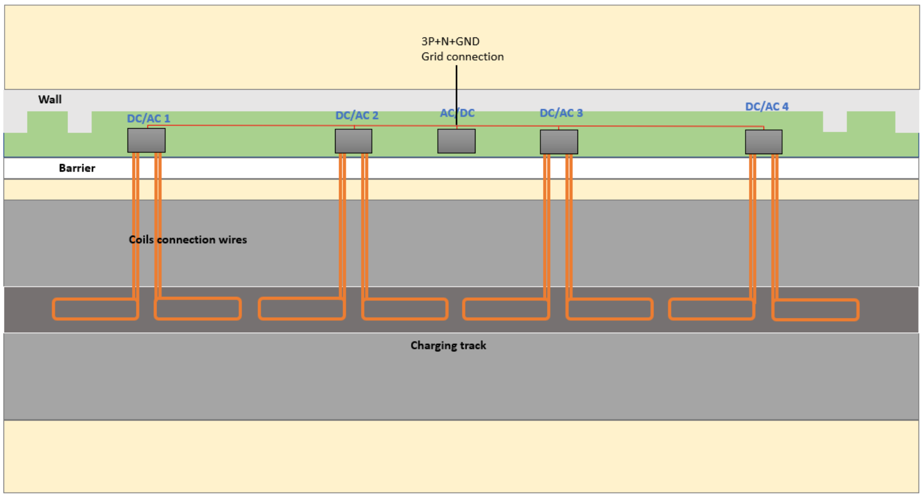


Figure 6 illustrates a detailed drawing of the system integration within the demonstration area. It will serve as a starting point for determining the scope of civil works.

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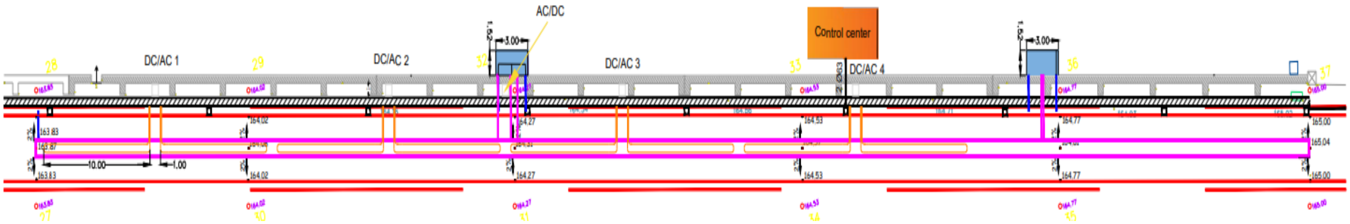
Figure 6: UC3 demonstrator drawing

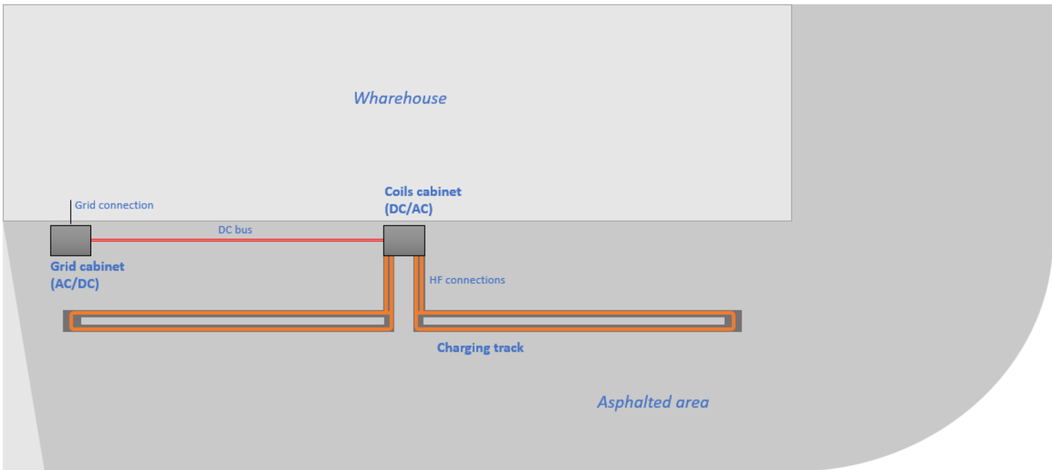


3.1.1.1 Simplified demonstrator at CIRCE's facility

A simplified demonstration site has been established at Circe's facilities as an intermediate stage prior to the commissioning of the UC at Versailles. This demonstrator incorporates a 20m low speed charging track based on two coils, a grid cabinet, and a coil cabinet, aimed at conducting preliminary testing of power electronics stages, primary coils, and control methodologies before the equipment is transported to Versailles. It is imperative that all HF cabinets undergo thorough testing prior to shipment.

The basic scheme of the simplified demonstrator is shown in Figure 7.

Figure 7: UC3 simplified demonstrator scheme.



As Versailles site has already a grid connection and is aiming to reuse an existing installation for induction, there will be no new grid connection for this site. In terms of power capacity, together with site owner and Enedis local team, data have been extracted (load curves), and show available room for the demo to run. Therefore, no extra power capacity will be needed.

3.1.2 Power grid and AC/DC converter

3.1.2.1 Power grid

The power quality analyzers will be connected at the point of connection to the public grid.

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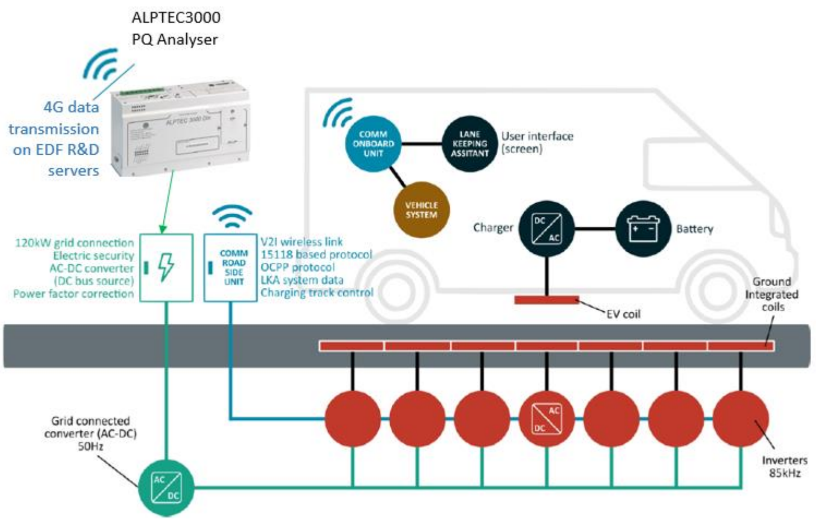
Two types of measurements will be done. The first equipment will be connected into the cabinet, on the smart meter and will allow to measure electrical values and power quality measurements.

- Measurements type 1:
- Device: ALPTEC 3000 Power Quality analyzer
- Means: Three-phase voltage / current measurements (sampling frequency = 10,2 kHz).
- Period: several weeks / months
- Acquisition step: 3s
- Remote reading: Yes
- Analysis of data:
    - Active and reactive power (load curves)
    - Harmonics: Individual harmonic levels up to order 51 and THD level
    - Flicker
    - Voltage sags

The following figure shows the schematic diagram of the instrumentation:

Figure 8: Instrumentation of the demonstrator



The second equipment will be connected on the dedicated power line of the low power distribution station and will allow to measure Supraharmonic (2 – 150 kHz) and DC leaks measurements. Depending on the technical specifications, the instrumentation could be moved into the cabinet (on breaker or smart meter).

Measurements type 2:

- Device: Specific power quality device developed by EDF R&D
- Means: Three-phase voltages / currents measurements (sampling frequency up to 1MHz)
- Period: 2 or 3 days

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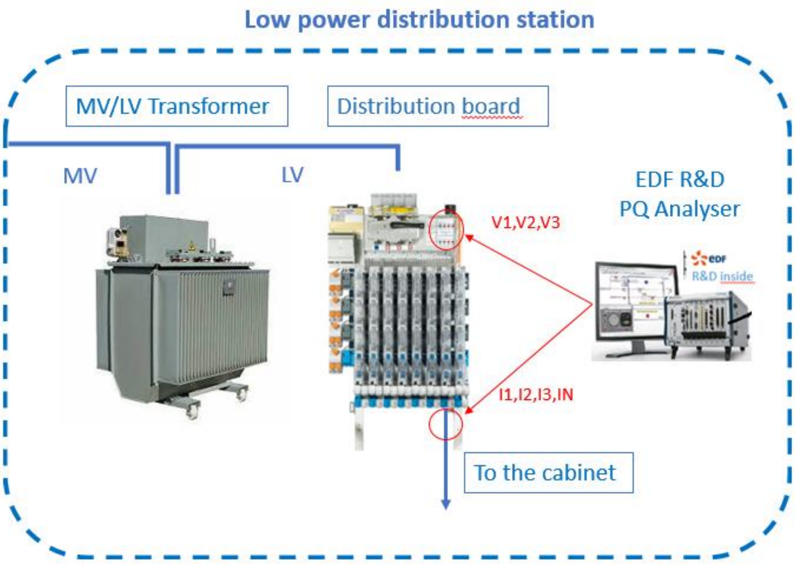
- Acquisition step: 200ms
- Remote reading: Yes
- Analysis of data:
  - Supraharmonic currents and voltages to study the impact of the charging equipment on PLC communication
  - DC current leaks analysis

The following figure shows the schematic diagram of the instrumentation:

Figure 9: Instrumentation of the grid installation



3.1.2.2 Grid cabinet

The conversion of three-phase network AC current to DC current and the generation of a stable DC bus is the main operation covered by the grid cabinet. Next scheme shows the basic stages included in the grid cabinet:

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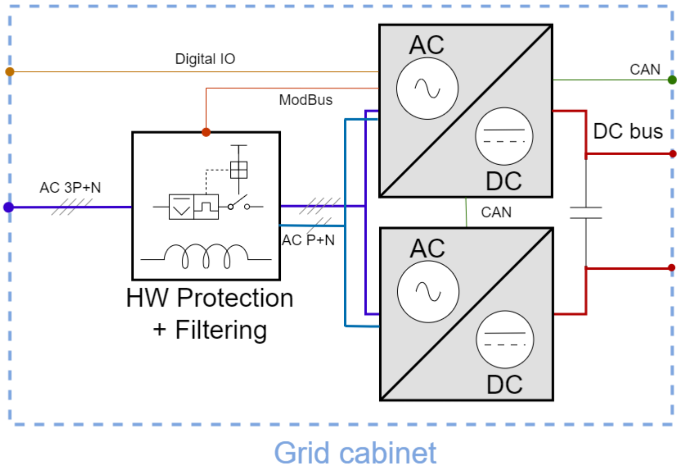
Figure 10: Grid cabinet block diagram



- Hardware protection and filtering stage are based on three-phase protection components, providing overcurrent, overvoltage and differential protection, network analysis and filtering of conducting emission.
- AC/DC stages provide three-phase AC current to DC current conversion. The components are integrated in rack modules. Modules' structure is defined in section 3.1.2.2.1. Grid cabinet includes two 50 kW AC/DC modules connected in parallel.

3.1.2.2.1 AC/DC module

The AC/DC module encompasses the integration of various components comprising the AC/DC converter, housed within a rack enclosure. This development has been undertaken as part of the INCIT-EV framework, with the overarching goal of establishing a standardized and benchmark reference model for a 50 kW AC/DC stage.

Figure 11: AC/DC module block diagram

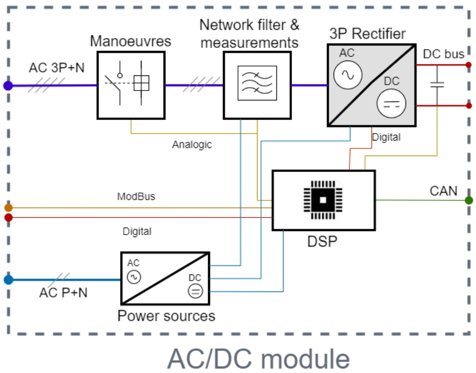


Figure 11 shows the block diagram of the AC/DC module. The main elements are described below:

- The AC/DC conversion is executed by a three-phase, two-level, four-legs active rectifier. The fundamental topology of this rectifier is depicted in Figure 12. The AC/DC converter itself relies on SiC MOSFETs, which are controlled through a control driver board.

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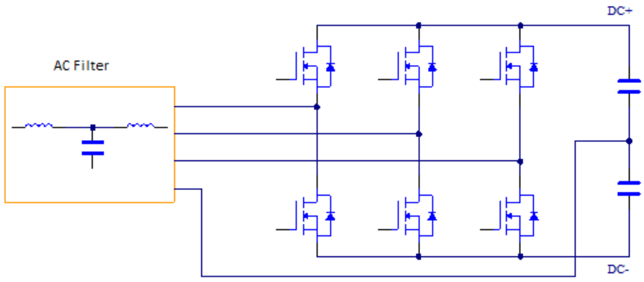
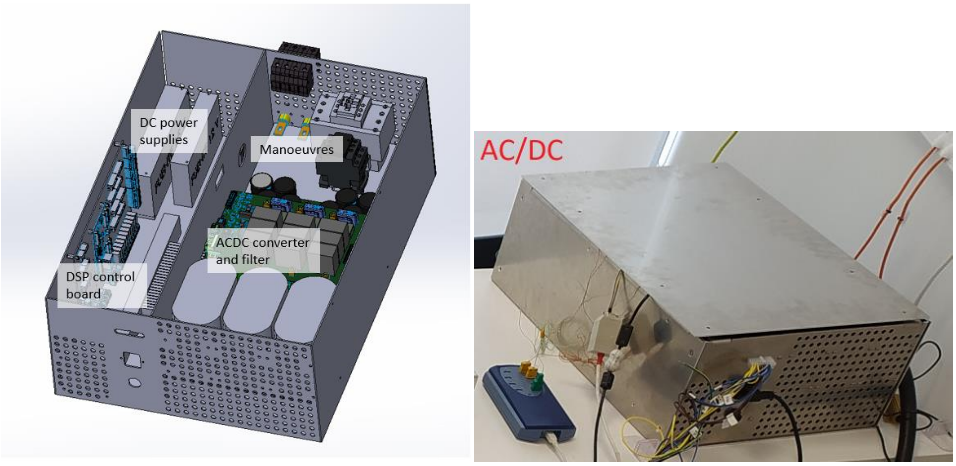
Figure 12: AC/DC converter topology



- The network filter is implemented on a printed circuit board (PCB) and three sizable inductors. Additionally, the filter board integrates the network and DC bus measurements adaptation circuit, responsible for generating proportional analog signals that will subsequently be processed in the DSP control board.
- The main components responsible for the system maneuvers are two contactors. These contactors, under the control of the DSP control board, are tasked with connecting the three-phase input of the AC/DC converter and performing the pre-charging function.
- The DSP control board, which is based on a Texas Instruments microprocessor, fulfills various functions including power control, generation of PWM signals, implementation of protection mechanisms, control of maneuvers, and facilitating Modbus and CAN communication protocols.
- The module comprises two power sources that supply the aforementioned boards.

Figure 13 illustrates the module's division into two primary sections: the control section and the power section. These sections are separated by an aluminum shielding plate, strategically implemented to mitigate potential electromagnetic interference (EMI) that may arise primarily due to converter commutation.

Figure 13: AC/DC module design and assembly



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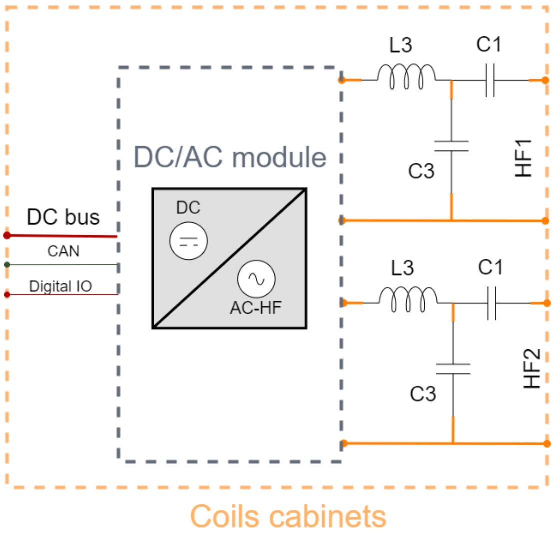
3.1.3 DC/AC (Inverters)

3.1.3.1 Coils cabinets

The conversion of the DC current to the high-frequency AC current, necessary for the inductive power transfer, is the primary operation performed by the coil cabinets, situated between the grid cabinets and the coils that form the charging track.

Next scheme shows the basic stages and components included in the coils' cabinets:

Figure 14: Coils cabinets block diagram



- The DC/AC stages are responsible for converting the DC voltage into a high-frequency square wave output voltage, which serves as the input for the resonant circuit on the primary side. Since there is one coil cabinet for every two coils, each cabinet is equipped with two DC/AC stages. In practice, both stages are integrated into a rack module, following the same principle applied to the grid cabinet. Further details regarding the module structure will be elaborated in section 3.1.3.1.1.
- In conjunction with the output of the DC/AC stages, the resonant network is connected, with the inductive power transfer coils playing a crucial role in this circuit. The specific topology of this network is described in section 3.1.3.1.2.

3.1.3.1.1 DC/AC modules

In accordance with the principles adhered to during the development of the AC/DC module, the DC/AC module consists of the integration of two DC/AC stages in a rack enclosure.

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Figure 15: DC/AC module block diagram

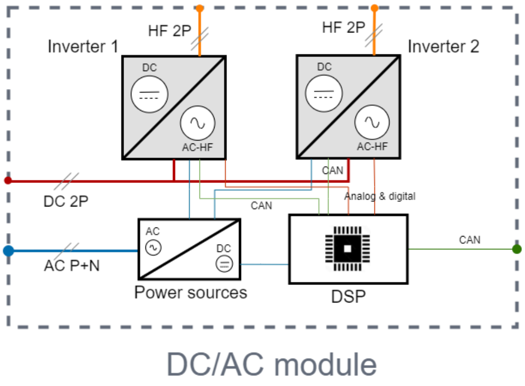
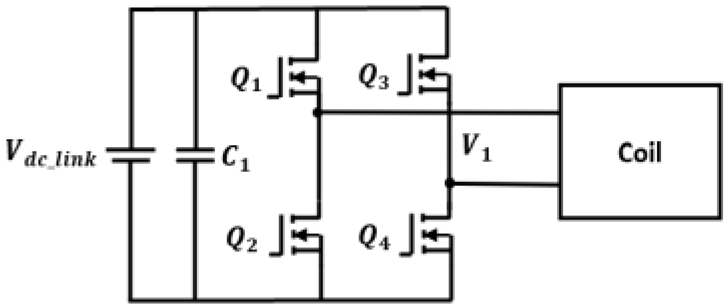


Figure 15 shows the block diagram of the DC/AC module. The main elements are described below:

- The DC/AC conversion process is executed by employing a two-level full-bridge inverter, as depicted in Figure 16. The basic topology of this inverter incorporates SiC MOSFETs, which are controlled through a dedicated control driver board.

Figure 16: DC/AC converter topology



- The DSP control board, based on a microprocessor from Texas Instruments, carries out various functions including power control, generation of PWM signals, implementation of protection mechanisms, control of maneuvers, and facilitation of Modbus and CAN communication protocols.
- The module incorporates two power sources that provide the necessary supply to the aforementioned boards.

Figure 17 illustrates the module division into two primary sections: the control section and the power section. In this configuration, the sections are arranged vertically and are separated by an aluminum shielding plate, which not only houses the DSP board and the power sources but also serves as a means to mitigate potential electromagnetic interference.

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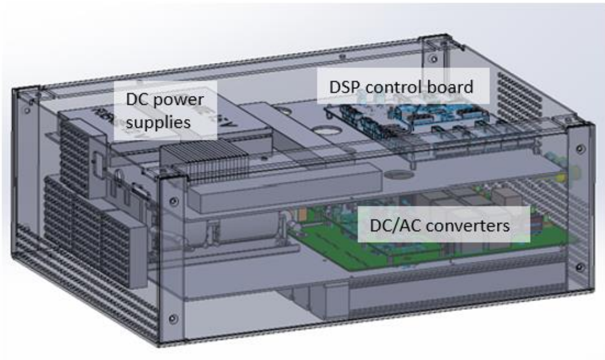
Figure 17: DC/AC module design and assembly



3.1.3.1.2 Primary side resonant network

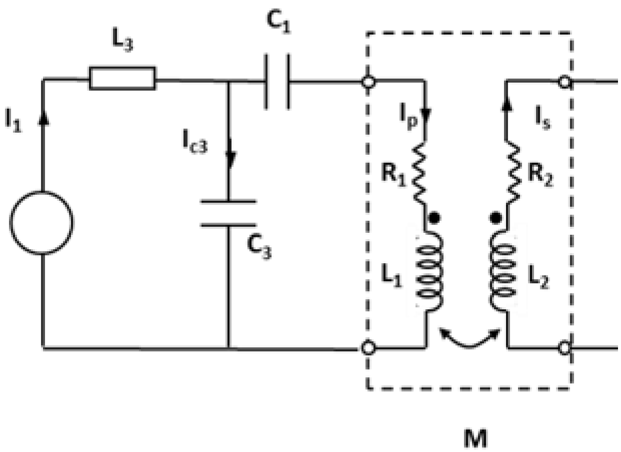
The primary side resonant network adapts the inverter square wave output to the primary coil, achieving a sinusoidal current flowing through it.

3.1.3.1.2.1 Topology description

During this period, an extensive study was conducted to investigate and define a LCC (L-series, C-parallel, C-series) topology for the primary side resonant network. The study was developed with the aim of improving the response of the originally designated S-S (series-series) topology to misalignment, particularly convenient in the entrance of EVs onto the charging track.

Figure 18 provides a visual representation of the proposed topology. As outlined in the subsequent section, the design of this circuit entails carefully selecting suitable values for the series inductance (L3), parallel capacitance (C3), and series capacitor (C1) in order to meet the specified requirements and specifications.

Figure 18: LCC resonant topology



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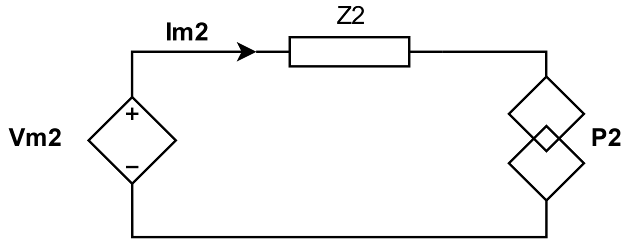
3.1.3.1.2.2 Topology analysis

Based on the selected LCC resonant topology, a simplified electrical model of the IPT system is developed. The inductive coupling design, characterized by primary and secondary inductors leakage inductance (L1, L2), the nominal mutual inductance (M) and the admissible misalignment range are initial conditions for the system modelling. A reference secondary IPT system is also defined and modelled. The interdependence between them is considered in Equations 1 and 2, where the influence of the primary over the secondary side is represented by the induced voltage Vm2. Some values of the secondary side, such as the maximum induced voltage ($Vm2_{max}$), the output peak power (Po_{max}) and the secondary circuit values range must also be defined for an effective primary system dimensioning.

Secondary side analysis

The secondary side equivalent model is shown in Figure 19, where a power control is assumed. It has to be noted that three secondary models will conform the secondary side. For this approach, the secondary current (Im2) is set as the phase reference. Additionally, the system switching frequency is chosen as equal to the resonant frequency of the secondary compensation network.

Figure 19: Secondary side equivalent model diagram



In the secondary side defined model, the output active power can be written as a product of current and the in-phase voltage (Eq.3). Substituting the current definition on the imaginary plane (Eq. 4), Eq. 5 is obtained. To merge in-phase and quadrature terms ("x" and "y" respectively), Eq. 5 was rewritten as presented in Eq. 6, where α is the phase shift between Vm2 and Im2. The maximum output power is obtained from Eq.7, where α = 45º. The reactive power can be extracted using Ohm's law (Eq.8) and the apparent power formula (Eq.9). Merging both expressions, Eq. 10 is obtained, where Q2 can be easily calculated.

$$Vm2 = Im1 * M * w_{sw} \quad (1)$$

$$Vm1 = Im2 * M * w_{sw} \quad (2)$$

$$P2 = Vm2_x * Im2 \quad (3)$$

$$Im2 = \frac{Vm2_y}{Z2} \quad (4)$$

$$P2 = Vm2_x * \frac{Vm2_y}{Z2} \quad (5)$$

$$P2 = \frac{|Vm2|^2}{Z2} * sen(\alpha) * \cos(\alpha) \quad (6)$$

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$$P2_{max}(Vm2, Z2) = \frac{|Vm2|^2}{2 * Z2} \quad (7)$$

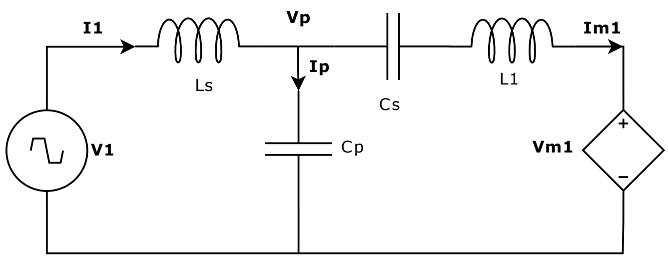
$$Q2 = Im2^2 * Z2 \quad (8)$$

$$(Vm2 * Im2)^2 = Q2^2 + P2^2 \quad (9)$$

$$Q2^2 - \frac{Vm2^2}{Z2} * Q2 + P2^2 = 0 \quad (10)$$

Figure 20 shows the simplified model for the primary side. The primary inductor current (Im1) is established as controlled variable in this approach. Unless otherwise noted, that current is considered as phasor reference.

Figure 20: Primary side equivalent model diagram



Since the system operates at a fixed frequency, Eq. 11 and 12 express impedances in function of the components of series and parallel impedances (Zs and Zp). Im1 is controlled such that, in the case of maximum induction, Vm2 does not exceed the limit imposed by the secondary side. Im1 is calculated by the substitution of w_{sw}, as well as the components of inducted voltage Vm1 can be expressed in function of secondary side active and reactive power, P2 and Q2, according to Eq. 13 and 14. The quadrature voltage across the parallel capacitor, Vp_y, is obtained in Eq. 15. To calculate the value of the parallel impedance, the Ip is also needed (Eq.16). The maximum Cp value, corresponding to the maximum voltage Vp, is obtained based on the primary inverter minimum current (Eq. 17), condition that occurs when all the reactive power is compensated by the parallel capacitor (Eq. 18). With the absolute values of Vp and Ip, the parallel capacitor capacity Cp is calculated (Eq.16 and Eq. 12).

Once the Cp value has been established, the values of Cs and Ls can be determined. Their values depend on the inverter voltage (V1). Two requirements should be met for the correct operation of the system: the inverter (V1, I1) never works outside the Zero Voltage Switching (ZVS) condition and that the demanded voltage V1 must be less than the available voltage. The first requirement can be assured by satisfying Eq. 20, which is a condition imposed by the chosen AVC modulation. The second one can be guaranteed if Eq. 21. takes place. From those inequalities the Zs impedance can be determined, and thus the values of Ls and Cs are extracted (Eq. 11). Previously, a phase reference swap between Im1 and I1 must be performed. Equations 22,23 represent that operation, where α can be obtained using the Law of Cosines on I1, Ip and Im1.

$$\boldsymbol{Zs = w_{sw} * Ls} \quad (11)$$

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$$Zp = \frac{-1}{w_{sw} * Cp} \quad (12)$$

$$Z_1 = w_{sw} * Ls - \frac{1}{w_{sw} * Cp} \quad (12)$$

$$Vm1_y = \frac{Q_2}{Im1} \quad (13)$$

$$Vm1_x = Vp_x = \frac{P_2}{Im1} \quad (14)$$

$$Vp_y = Vm1_y + Im1 * Z_1 \quad (15)$$

$$Z_p = \frac{|Vp|}{|Ip|} \quad (16)$$

$$\overrightarrow{Ip} = \overrightarrow{I1} - \overrightarrow{Im1} \quad (17)$$

$$I1_{min} = \frac{Po_{max}}{V1_{x,max}} \quad (18)$$

$$V1_{y,ref_{I1}} = (Vp_{y,ref_{I1}} + I1 * Zs) \quad (19)$$

$$V1_{ref_{I1}} > \frac{2 * \sqrt{2} * V1_{DC}}{\pi * 4} \quad (20)$$

$$V1_{ref_{I1}} < \frac{2 * \sqrt{2} * V1_{DC}}{\pi} \quad (21)$$

$$Vp_{y,ref_{I1}} = Vp_{y,ref_{Im1}} * \cos(\alpha) - Vp_{x,ref_{Im1}} * \sin(\alpha) \quad (22)$$

$$Vp_{x,ref_{I1}} = Vp_{y,ref_{Im1}} * \sin(\alpha) + Vp_{x,ref_{Im1}} * \cos(\alpha) \quad (23)$$

3.1.3.1.2.3 LCC circuit design

For the design of the values, an iterative script involving the modelling was used, based on a Montecarlo algorithm.

First, the values where the circuit is to be designed are set, such as the switching frequency and the primary coil current. Then, a set of parallel and series capacitor and series coils are created. The idea is to generate random values of the expected changing variables (including position between coils and the tolerances of the components) for a determined number of iterations, and extract the possible errors of each combination (overvoltage, overcurrent, capacitive behavior…). Once all the Cs, Cp and Ls combinations are tested, the 3 combinations with less percentage of errors (in case of similar percentage, the ones with least inverter current) are selected and verified.

3.1.3.1.2.4 LCC circuit Verification

For the verification of the values, two methods are used: an iterative script (similar to the one used for design) and a Matlab/Simulink simulation for some of the cases.

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The iterative script is like the design one, with the difference that it implements more iteration steps and extracts some more graphs about the results (fig.17).

Regarding the simulation, a circuit with the primary and secondary control was designed in Simulink (fig. 21) the results are shown in the following section.

3.1.3.2 Components values

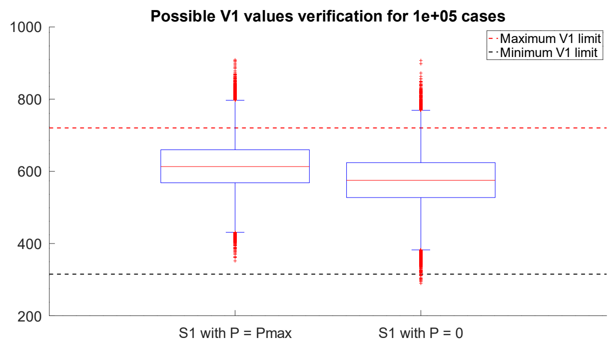
From the LCC circuit design the optimal values were obtained. The fixed values chosen for the simulation were Im1 = 290A and f = 73.5kHz.

For those values, there is a failure in 11.87% of cases, of which:

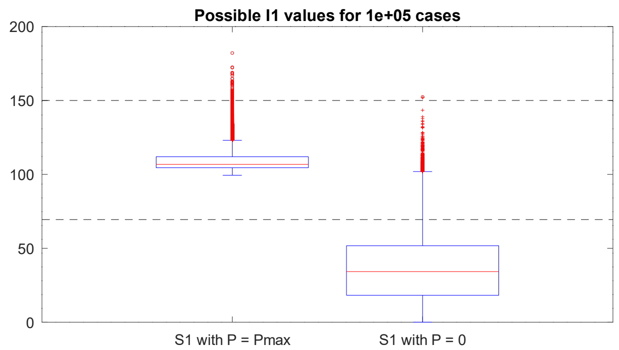
- 6.13% are because the required voltage is too high,
- 0.18% are because it does not work in ZVS,
- 5.56% because the behavior turns capacitive.
- 0.00% because the 3rd harmonic is larger than the first one.
- 0.00% because the inverter current is too high.

The boxplots of the 1st harmonic of Voltage and current are the following:

Figure 21: Primary side equivalent model diagram



a)



b)

3.1.4 Coils

Primary coils have the function of coupling with secondary coils and establish the inductive power transfer. As mentioned in the previous sections, primary coils are part of the resonant network of the primary or ground side and constitute the charging track.

3.1.4.1 Litz wire

Following an optimization process aimed at minimizing estimated losses and considering ground integration factors outlined in D4.10 "Update of Road Infrastructure upgrading for dynamic wireless charging," Litz wire has been chosen (figure 22). The selection of Litz wire involved determining the strand diameter based on the frequency range, selecting the number of strands based on the maximum estimated current and incorporating a safety factor. Furthermore, the external covering of the wire has been designed to ensure a good mechanical, electrical, and thermal performance.

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According to the supplier, the estimated overall diameter of the wire is 23.5 mm, with a turn radius of 25 cm. Upon receiving the wire, it has been observed to possess a higher degree of flexibility. Nonetheless, it is imperative to consider a significant turn radius when defining the geometry of the coils.

Figure 22: Coils' Litz wire

3.1.4.2 Geometry and dimensions

The principle of achieving a quasi-continuous charging track is upheld in the dimensional design of the coils. While long coils contribute to track continuity, they also result in elevated inductances and unmanageable voltages. Through an optimization process considering these factors, a length of 10 meters has been determined as the optimal compromise.
Based on the dimensions established during the design phase (10x0.45 m), the width of the coils has been readjusted to 0.5 meters in order to accommodate the estimated turn radius of the Litz wire provided by the manufacturer (figure 23). Simulations have indicated that despite this modification, the mutual inductance remains within an acceptable range.

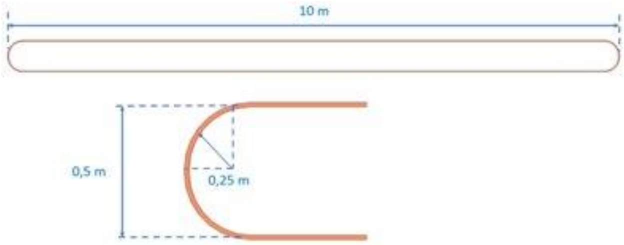

Figure 23: UC3 coil geometry.

3.1.5 Solar panels

An installation of solar panels is expected for this use case. This installation will be made at the same delivery point of the power grid. The impact on the power grid of a particular charging system (wireless dynamic charging system) and a renewable energy source will be evaluated and can help the design of future energy sources around this kind of charging infrastructure.

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3.1.6 Electric installations

The schematic of the grid and solar panels and the specifications of the installation are presented in Figure and Table :

Figure 22: Schematic of power grid connection

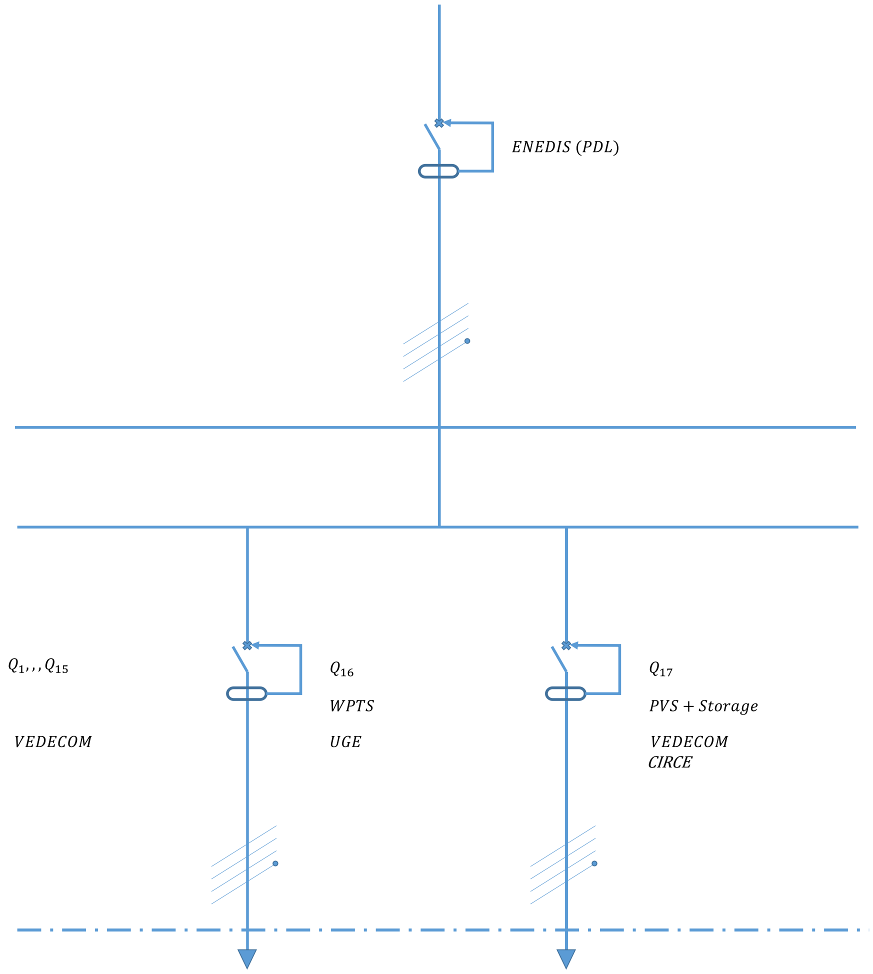

Table 3: Power grid specification with solar panels generation

Destination	WPTS	PVs + Storage
Phases	L1 L2 L3	L1 L2 L3
Powe	$P_u = 90\ kW$ $P_a \approx 110\ kW$? (Global efficiency 82%)	15 kVA
Device	Circuit breaker	Circuit breaker
Limit	160 A	32 A

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Number of poles	4P4D	4P4D
Differential	300 mA	30 mA

The specific location of the solar panels and grid connection point are still in discussion.

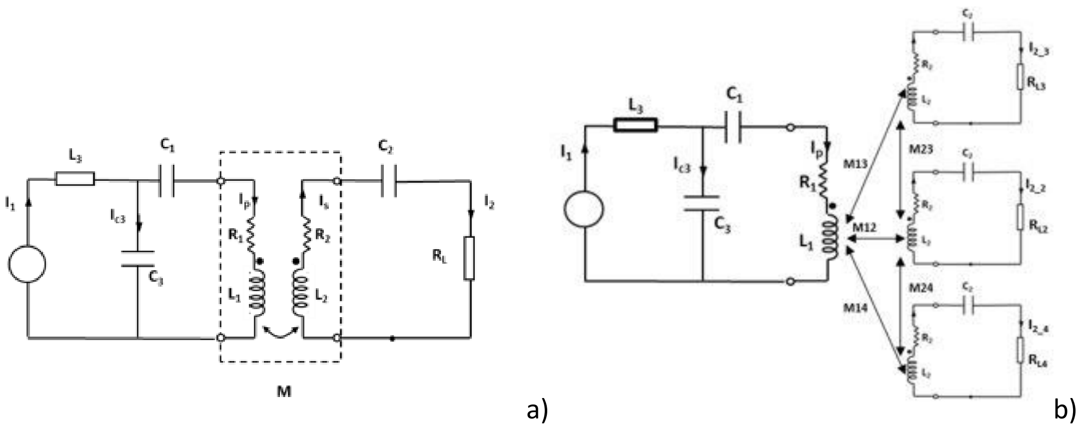
3.2 UC3 Final modelling and engineering results

3.2.1 Modelling

3.2.1.1 IPT system modelling

As part of the validation process for the resonant circuit network, circuit models have been developed to represent the primary side coupled with the secondary sides installed on Zoe and Master vehicles. Figure 25 showcases the respective models for Zoe and Master. Notably, for the Master, a matrix of mutual inductances has been defined.

Figure 235: Circuit models for LCC primary side coupled with Zoe's (a) and Master's secondary side (b)



A simulation model has been created including resonant networks, coupling and electronic stages where control is implemented. Figure shows the basic scheme of the simulation model considering three secondaries to englobe the Master case.

A dependence of mutual inductances between primary and secondary sides with the relative position is included in the model to consider the entrance and exit of the EV onto the track and the transitions between primary coils. Graphs in Figure 24 show the representation of the defined function.

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Figure 26: Simulation model

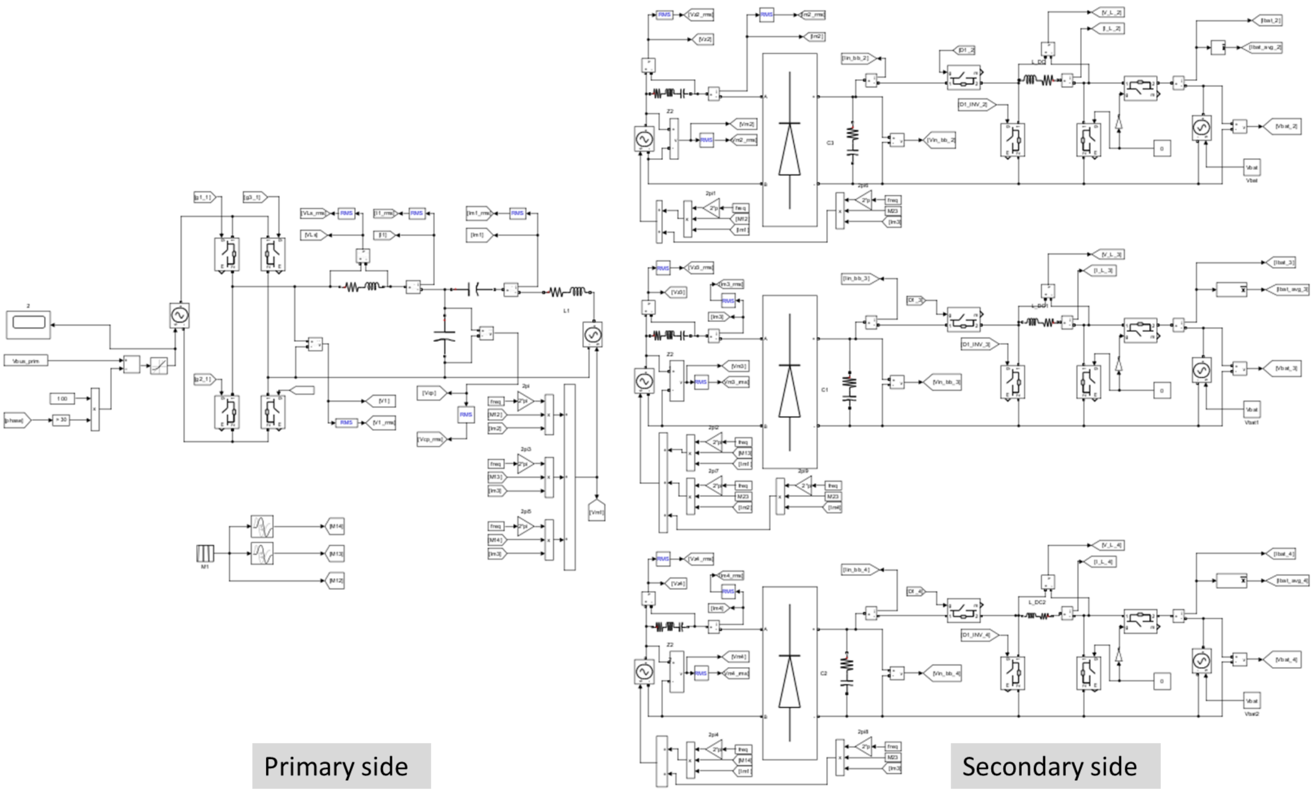
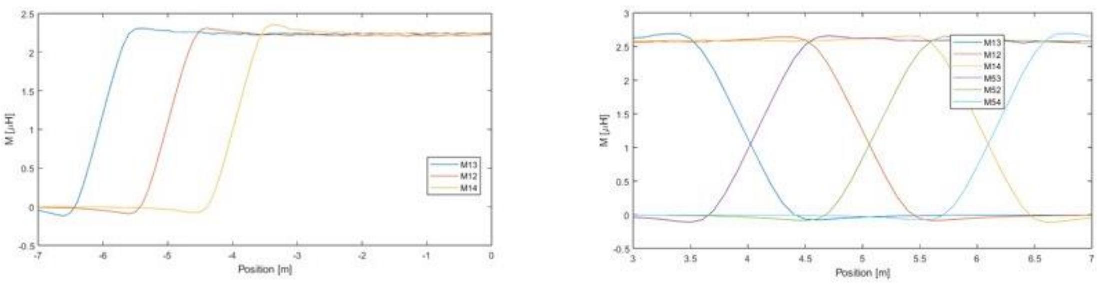


Figure 247: Mutual inductances between primary coils and Master secondary coils, first coil entrance (a), transition between coils (b)



a) b)

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3.2.1.2 *Control simulations*

By running the model simulation, the most important parameters are plotted and shown in figures 28 and 29. The movement of the vehicle is modelled by the gradual introduction of the mutual inductances of the three coils.

Figure 25: Simulation graphs of the simulation of a Master vehicle (3 coils). The movement of the vehicle is simulated by changing the mutual inductances throughout time. The power, duty and the important currents are represented.

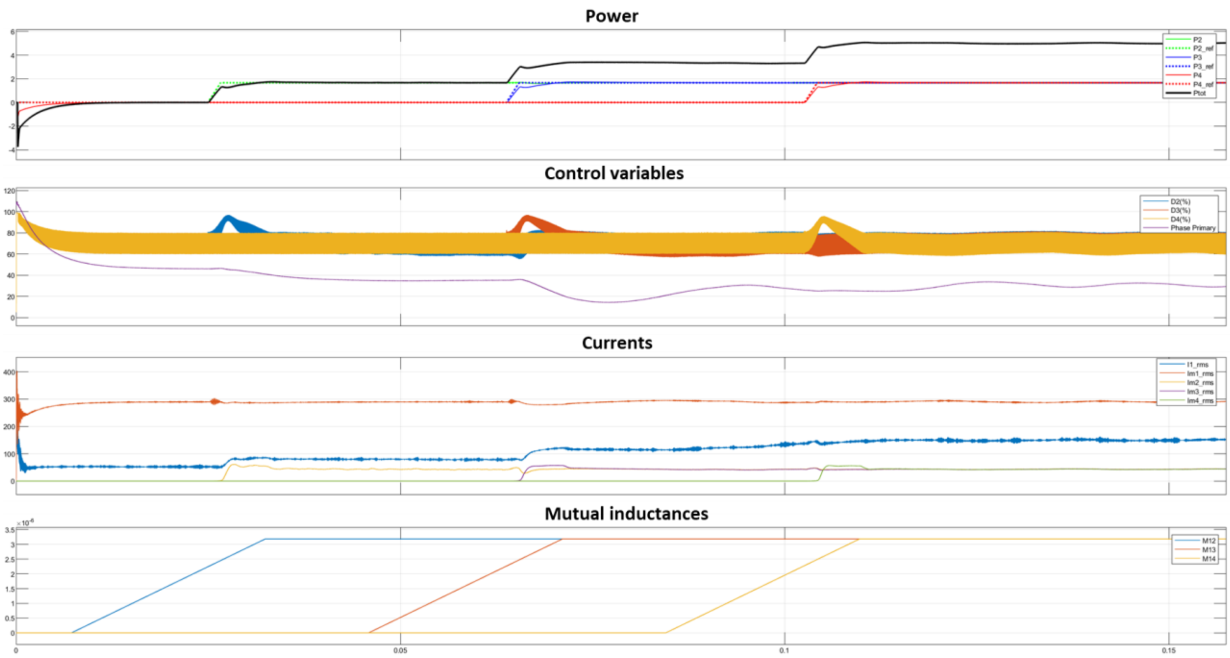

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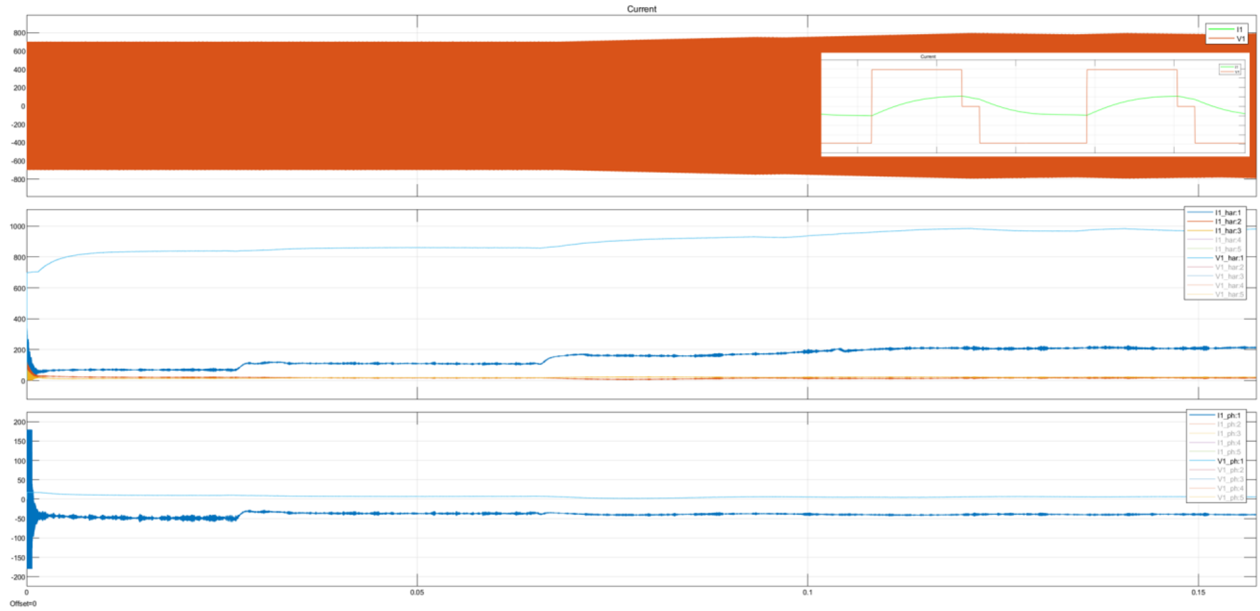
Figure 26: Simulation graphs of the simulation of a Master vehicle (3 coils). The movement of the vehicle is simulated by changing the mutual inductances throughout the time. Harmonic analysis of current and voltage and sample of the modulation.



3.2.2 Tests

At this stage, the AC/DC module has undergone rigorous validation in a laboratory setting. The validation process for the AC/DC module encompasses a series of tests, as outlined below. Examples of measured quantities are presented in the subsequent figures.

- Reactive power tests: Figure 30a shows grid phase voltage (yellow, blue and red) and current waveforms (green, orange and blue), with a 90-degree phase shift resulting from testing with a purely inductive load.
- Active power tests: Figure 30b showcases the waveforms of two-phase voltage (yellow and blue), current (green and orange), and the output DC voltage, which forms the DC link, during a test with an active load.
- Thermal tests: the graph in Figure illustrates the temperature evolution of various components of the module (heatsink, case, and grid coil winding) during a 40-minute test at full load.
- THD measurements: as an example, *Figure* presents an average measurement obtained from a grid analyzer for Total Harmonic Distortion (THD)
- EMC measurements: conducted emissions tests in accordance with UNE-61851-21-2 EMC standards are planned to be conducted to evaluate the electromagnetic compatibility (EMC) characteristics.

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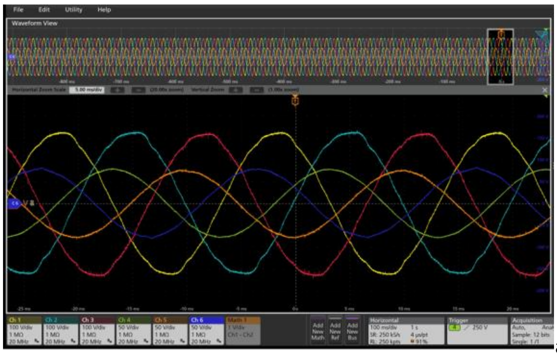
Figure 30: Measurements taken on AC/DC module reactive (a) and active power tests (a).


a)

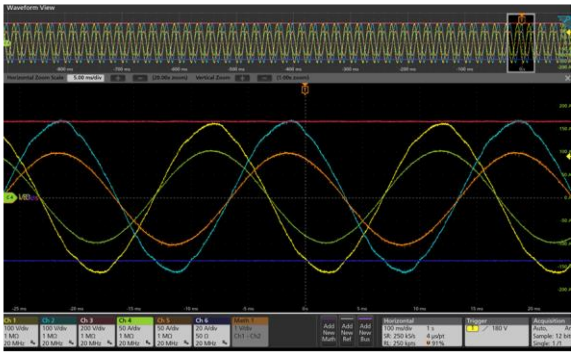

b)

Figure 31: ACDC module temperature measurements.

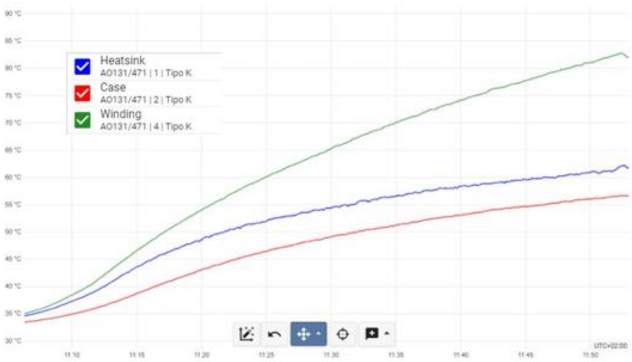
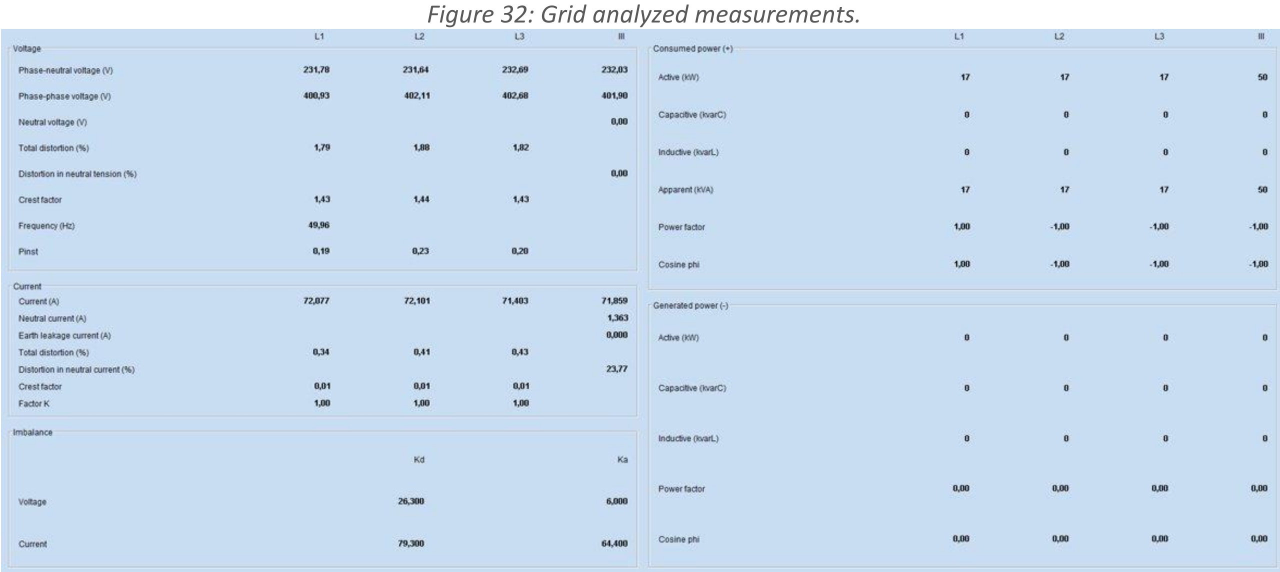


Figure 32: Grid analyzed measurements.



	L1	L2	L3	III
Voltage				
Phase-neutral voltage (V)	231,78	231,64	232,69	232,03
Phase-phase voltage (V)	400,93	402,11	402,68	401,90
Neutral voltage (V)				0,00
Total distortion (%)	1,79	1,88	1,82	
Distortion in neutral tension (%)				0,00
Crest factor	1,43	1,44	1,43	
Frequency (Hz)	49,96			
Pinst	0,19	0,23	0,20	
Current				
Current (A)	72,077	72,101	71,403	71,859
Neutral current (A)				1,363
Earth leakage current (A)				0,000
Total distortion (%)	0,34	0,41	0,43	
Distortion in neutral current (%)				23,77
Crest factor	0,01	0,01	0,01	
Factor K	1,00	1,00	1,00	

Imbalance	Kd	Ka
Voltage	26,300	6,000
Current	79,300	64,400

	L1	L2	L3	III
Consumed power (+)				
Active (kW)	17	17	17	50
Capacitive (kvarC)	0	0	0	0
Inductive (kvarL)	0	0	0	0
Apparent (kVA)	17	17	17	50
Power factor	1,00	-1,00	-1,00	-1,00
Cosine phi	1,00	-1,00	-1,00	-1,00
Generated power (-)				
Active (kW)	0	0	0	0
Capacitive (kvarC)	0	0	0	0
Inductive (kvarL)	0	0	0	0
Power factor	0,00	0,00	0,00	0,00
Cosine phi	0,00	0,00	0,00	0,00

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3.3 UC3 Expected data to be collected.

Table 4 presents the information to be collected. This will feed the KPIs

Table 3: Data to be collected on the UC3 demonstrator

Component	Quantity	Comments	Unit
Electromagnetic Field	The magnetic induction inside the vehicle		[μT]
	The magnetic induction around the vehicle		[μT]
Weather conditions	Temperature	Ambient / Air temperature	[C°]
		Road temperature Optic fiber	[C°]
		Power Electronics' temperatures	[C°]
Electrical	Grid cabinet (AC/DC)	Input phase voltages	[V]
		Input phase currents	[A]
		MOSFETs temperature	[°C]
		Contactors state signals	
		Efficiency	%
		DC output voltage	[V]
		Output current	[A]
		Instantaneous power	[kW]
	Coils cabinet (DC/AC and resonant circuit)	Frequency	[kHz]
		MOSFETs temperature	[°C]
		Inverters output HF currents	[A]

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		Primary coils HF currents	[A]
Other	Charging time Vehicle data	Vehicle over transmitting track	[s]
		Transferred energy	[kW/h]
		Global efficiency	%
		Speed	[km/h]
		Traffic Data	[vehicles/day]
		Misalignment rate	[%]

3.4 UC3 Innovation

As explained in the objectives of this use case, the interoperability, power level and connectivity are the main advances expected from this demonstration. The cost aspects and long-range adaptation of the system and technology were considered and will be demonstrated in a real system and experimentation.
The interoperability aspects regarding two different manufacturers that will be able to charge the same vehicle is an important challenge that can help the next generation of standards and technologies for the charging lane and for the embedded system.

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4 CONCLUSIONS

The UC3 experimentation will quantify the efficiency of dynamic wireless power transfer in a long-range circuit at speeds up to 90km/h.

The charging system consists of 8 coils (each 10 meters long) installed inside the Fabric testing lane, powered by 8 inverters located at the side of the road, themselves being powered and controlled by a power supply unit.

The demonstration will take place at VEDECOM's facilities in Versailles, Satory.

Three different vehicles will be adapted to be charged on the wireless charging lane: a Renault Zoe, a Stellantis DS3 and a Renault Master; The Zoe and DS3 vehicles will be equipped with just one coil for a nominal power of 30kW. The Master will include three coils to be charged at 90 kW.

The same vehicles will be used in the other inductive demonstrators of the INCIT-EV project (UC2).

The main challenges of this use case are to demonstrate the interoperability between different systems, different vehicles and power levels.

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