D3.10: Update of Report on user centric EV charging infrastructure.

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D3.10: Update of Report on user centric EV charging infrastructure.

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Technical References

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Project Coordinator	CIRCE Miguel Zarzuela - mzarzuela@fcirce.es
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[1] PU = Public

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Document history		
V	**Date**	**Beneficiary partner(s)**
1	12/01/2021	CIRCE - First draft from WP3 deliverables
2	28/01/2021	CIRCE – Final Quality Revision
3	15/02/2021	CIRCE – Improvement of first draft

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ACRONYM LIST

Table 1 Acronym List

Acronym	Definition
AC	Alternative Current
AV	Autonomous Vehicle
CAV	Connected Autonomous Vehicle
CERV	Conference on Electric Roads & Vehicles
CWD	Charge While Driving
DC	Direct Current
DSO	Distribution System Operator
DSS	Decision Support System
DWPT	Dynamic Wireless Power Transfer
DWPTS	Dynamic Wireless Power Transfer System
DSO	Distribution System Operator
TSO	Transmission System Operator
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
EM	ElectroMagnetic
EMC	ElectroMagnetic Compatibility
EMF	ElectroMagnetic Field
EMI	ElectroMagnetic Interferences
EVCS	Electric Vehicle Charging Station
GA	Ground Assembly

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Acronym	Definition
GB Standards	GuoBiao (Chinese National) standards
HEV	Hybrid Electric Vehicle
HMI	Human Machine Interface
ICT	Information and Communication Technology
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEA	International Energy Agency
IPT	Inductive Power Transfer
IEC	International Electrotechnical Commission
ITS	Intelligent Transport System
ISO	International Organization for Standardization
KAIST	Korea Advanced Institute of Science and Technology
LDV	Light Duty Vehicle
LKA	Lane Keeping Assistance
LTE	Long Term Evolution
ORNL	Oak Ridge National Laboratory
OPTW	Opportunistic Wireless Power Transfer
PKI	Public Key Infrastructure
PTW	Powered Two Wheelers
REN	Renewable ENergy
RSU	Road Side Unit
SAE	Society of Automotive Engineers
SoA	State of Art

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Acronym	Definition
S-WPT	Static Wireless Power Transfer
SFT	Super Fast Charging
TEN-T	Trans-European Transport Network
TSO	Transmission System Operator
UC	Use Case
TCP/UDP	Transmission Control Protocol/ User Datagram Protocol
V2I	Vehicle To Infrastructure
V2C	Vehicle to Centre
V2G	Vehicle To Grid
V2R	Vehicle to Roadside
V2V	Vehicle to Vehicle
VRU	Vulnerable Road Users
WAVE	Wireless Advanced Vehicle Electrification
W-CDMA	Wideband Code Division Multiple Access
WPT	Wireless Power Transfer
WPTS	Wireless Power Transfer System

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0 EXECUTIVE SUMMARY

This document is the deliverable **"D3.10 – Report on user centric EV charging infrastructure"** of the H2020 project INCIT-EV (project reference: 875683) which is an update of D3.5 after the Iterative Validation Loop.

The main objective of this deliverable is to summarize the developments of WP3 task. This deliverable will be made public the general information of the reference charging solutions designed.

The following deliverables of the associated WP3 tasks are summarized:

- D3.6 Update of cost-effective low and medium Power DC-DC bidirectional chargers (M4-M24)
- D3.7 Update of superfast conductive charging systems improvements (M4-M24)
- D3.8 Update of Opportunity Wireless Power Transfer (OWPT). Stops and Static en-route charging (M4-M24)
- D3.9 Update of Dynamic Wireless Power Transfer (DWPT). Urban and extra-urban charging (M4-M24).

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

This deliverable is an updated version of D3.5. The main improvements in regard to the previous version are:

The progress made in the design and manufacture process of the low and medium power charger is presented in section 2.

Section 4, "OWPT reference charger models", shows that the design of the primary coil has been finalized. This is an interoperable system with Vedecom's 30-kW coil and Circe's 50-kW coil.

In respect of section 5, the influence that the different secondary coils exert on each other in the Master van has been studied, analysing the way to solve this problem by introducing aluminium barriers to reduce the mutual inductance. Besides, the study of losses in the coil cables has been included as a function of the number of strands and the cable section. The shielding of the vehicles has been studied and the communication system proposed.

The pending work to design the final prototypes for all UCs will continue under WP7 and WP8 development

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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:

- Smart and bi-directional charging optimized at different aggregation levels. (UC1, UC4, UC5, UC6)
- Dynamic wireless charging lane in urban areas (UC2)
- Dynamic wireless charging for long distances (e-road prototype for TEN-T corridors) (UC3)
- Low power DC bidirectional charging infrastructure for EVs, including two-wheelers. (UC6)
- Opportunity wireless charging for taxi queue lanes in airports and central stations (UC7)

1.1 WP3 contribution to INCIT-EV objectives

The WP3 "User Centric charging solutions" of the INCIT-EV project has the objective of design and model the innovative charging equipment required to perform the rest of the project activities. The impact of these solutions will be evaluated associating them to a set of indicators which will feed the Decision Support System (DSS) libraries.

Besides, this work package has a series of specific objectives:

- To establish and model the basics and functionalities of general charging solutions that will be used in each Demo areas use cases which will be demonstrated during the project.
- Adapt these reference solutions to the specifications of demo-sites.
- Carry out an evaluation of the innovative solutions and their potential impacts to feed the project library
- To assess the scalability, reliability and interoperability of the solutions that will be deployed in the Demo site areas.
- Considering the rest of the information generated by the rest of the WPs, be able to carry out an iterative validation loop phase for every task. This phase is planned to be completed in 12 months.

This deliverable D3.10 addresses the completion of all these objectives and feed the DSS tool.

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2 LOW AND MEDIUM POWER CHARGER MODELS.

Within WP3 "User Centric charging solutions" of the INCIT-EV project, Task 3.1 has the following objectives:

- To establish and model the basics and functionalities of the cost-effective low and medium power DC-DC bidirectional chargers' solutions.
- Adapt these reference solutions to the specifications of demo-sites.
- Carry out an evaluation of the innovative solutions and their potential impacts to feed the project library.
- To assess the scalability, reliability and interoperability of the solutions that will be deployed in the demo site areas.
- Define a set of indicators associated with the task so that they can feed the DSS library.

This deliverable summarizes the development of task 3.1 and addresses the completion of objectives at M24.

2.1 Task development

2.1.1 EV Related requirements and interoperability

Up to M24 of INCIT-EV project in task 3.1, general requirements have been studied, especially those regarding charging modes, plug types and V2G bidirectional DC charging protocols and physical interface.

Several standards have been followed in order to obtain an interoperable product that holds the European requirements (set by the IEC and ISO). These standards are represented in Figure 1 in a schematic way regarding to its relationship with the electric vehicle. For instance, regarding plug types, the work has focused on CHAdeMO and CSS standards and V2G Bidirectional DC charging requirements, and the conclusions reflect that the system should be compatible with ISO/IEC 15118 and CHAdeMO standard.

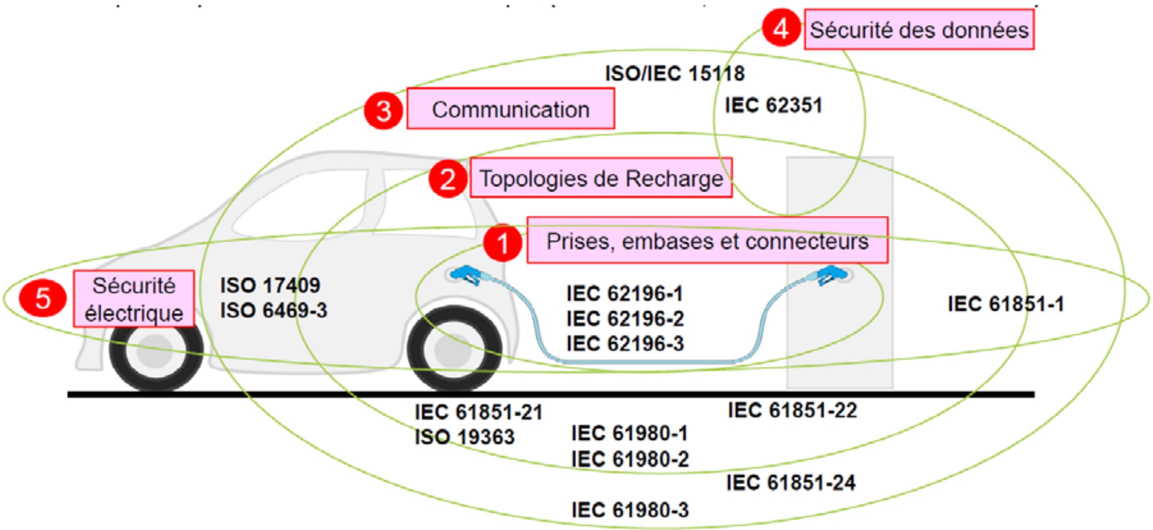

Figure 1: Aval standards overview for EV charging [VEDECOM/Project ICOFI]

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Due to the characteristics of the system, the forementioned interoperability has been studied. These studies let us find the low and medium power charging system's interoperability solutions, being the most important areas of work, the relationships between the aggregator and the electric vehicle supply equipment (EVSE), the physical charging interface, and EV/EVSE communications.

2.1.2 Converter topology design and model

The state-of-the-Art topologies for AC/DC, DC/DC bidirectional, and low power DC/DC stages have been extensively described and compared previous to the design of all the prototypes' topologies. This have been made to have a holistic vision of the nowadays possibilities of these types of converters, allowing the design team to make better choices.

2.1.2.1 50kW bidirectional fast charger

The expected overview and detailed results to obtain in the design of the CIRCE's 50-kW bidirectional fast charger are represented in Figure 2 and Figure 6, illustrating the rated power of the converters to design and their parallelization.

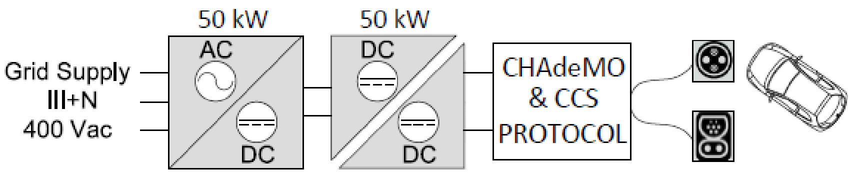

Figure 2: Fast charger block diagram.

In use cases 6 and 7, coordinated by CIRCE, two three-phased fast chargers are being developed. The use of an innovative configuration of power electronics, based on a 4-legs converter topology to perform a single-phase operation, allowing the EV charger to provide additional grid services beyond V2X services:

- The single-phase active power control implemented in the AC/DC converter allows to choose from which phase the power is consumed, avoiding line congestion. In this way, the EV charger can perform grid balancing tasks, consuming power from the less loaded phases of the grid to inject it in the most loaded ones. The grid current balancing also eliminates neutral current, especially damaging for distribution transformers. Figure 3 shows an example where power is mainly consumed from the yellow phase to balance line currents.

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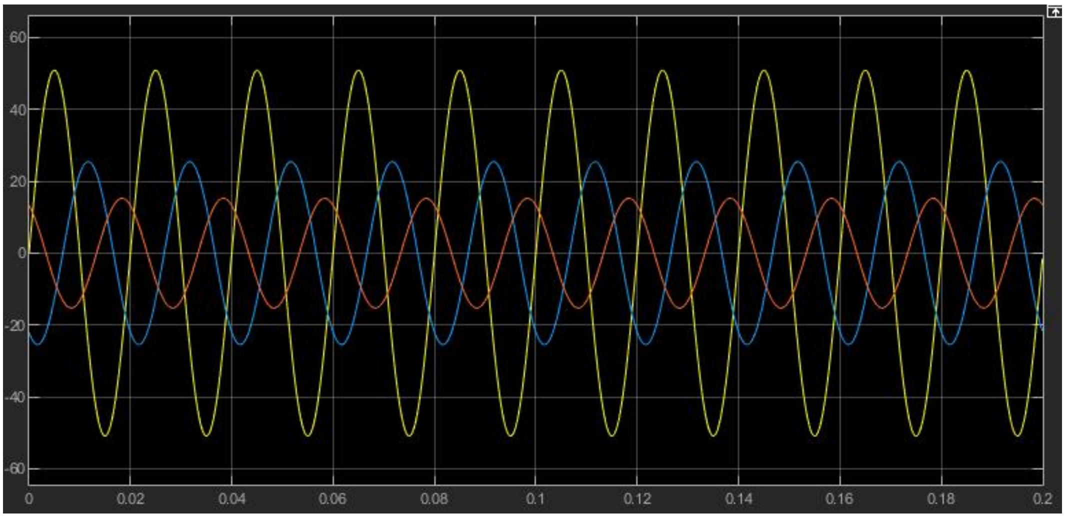

Figure 3: EV charger consuming unbalanced from three phases (only currents, computer simulation capture).

- Single-phase reactive power injection. Reactive power increases technical losses and voltage drops in distribution lines. The developed EV charger allows to compensate reactive power to minimise power waste or regulate voltage using the Ferranti effect, through reactive power injection, independently in each phase.
- Harmonic filtering. The presence of harmonic currents produces distortions in the supply voltage that can damage the loads connected to the grid and equipment such as distribution transformer and protections.

In addition, as Figure 6 shows, the EV charger has been built from modular parallelizable **12.5-kW DC/DC** and **25-kW AC/DC** modular converters, as Figure 4 and Figure 5, allowing a high scalability to larger charging station. The charging station developed for the INCIT-EV project consist of two AC/DC and four DC/DC modules (Figure 7) parallel connected to reach the rated power of 50 kW. Both systems, AC/DC and DC/DC, have been designed using SiC components and methodologies to reduce their size.

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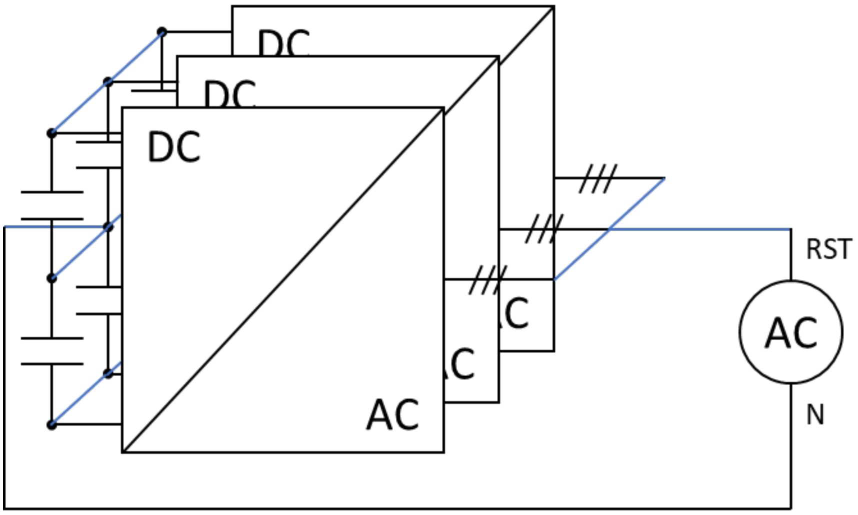

Figure 4: Connection diagram for an AC/DC converter composed of 3 modules parallel connected.

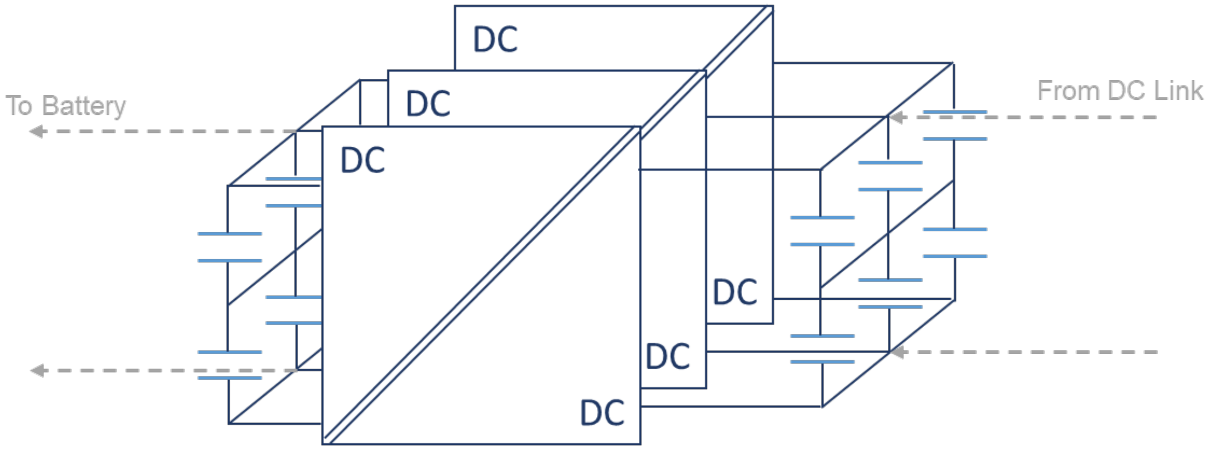

Figure 5: Connection diagram for an DC/DC converter composed of 3 modules parallel connected.

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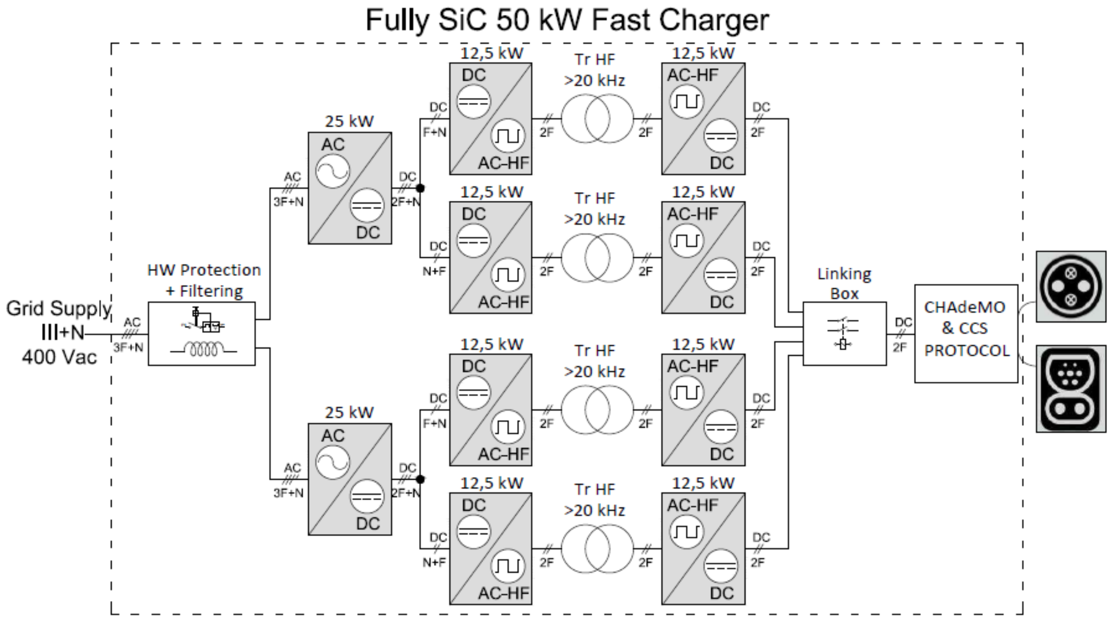

Figure 6: Fast charger detailed system description.

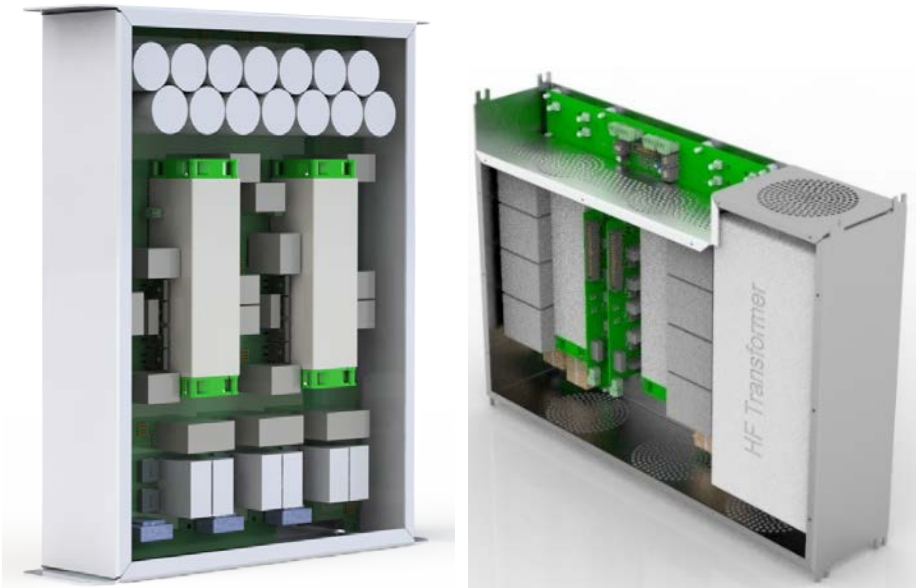

Figure 7: 25-kW AC/DC (left) and 12.5-kW DC/DC (right) power modules.

The plastic enclosure shown in Figure 8, which includes two uses to allow charging through the most used EV-charging standards, CHAdeMO and CCS protocols) has been designed to protect the power electronics from environmental hazards.

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Figure 8: CIRCE EV fast charger 3D design.

2.1.2.2 Low power converter for 2 wheels vehicles

UC6 demonstration ecosystem includes a low power 250-W Synchronous Buck-Boost DC/DC charger system has been designed to create a user centric station for two wheels vehicles.

The general concept of this low power charger model architecture for 2 wheelers, joined with the 50-kW charger is represented in Figure 9.

This system developed by IDNEO allows to charge 2-wheelers using the same DC grid provided by the charger. The chargers are prepared for bidirectional capabilities and the number of stalls can be easily expandable.

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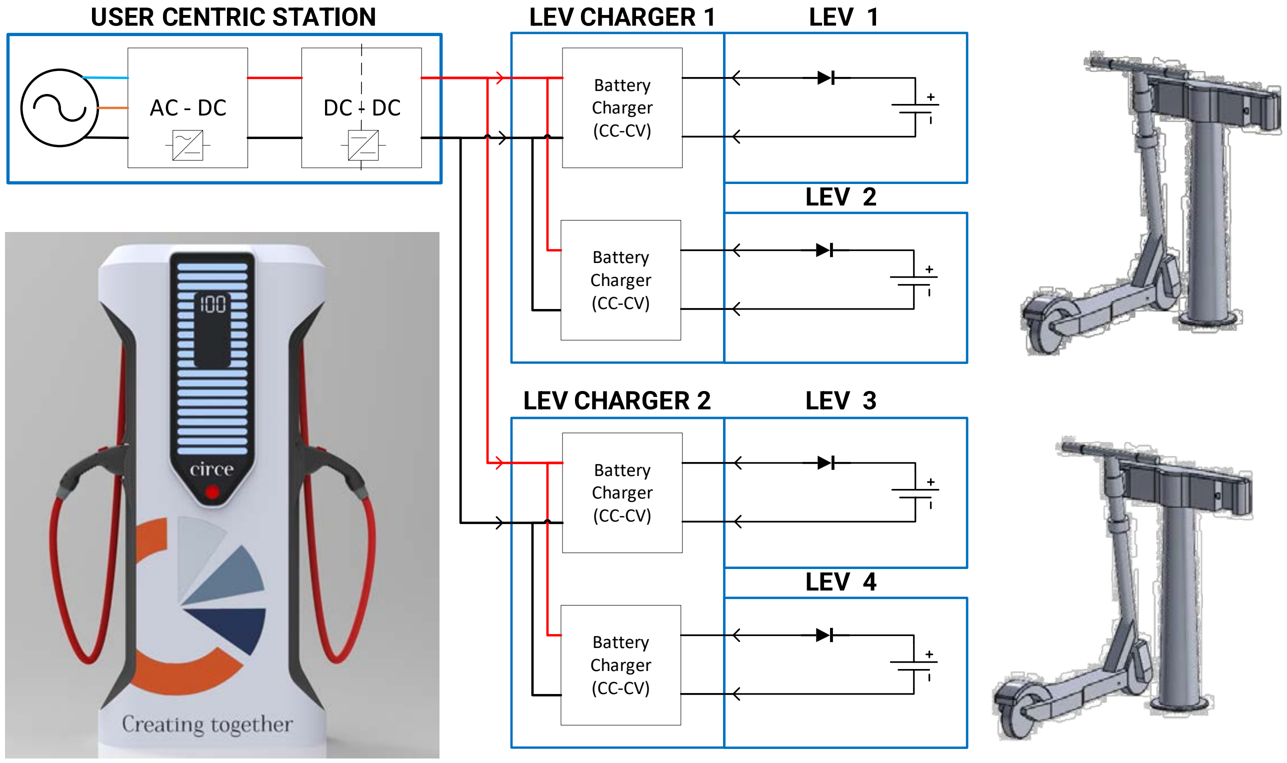

Figure 9: Two wheels vehicles charging system architecture

2.2 Task Conclusions

In task 3.1 the requirements to accomplish in the final system have been depicted, and the main standards to be considered in the design to agree with normative have been studied. Also, the first version of the interoperability parameters and characteristics has been presented.

The state of the art of the power electronic topologies to be considered in the design of each sub-system was reviewed. This study results in all the designs in this first stage of the project.

However, to definitively define the specifications and get the final design of the system, the following task should be performed in next months of task development:

- Analysis of the refrigeration of the solution
- Scalability of the solution and reliability.
- At least, an iterative validation loop phase will be executed

This work will be completed under WP7 activities during the modelling and engineering of the UCs solutions.

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3 SUPERFAST CONDUCTIVE REFERENCE CHARGER MODELS.

Within WP3 "User Centric charging solutions" of the INCIT-EV project, Task 3.2 has the following objectives:

- To establish and model the basics and functionalities of the SFC DC V2G chargers' solutions.
- Adapt these reference solutions to the specifications of demo-sites.
- Carry out an evaluation of the innovative solutions and their potential impacts to feed the project library
- To assess the scalability, reliability and interoperability of the solutions that will be deployed in the Demo site areas.
- Define a set of indicators associated with the task so that they can feed the DSS library.

This deliverable summarizes the development of task 3.2 and addresses the completion of objectives at M24.

3.1 Task development.

3.1.1 SF Chargers requirements and interoperability

Up to M24 of INCIT-EV project in task 3.7, general requirements and interoperability have been studied.

The three aspects to consider for the mass implementation of SF chargers are: the minimization of the charging time for long-distance, the development of a user-friendly interface and the development of a scalable charging network, apart from the regulations imposed by the European law, as mentioned in 2.1.1.

Regarding interoperability, the most important aspect to the super-fast conductive system is its ease of communication with all the actors it interfaces, being the most important the relationship between the GRID and GRID Operator, the EV vehicle and EV user, and the CPO Backend (EV and user identification and payment). These interfaces and the solution's implementation have been studied, addressing in last one synergy between ICT platforms, due to issues regarding GRID and EV are standard.

3.1.2 Charging time for long distance

Focusing in to minimize the charging time for long-distance, a 350-kW 20-kHz converter has been designed to use in the super-fast conductive charging station. The overview scheme of the converter is shown on Figure 10 Full topology of a fast charger. The design was made by modular SiC components, which allowed to achieve a power efficiency conversion above 97%, with a considerable size and unitary-cost reduction.

One of the main problems of a high-power converter is the heat management. Aiming to manage it, two cases have been studied for the refrigeration system:

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- A passive refrigeration, that uses a pump to circulate a liquid coolant into the charging cable with a certain flow rate. The hot liquid circulates through a liquid/air heat exchanger which is cooled down by forced air convection using to a fan.
- An active refrigeration system, that uses a thermodynamic system to cool down the heat. It increases the electric consumption of the refrigeration system, but it has a better cooling capability.

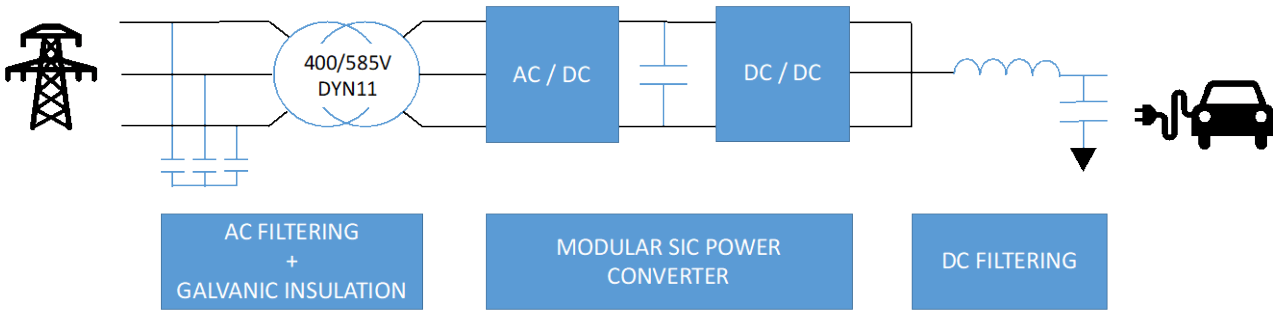

Figure 10 Full topology of a fast charger

Regarding the improvement of current protections, the main of they described in the IEC 61851 For SFC system, several protections shall be implemented and improved, for the users and the hardware parts.

- The protection of the users consists of avoiding any direct and indirect contact with active parts that can present hazardous voltage.
- The protection of the hardware is used to prevent any short circuits or fire in the charger.

Designing work has been done, to accomplish and improve that protections mains and systems.

3.1.3 User friendly interface

Another of the important tasks to perform in the development of the system has been to optimize the charger accessibility and the ease of use.

Regarding accessibility two main actions were carried: first, a simple user application interface (Figure 11), implemented in several languages, was developed for an intuitive use of the charging and payment functionalities, and second an ergonomic physical design adapted to all types of possible users, presented in Figure 12.

Apart from the two explained actions, aimed for a better regular use, easiness has also been considered in all aspects of design, focusing in integrate cable management system, which is expected to improve the user experience. This cable system allows the user to connect his car easily, wherever the charging plug of the EV is located. It is designed to balance the weight of the cable and avoid the cable touching the ground, thus minimizing wear and tear.

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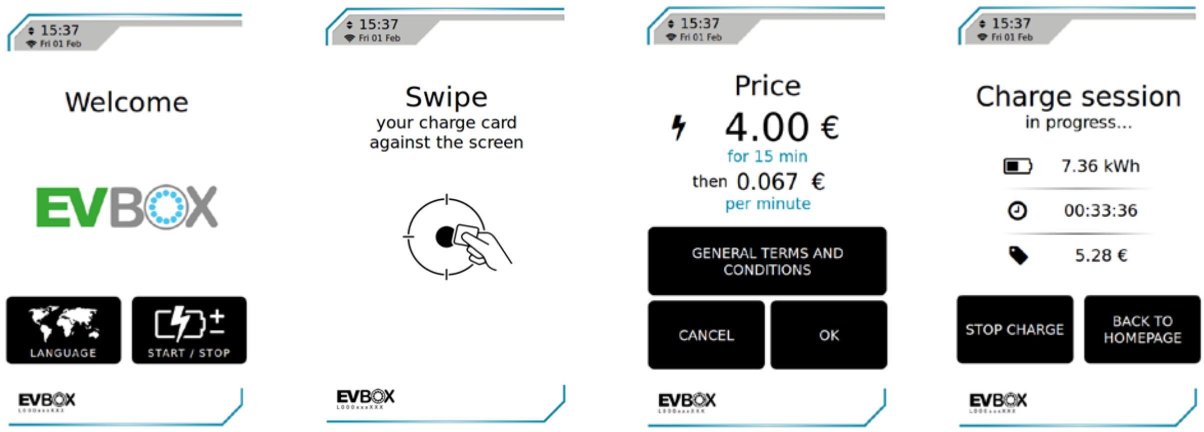

Figure 11 User Interface Example

Figure 12 All user-friendly ergonomic EV charger

3.1.4 Development of the charging network

Finally, in addition to being fast and user friendly an SFC system should also be scalable to deploy in the variety of needed location with different power supply constraints. For this, the study of better grid integration has been done. An Energy Manage System with an algorithm computing the maximum power set-points of all connectors that compose a Charging Station, based on priority rules for the simultaneous charging sessions, has been considered to adjust the power delivery to the chargers to the current grid conditions. Besides this system could be communicated with the smart grid. Furthermore, low voltage feeders, 400 V on three phases, have been considered as the current preferred and easiest way to mass install SFC systems, despite in the future medium voltage ones could be considered.

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3.2 Task Conclusions

The functional specifications of the state of art SFC system presented in Chapter 4 cover the requirements introduced in Chapter 3. These specifications tackle the main issues for SFC system usability and grid integration. Additionally, examples of the solutions from the SFC used in the project show concrete ways on how those specification can be implemented.

While the SFC systems have many more lower impact requirements, the ones mentioned in this document represent the most influential ones for mass adoption of SFC systems.

All in all, the requirements are outlined to make an SFC system fast, user friendly and scalable, to be able to present a gas station like experience to the end user. This will greatly decrease the range anxiety of the typical EV user, thus further promoting electric transport vehicles, while enabling the scalable deployment of SFC systems.

Final design of the SFC to be used in UC5 – Super Fast Charging systems for European Corridors – Tallin Area (Estonia) will be developed under WP8

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4 OWPT REFERENCE CHARGERS MODELS.

Within WP3 "User Centric charging solutions" of the INCIT-EV project, Task 3.3 has the following objectives:

- Design and model a OWPT (Opportunity Wireless Power Transfer) solutions that will be later used to conform the Demo areas
- Carry out an evaluation of the innovative solutions and their potential impacts to feed the project library
- To assess the scalability, reliability and interoperability of the solutions that will be deployed in the Demo site areas.
- Define a set of indicators associated with the task so that they can feed the DSS (Decision Support System) library.

This deliverable summarizes the development of task 3.3 and addresses the completion of objectives at M24.

This task is very linked to T3.4 for dynamic charging operation. One big ambition and goal of INCIT-EV project is the interoperability of the wireless solutions, therefore both tasks have worked together to reach to allow the same vehicle to charger under any charging solution, independently of the static or dynamic nature.

4.1 Task development

4.1.1 Requirements and interoperability

For the INCIT-EV project's Task 3.3 up to M24 general requirements have been studied. This study has been focused on different standards not only EMC standards but also all the standards related to opportunity wireless power transfer. Among other standards about communications, measure procedures, etc.

The OWPT primary system has been designed and optimized to be able to transfer 50 kW operating with the secondary coil designed by Circe. This design, in turn, has been made considering interoperability with Vedecom's 30 kW secondary coil. This system operates, as specified in the specifications, in the 81.5-90 kHz range. The same secondary coil is used in all wireless Use Cases for static and dynamic charging.

4.1.2 50 kW system design

The state-of-the-Art topologies for IPT (Inductive Power Transfer) system have been described and compared. Evaluating and comparing the different topologies for IPTs, the SP-S topology has been selected, whose scheme is represented in Figure 13.

From this comparison and its conclusions, **a 50-kW system interoperable with 30-kW secondary coil** has been designed. To perform the design of the system, traditional road integration with a minimum distance of 5 cm below the road surface has been considered for the coils. And FEM (finite element method), moreover analysis, have been used to model the system inductor.

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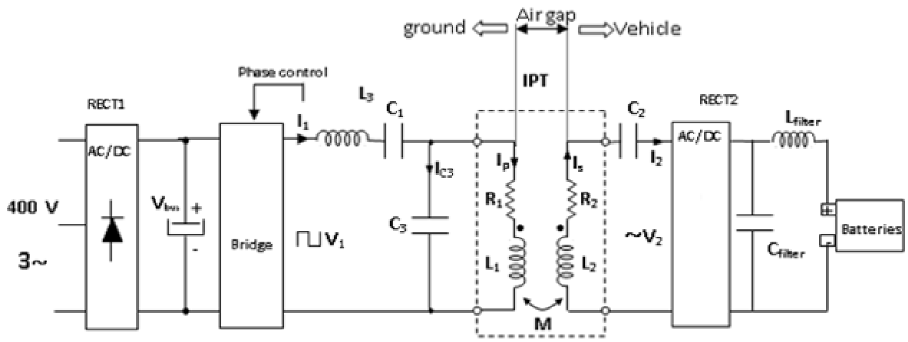

Figure 13. SP-S 50 kW topology

A 50-kW 85-kHz DC/DC bidirectional converter has been designed that allows the use with the primary of IPT system previously design (Figure 14). This system has been designed using SiC components and specific methodologies, to reduce their size.

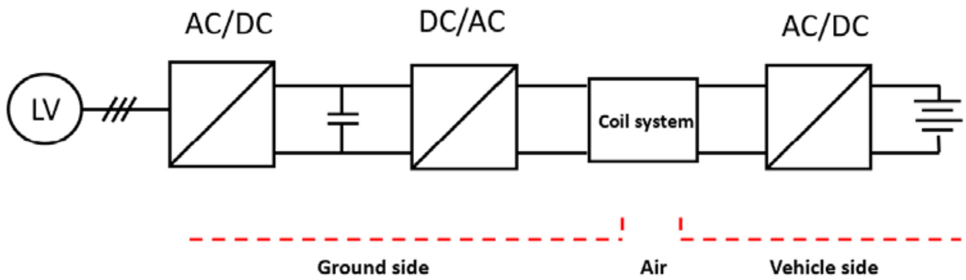

Figure 14 Power electronics stage representation

The **coil system** design process consists of a first step, in which a theoretical study is carried out using Matlab®. In this first theoretical study, a sweep of all possible system configurations capable of transferring the desired power with the available dimensions and in the operating frequency range of interest, in this case, between **80 and 90 kHz** is carried out. This first study ends with the selection of the optimal configuration based on the efficiency, the current density of the cables and the stability of the system.

Once a theoretical system capable of transferring power at the desired frequency has been achieved, it is necessary to create a model that faithfully reproduces the real behaviour of the system. For this second study, the Comsol Multiphysics finite element simulation tool is required. Using this tool, a model is created in which all the elements of the system that influence the transmission of the electromagnetic field are introduced, which are described below. The geometric configuration of these elements is studied and optimized to achieve a system as similar as possible to the theoretical system.

As just mentioned, the inductive system does not consist only of the coils. An **aluminium shielding system** is necessary to protect people and nearby ferromagnetic elements. To compensate for the negative effect on the coupling of the shielding system, ferrite is introduced between the coil and the aluminium to concentrate the magnetic flux. All these elements have been designed and optimized in such a way that they provide the best performance of the system and comply with current emission regulations. The schematic representation is shown in Figure 15 and Figure 16.

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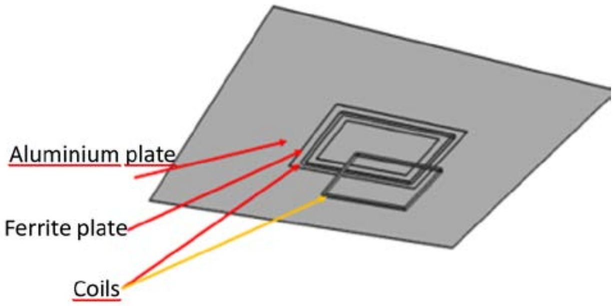

Figure 15. Arrangement of the 50-kW secondary system elements.

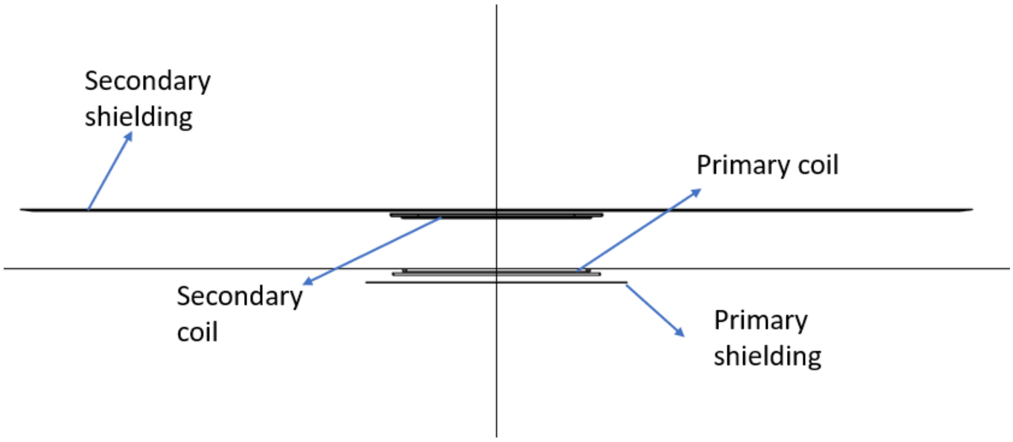

Figure 16. Schematic representation of the system.

4.2 Task Conclusions

According to the requirements of the task, an interoperable induction power transfer system has been designed **to transmit 30 and 50 kW**.

After the interoperable primary system was designed, the values of the electronic components of the compensation topology were defined. For this, unfavourable cases were simulated in which the frequency, airgap and misalignment were modified.

The simulated system, working with both the 30 and 50-kW coils, meets all the requirements of the task and complies with the regulations for magnetic field emissions.

Work has been done on the development of cooling for the primary system coil, concluding that the **best option is liquid cooling**. In the coming months, work will continue on this development in WP7 to define the complete cooling system of UC7 – The Static Wireless Charging in Zaragoza, Spain.

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5 DWPT REFERENCE CHARGERS MODELS.

Within WP3 "User Centric charging solutions" of the INCIT-EV project, Task 3.4 has the following objectives:

- Design and model the general DWPT (Dynamic Wireless Power Transfer) solutions that will be later used to conform the Demo areas
- Carry out an evaluation of the innovative solutions and their potential impacts to feed the project library
- To assess the scalability, reliability and interoperability of the solutions that will be deployed in the Demo site areas.
- Define a set of indicators associated with the task so that they can feed the DSS library.

This deliverable summarizes the development of task 3.4 and addresses the completion of objectives at M24.

As already introduced, due to the interoperability requirements this Task has been developed in synergy with T3.3 for OWPT design.

5.1 Task development

This task comprises two different developments, wireless charging at urban speeds and at high speeds. The operation conditions are different for both scenarios (presence of pedestrians, available space, speed…), therefore two different approaches have been followed.

5.1.1 Urban primary system Model (VEDECOM)

A dynamic wireless charging system should be fully integrated in the road infrastructure. An important aspect and advantage of the charging system is that it will not be one more visual pollution agent in the urban scenario. Besides, the system does not need and will not take up public place that can be used for pedestrian's accessibility or afforestation. Therefore, more than a possibility, the fully integration is an unavoidable advantage. The charging system needs to be compatible with the others integrated systems in the urban infrastructure like communication tunnels, water supply, heating system, urban drainage, sanitation, and power grid connections. Figure 17 shows the proposal for urban integration.

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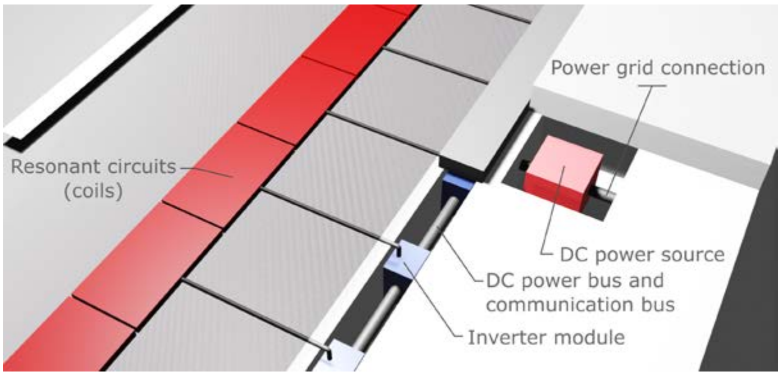

Figure 17. First urban integration proposition.

Regarding the modes of operation of the system, the track can be seen, as a sequence of **30 kW coil** and inverter module assemblies in different states (see Figure 18). Each set can be in three different states:

On: The coil is powered by the inverter module generating a magnetic field and is transmitting energy to the secondary coil inside the vehicle.

Short Circuit: The two neighbouring coils of the **On** coil are in short circuit to provide a path to the magnetic field and to raise the transmitted energy efficiency.

Off: The circuit is opened to avoid current flowing.

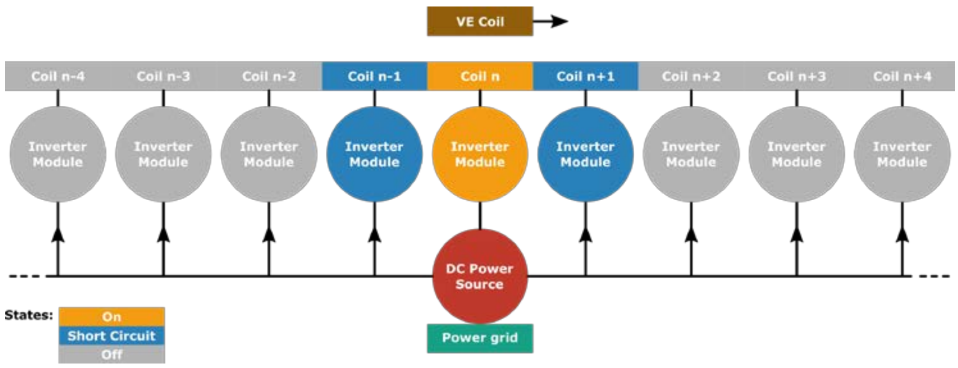

Figure 18. Track states and behavior.

It is necessary for the system to always know what state it is in to be able to control the charging process. Therefore, a communication system between primary and secondary and its control system has been designed.

5.1.2 Inter and Extra Urban primary system Model (CIRCE)

Circe is developing a **90 kW DWPT** (Dynamic Wireless Power Transfer system) to charge vehicles up to **130 km/h** which will be designed and manufactured and pre-tested in Zaragoza, and installed and demonstrated in Versailles facilities. This wireless charger is thought to be used for fast dynamic charging in circuit of test conditions.

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In this prototype, three novel concepts are going to be used in the design; firstly, **the operating speed will be up to 130 km**/h, typical of a motorway, secondly, **a primary coil longer than the secondary** one to avoid the use of ferrite and aluminium in the ground side and thirdly the **possibility to operate with multi-secondaries** (from one to three).

The system has been developed taking into account tolerances in the x and y axes and in the airgap (z axis). The S-S configuration has been selected as the compensation topology. In addition, the system works at a working frequency according to the IEC 61980 standard in the **range of 81.5-90 kHz**. The shielding system has been designed according ICNIRP 1998 (6.25 μT).

The primary consists of a **10 m** long coil able to charge **30 kW** when the vehicle has only a secondary coil (ZOE) and **90 kW** when the vehicle has three secondary coils (MASTER). The ground power system controls the primary current and the frequency to source the desired power, and the vehicle is in charge of control the power absorbed from the primary. Figure 19 shows the dimensions of the primary and secondary coils.

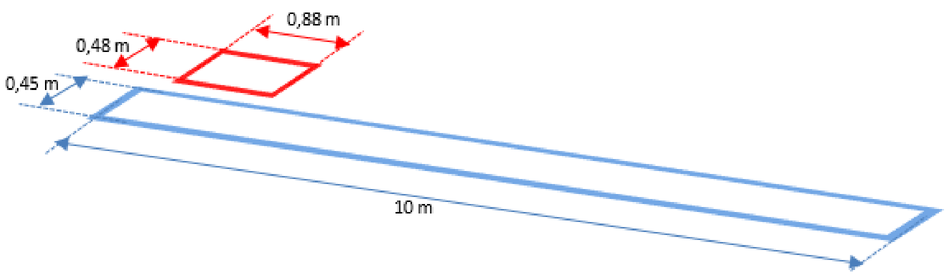

Figure 19. Medium Dimensions considered in the design.

Figure 20 represents the schematic inductor system for the case of the MASTER van.

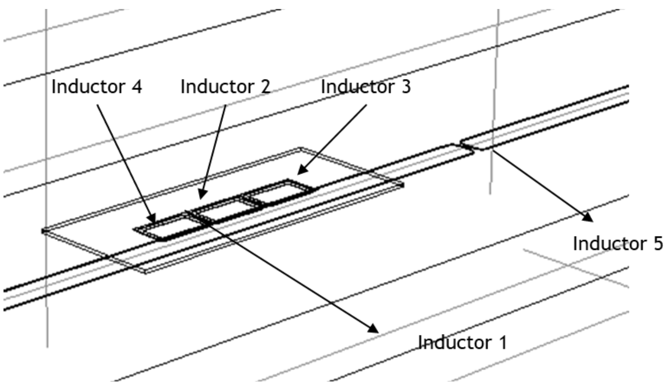

Figure 20. schematic inductor system and definition of the numbers of the inductors.

Regarding the operation of the system for the MASTER van, the system behaves correctly except for inductor 2, which is the central inductor of the MASTER induction system. This behaviour is due to the introduction of two additional voltage sources, due to the coupling with the other two secondaries (3 and 4). In order to counteract this effect, it would be necessary to introduce a higher current into the system. Therefore, it

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should be mitigated as far as possible. For this, a solution has been proposed that consists of the introduction of a barrier between the inductors. This barrier has the function of hindering the path of the field lines between the two inductors. Figure 21 shows how this barrier works.

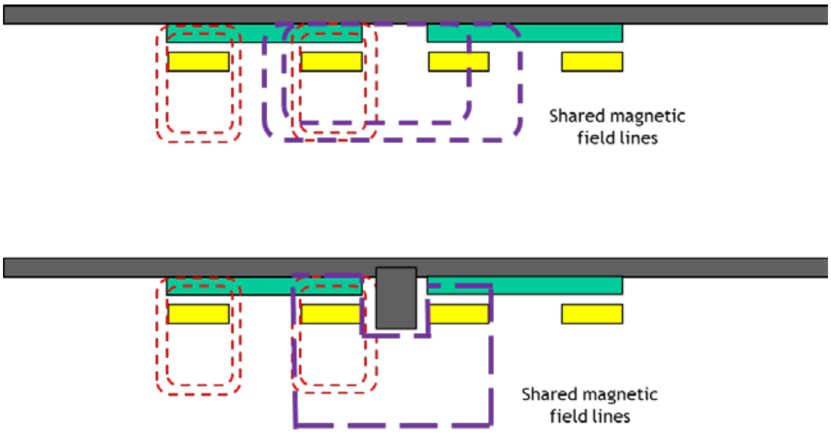

Figure 21. Introduction of an aluminum barrier to avoid the coupling between secondaries.

Another problem results from trying to use a single topology for both the ZOE system and the MASTER system. The ZOE system consists of a single inductor in the secondary and its shielding and the MASTER system consists of three inductors and a much larger shield. The problem is due to the fact that, due to the different size of the shield, **the value of the primary inductance is affected**, and it is modified. Therefore, the resonance capacitor in both cases should be different if we want to work in resonance in both cases, which would lead us to work with a relay that selects between both systems. This adds price and complexity to the system and prevents the system from being used for different vehicles or intermediate systems such as with two inductors.

Therefore, as a solution, a resonance capacitor has been selected whose value is between that of the resonance capacitors of both systems. The behaviour with this capacitor has been verified, taking into account the following assumptions.

- The current in the secondary is not balanced, but we have managed to reduce it to values that are within the specification of the secondary.
- In the secondary there is a DC/DC converter that allows to balance the currents in the batteries, this converter has been modelled.

The shielding system has been designed in accordance with compliance with the requirements standards.

Finally, a study has been carried out to estimate the losses generated in the litz wires of the winding (due to conduction and proximity effects) as a function of the strand radius and the number of strands (Figure 22). The final cable configuration has been chosen based on a balance between economic cost and losses.

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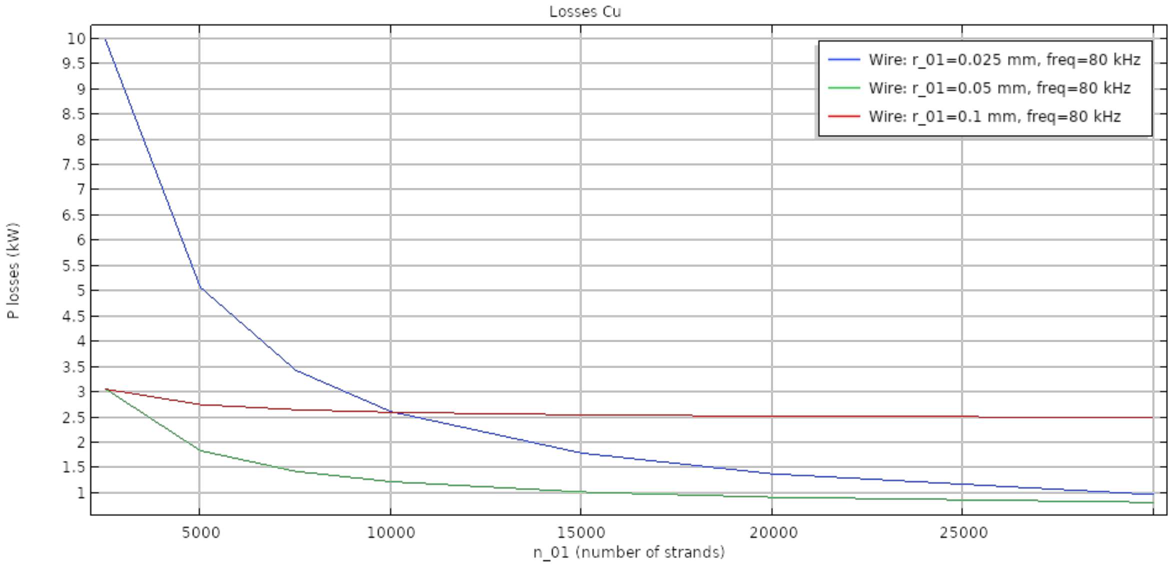

Figure 22. Power losses of a copper Litz wire with different radius of strands and number of strands.

5.1.3 On-Board System Model (Secondary) (RSA)

An increase of the **ground clearance** of the secondary system has been conducted on a mule to be equivalent to a production vehicle. After adding a mimic of the coil (Figure 23, without shielding), a ground clearance and underbody protection evaluation has been done as well as a dynamic test to ensure that these modifications are safe for the vehicle and their users.

Figure 23. Mule with increased ground clearance and coil mimic.

The next step is to study the **shielding of the vehicle** and its integration. To the electromagnetic model, only few parts were selected to maintain an acceptable simulation time (Figure 24). These results will be compared with measurement once a secondary coil with shielding will be available.

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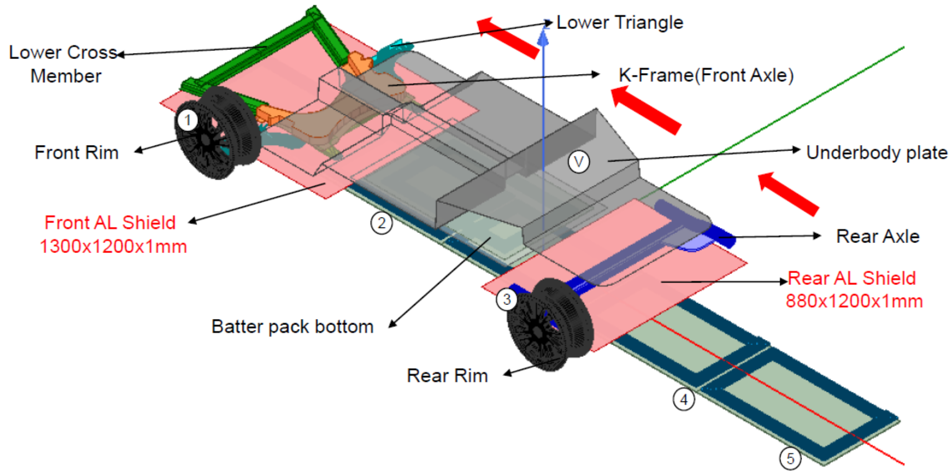

Figure 24. Parts of the vehicle included in the model.

In a second step, after running the electrical simulation, the losses in body parts were evaluated, identifying the eventual hotspot, and assessing the effectiveness of the shielding. Simulations were done with both CIRCE ground coil and Vedecom coils.

Regarding the electrical model in Matlab/Simulink, it needs to include both the primary side and the secondary side, with their control. This model should also consider interoperability aspects. The control on the primary side includes variable frequency control with a PID controller, coils sequencing, inrush current control and protection. On the secondary side, the rectifier is passive, and the DC/DC includes a feed-forward control (Figure 25).

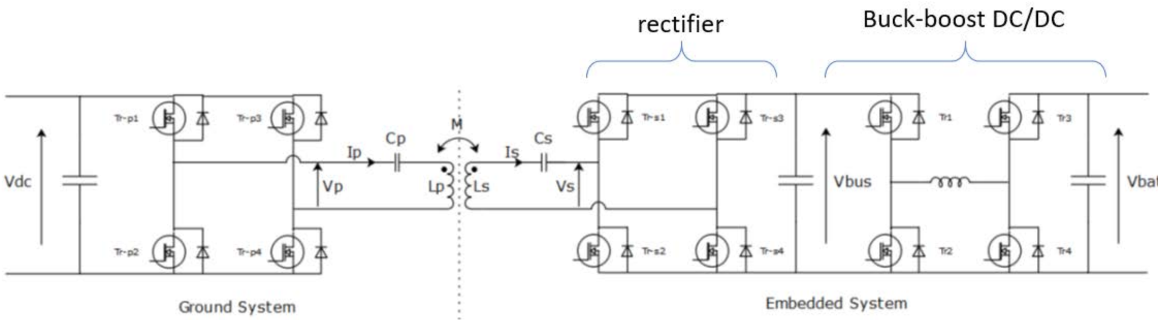

Figure 25. Selected on-board topology.

This model is used as an input for the electromagnetic model. It includes the displacement of the vehicle, the speed being an input parameter.

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5.1.4 The Lane Keeping Assistant System (VEDE)

Precise lateral localisation of the vehicle system has been depicted, from the point of view of been based on road markings and how to auto-calibrate the camera system with load feedback. This allows the accomplishing of a system to have a precise and robust estimation of the misalignment requirement. Besides, the necessity of a system to provide the driver with visual feedback on its actual alignment conditions, makes that a manual and automatic guidance system have been studied.

5.2 Task Conclusions

Several systems to make part of urban and extra-urban DWPT system have been modelled and design. Requirements for the final DWPT system and the systems to vehicle localization and guidance has been studied and depicted.

However, to definitively define the specifications and get the final design of the system, is necessary to keep working in the following in the next months of task development in WP7 and WP8:

- Data collection and measurements needs will be listed (car, infrastructure) so all information for related to charge actual performance can be extracted for further billing post-treatment.
- Study the magnetic field to ensure the EMC and an electromagnetic field safe for users.

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6 CONCLUSIONS

This document sums up the activities accomplish for the different task on Work Package 3 in the first 2 years of INCIT-EV project.

The state of art topologies of **low and medium power charger** electronics has been described. The final design is made of low power (12,5 to 25 kW) fully SiC AC/DC and DC/DC converters than can be parallelized to obtain any rated power. SiC components and methodologies allows to reduce the size and weight of the final equipment increasing the power density. This power electronic designs allows **bidirectional capabilities**, allowing V2G and **ancillary services as voltage control, frequency regulation or phase balance**.

The functional specifications of the state of art **SFC** system tackle the main issues for SFC system usability and grid integration. Additionally, examples of the solutions from the SFC used in the project show concrete ways on how those specification can be implemented. All in all, the requirements are outlined to make an **SFC system fast, user friendly and scalable**, to be able to present a gas station like experience to the end user. This will greatly decrease the range anxiety of the typical EV user, thus further promoting electric transport vehicles, while enabling the scalable deployment of SFC systems. This Super-Fast Charging system will be eventually composed of the modules from the low and medium power charger electronics allowing the system to reach any power.

The state-of-the-Art topologies for **IPT (Inductive Power Transfer**) system have been described and compared for static and dynamic charging modes. INCIT-EV project has worked in the interoperability of the wireless solution in the 85 kHz frequencies.

The same **30 kW secondary inductor** (coil in the vehicle) is used in all the use cases allowing **interoperability for all the wireless technologies**.

The static charging system of 50 kW with liquid cooling has been designed to be installed below the road surface for **opportunity charging** scenarios. For **dynamic charging** two different solutions have been designed for urban (<60 km/h) and highway speeds (<130 km/h) capable of charging up to **120 kW simultaneously per charge segment** (10 to 25 meters).

Multiple but small inductors are proposed for the urban environment, with a limited electromagnetic field allowing pedestrian presence in the vicinities of the charging lane.

Fewer but large inductors are proposed for the inter-urban environment, allowing charging multiple coils from only one primary coil on the ground. Both systems can reach **90 kW charging in one single vehicle**.

The detail study of the magnetic fields has leaded to design aluminum barriers to reduce the mutual inductance of the coils in the e-Van.

An onboard charger is included in the vehicles to control the current for charging the onboard batteries. The shielding of the vehicles has been designed in accordance with the requirements standards.

A Lane Keeping Assistant has been proposed to keep the vehicle aligned when charging.

Although most of the task has been fulfilled, it is necessary to keep working in some activities up to be totally complete, like the systems design and EMC or electromagnetic field issues.

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Few activities are not started or slightly beginning. However, it is necessary to push tasks related to data collection and measurements due to the necessity to be listed (car, infrastructure) so all information for related to charge actual performance can be extracted for further billing post-treatment.

The final design of the charging technologies and the prototypes will be done in WP7 and WP8 during the 3rd year of the project.

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