D8.2 Turin peri-urban area energy model and UC-4 equipment detail engineering and development

Date of document – 06/22 (M30)

D8.2: UC4 Complete solution description. Authors: Alfredo Felix Cota; Roberto Re.

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Technical References

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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
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Deliverable No.	D8.2 - Turin peri-urban area energy model and UC-4 equipment detail engineering and development
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[1] PU = Public

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Document history			
V	**Date**	**Partner(s)**	**Action**
V0.1	06/04/22	CIRCE	Table of Content available for WP7 and WP8 deliverables
V0.2	29/06/22	POLITO	First Draft. Contribution from all partners
V0.3	06/07/22	POLITO	First Consolidated version
V1.0	08/07/22	VEDECOM	Approved version by WP leader
V1.1	10/07/22	CIRCE	Final Quality Review by Coordinator
V1.2	12/07/22	POLITO	Final Version

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0 EXECUTIVE SUMMARY

This document is the deliverable "D8.2 - Turin peri-urban area UC-4 complete solution description" 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-4.

This deliverable will illustrate the objectives, the layout, the technical specification and the engineering results of the UC-4 Charging HUB in a Park & Ride facility in Torino. The results presented will include what civil work operations will be done in the Park & Ride facility, what electric works will be necessary and all the engineering activities related to the charging infrastructure developed specifically for the UC-4. A focus on the data to be collected and the risks and innovation qualities of the UC-4 will complete this deliverable.

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.

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List of figures

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ACRONYM LIST

AC – Alternating Current

CA – Consortium Agreement

CAN – Controller area network

CCS – Combined Charging System

DC – Direct Current

DLV – Deliverable

DoA – Description of actions

DSO – Distribution System Operator

DSS – Decision Support System

DWPT – Dynamic Wireless Power Transfer

EC – European Commission

EES – Energy Storage System

EU – European Union

EV(s) – Electric Vehicle(s)

GA – Grant Agreement

HMI – Human Machine Interface

ICT – Information and Communication Technologies

IPR – Intellectual Property Rights

KPI – Key Performance Indicator

OCPI – Open Charge Point Interface

OCPP – Open Charge Point Protocol

ORDP – Open Reaserch Data Pilot

OWPT – Opportunity Wireless Power Transfer

P2P – Peer-to-peer

PC – Project Coordinator

PM – Person Month

PT – Public Transport

SC – Steering Committee

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TSO – Transmission System Operator

UC – Use case

V2G – Vehicle-to-Grid

V2V – Vehicle-to-Vehicles

V2X – Vehicle-to-X

WP – Work Package

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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 – Zaragoza
- UC7: Opportunity wireless charging - Zaragoza

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-4 in Turin.

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Contribution from partner table

Table 1 - Contribution table

Partner	Contribution
POLITO	General coordination, power electronics design and modelling, civil works planning and tendering.
PRIMA ELECTRO	Power electronics design, modelling and assembly.
IREN	Electric works tendering, support for both the civil works and the power electronics development, supply of vehicles to recharge.
CoT	Support for the civil works project.
GTT	Support for the electric and civil works projects.
FPT/IVECO	Support in the charger development and for the future charging activities by supplying vehicles.
LINKS	Support for the electric works through the measurement system, smart charging algorithms development.

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
T7.5 - Evaluation and impacts assessment	Short term impacts

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2 UC4 OBJECTIVES

The idea behind the Turin Use Case (UC4) is to exploit the existing urban DC grid that is Turin's tramway grid, in order to power a charging hub especially thought for those who want to explore intramodal commuting while coming into the city from other municipalities of the Turin Metropolitan Area. UC4 activities will take place in the Mirafiori quarter, located in the southern outskirts of Turin and whose name is deeply tied with the history of the Italian automotive industry. More specifically, the Caio Mario Park will host the charging hub and all the testing operations. UC4 will not allow free access to the public, opting instead for a closed demo site accessible only to authorized, partners-operated testing. UC4 activities include the following partners:

- The Turin Municipality (COT);
- GTT (Turin public transport company);
- Iren S.p.A. (Turin based multi-utility);
- Prima Electro S.p.A;
- LINKS Foundation;
- FPT & Iveco;
- PoliTO, coordinator of UC4 and in charge of all its related WP8 activities.

The expected outcome of the project will include the installation of 10 CCS2 low power DC charging points (3.6kW), 1 CCS2 Ultrafast Charging point (150kW), one simulated common energy storage.

The demonstration of these applications aims to address different important aspects of the possible synergies between pre-existing infrastructures and future technological needs, specifically:

- Existence of robust, dependable and overly-dimensioned DC grids in city centres;
- Synergies between municipalities and CPOs;
- Enhancement of the low power public charging points market;
- Experimenting the ultrafast charging infrastructures' impact within the city's outskirts in the italian context.

The main objective is to prove that there are alternatives to redundant, expensive and often not practicable solutions for the meticulous infrastructural updates needed in order to improve both the number of charging points as well as the average power outputs of urban charging infrastructures. Using the available power provided by the conversion substations is definitely one of the smarter solutions out there.

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3 UC4 COMPLETE SOLUTION

As anticipated in the previous deliverable, the outcome of the use case includes the installation of 10 CCS2 low power DC charging points (3.6kW), 1 CCS2 Ultrafast Charging point (150kW) and one simulated common energy storage. This provides both low power and ultrafast charging services in one practical hub designed to accommodate every user need. The service is already being thought as an integral part of the IrenGO charging ecosystem, and will be signalled in IrenGO's smartphone app and fully integrated in their network (albeit public access to the site will be guaranteed only after the project's end).

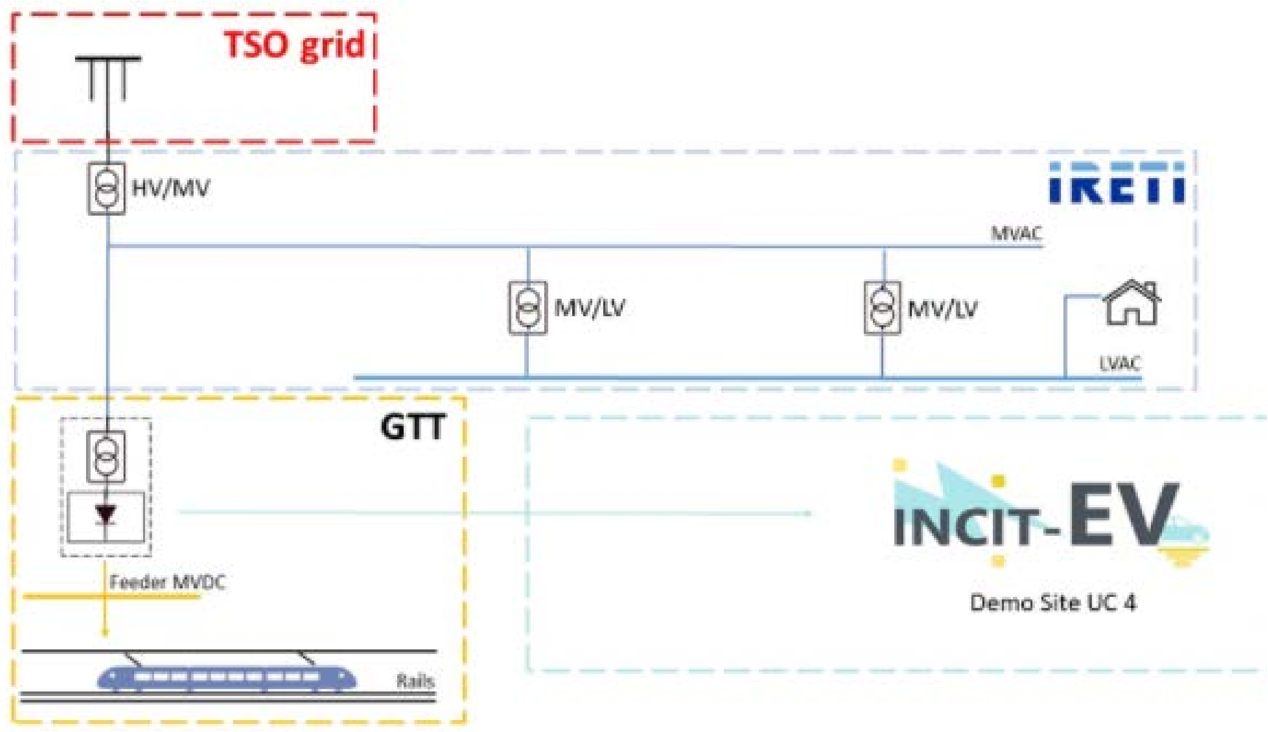

Figure 1: Distribution scheme of UC4.

The problems solved, aside from the intuitive fact that there will be more charging points even in a peripheric context, one of which will be the single most powerful charging solution in the city, it's that both the potential customers and the local public transport company will benefit from this initiative. The LPT company, project partner GTT, will benefit from increased grid stability thanks to the fixed load that will be the cars charging, thus stabilising its voltage peaks that often cause damage to the voltage arresters. Especially during the last year, another problem solved has emerged: with the simplification of the architecture made possible by the native DC status of the connections both from the power supply side as well as that of the charger, the increasing costs and time of procurement are being, at least to an extent, reduced.

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Starting from the Caio Mario substation which is the power source for the UC4 charging HUB, the design of the solution was optimized with the aid of the tendering winners of the electric works, a specialized firm that already has many tramway related collaborations with both Iren and GTT.

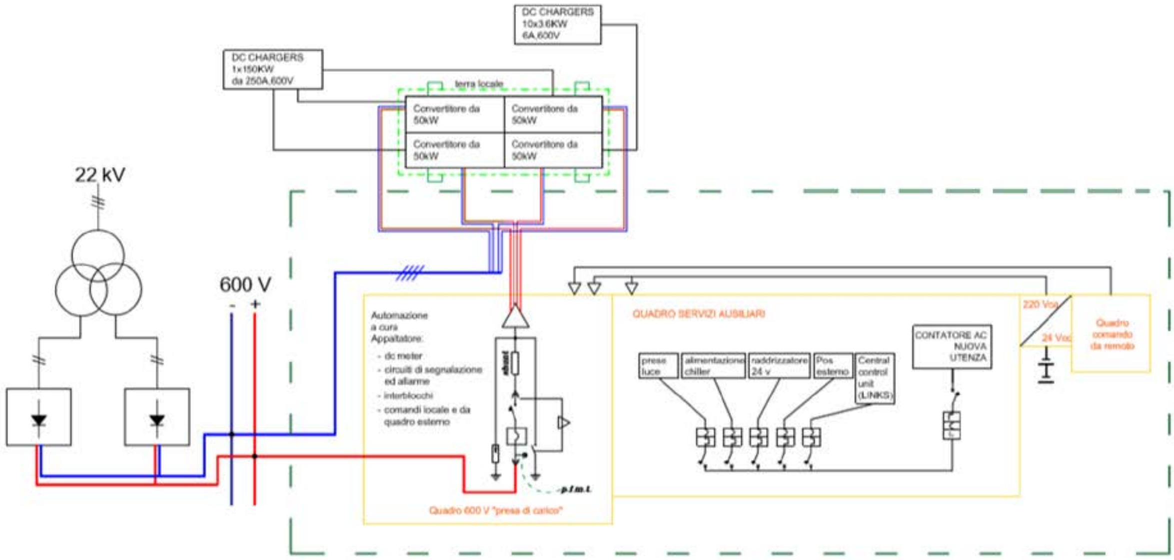

Figure 2: Electric scheme of the substation installation.

The image above depicts the electric scheme of the installation commissioned by Iren. From left to right, the 22kV AC current input, transformed and rectified into 600V DC is brought to the omnibus electric busbar that feeds the tramway lines. Directly derived from the busbar, the new feeding line for EV charging will power the charging infrastructure. For connection to the busbar of the substation, a circuit braker able to open –kA, voltage surge arresters with a discharge voltage of 1200V and disconnectors have been installed for safety reasons. Four isolated DC/DC converters of 50 kW each will be supplied from the circuit braker. Three of these will form the heart of the 150kW charger while the fourth to which the output of all 3.6kW chargers will be connected will act as a voltage regulator so as to maintain the output voltage at 500V. The DC/DC are able to work with a wile voltage input 500-950V. This range is due to the fact that the tramway network allows from standards to have large voltage fluctuations. The output voltage range of each DC/DC are 250-500V, and with a current up to 62.5A. The design of the DC/DC in order to minimize the reactive elements required for the isolation stage work with high switching frequencies up to 80kHz, so SiC MOSFETs were chosen as the semiconductor technology that allow for very good preforms for the high switching frequencies and the voltage and current levels in which the converter operates.

As seen in the top part of the image, there are four 50kW modules mounted in “push through” fashion onto the new building wall facing north.

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Figure 3: Render view from the north side of the new building that will house the 50kW modules.

The converters have their passive ventilation coming from the four holes of the wall. The 150kW CCS2 charger refrigerated cable will come out directly from the wall and it will have its emergency button in order to be compliant with the Italian law on charging infrastructure.

The new building will host the dedicated electrical cabinet, the chilling device for the 150kW ultrafast charging cable and the CSCU computer that will provide real time data flow from the charging points and the Raspberry Pi data collecting device installed inside the substation. Particular attention during the design phase was destined to the bordering zone – both topologically and of responsibility – between the substation building (property of GTT) and the new building commissioned by Polito. For practical reasons regarding mainly power cable management, the operation involved small core drilling activities into the substations' foundation. The following scheme illustrates the disposition in the Caio Mario parking of the charging station that will be installed.

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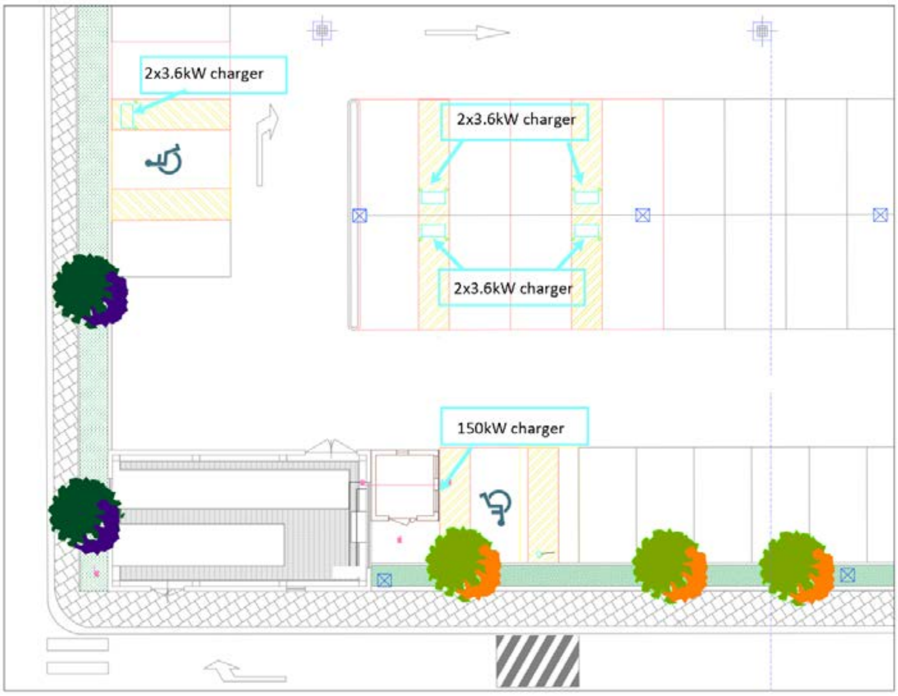

Figure 4: Aerial view of the charger location in the Caio Mario Park.

The low power chargers feeding cables - all powered by one of the four 50kW converters - as well as the ethernet cables that will provide the communication between the CSCU computers and the charging points will be buried under the ground up until the manholes located under the charging points.

As for the 50kW DC/DC also, the power electronics of the 3.6kW charger for safety reasons adopt an isolated and bidirectional DC/DC structure, in this case the input voltage is stabilized at 500V, while the output voltage has a wide range from 250-500V, with a maximum output current of 9A. Also, in this case the semiconductor technology used is a MOSFET SiC due to the high switching frequency. All relicensed DC/DCs guarantee output voltage and current ripple in accordance with IEC EN 61851.
The low power charging points will be located, as previously decided, in four different couples distributed among the parking island in front of the substation and one couple of charging points located by the fence that divides the street (via Alessandro Pernati di Momo) from the parking lot area. All the applications had to comply with the strict legislation regarding green areas and trees, as well as the guaranteed accessibility for people with impaired mobility – a theme of particular interest for the city of Torino.

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Figure 5: Rendering of the demo site.

Renderings of the way the demo site will soon be laid out, highlighting accessibility (above), as well as the new small buiding that will contain the CSCU and the 50kW power modules (below).

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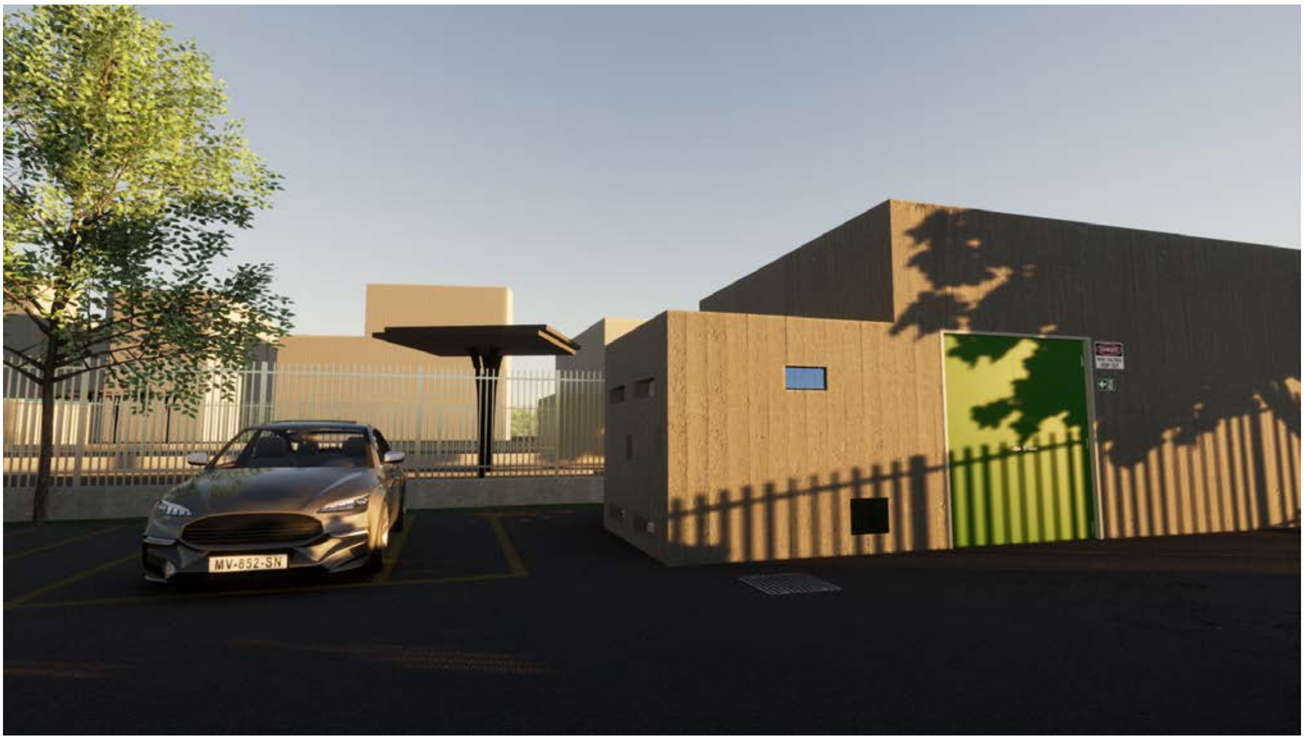

Figure 6: Rendering of the demo site #2.

Concerning the general communication architecture of UC4 in the figure below it is possible to see a block diagram of the communication. The communication between vehicle and charger, and more specifically between EVCC and SECC complies with iso 15118, with PWM and PLC communication. Communication between SECC and power electronic is via CAN. The SECC communicates via an OCPP 2.0.1 to the CSCU, the brain of the charging hub. In the CSCU, the voltage and current values of the substation and the real-time position of the streetcars are collected.

In this way, it is possible to define the absorption limits of the charging hub so as not to overload the substation and at the same time ensure the smart grid service by absorbing the energy that causes voltage surges in the tram network. This operating scheme was realized between Politecnico di Torino Links and Prima Electro.

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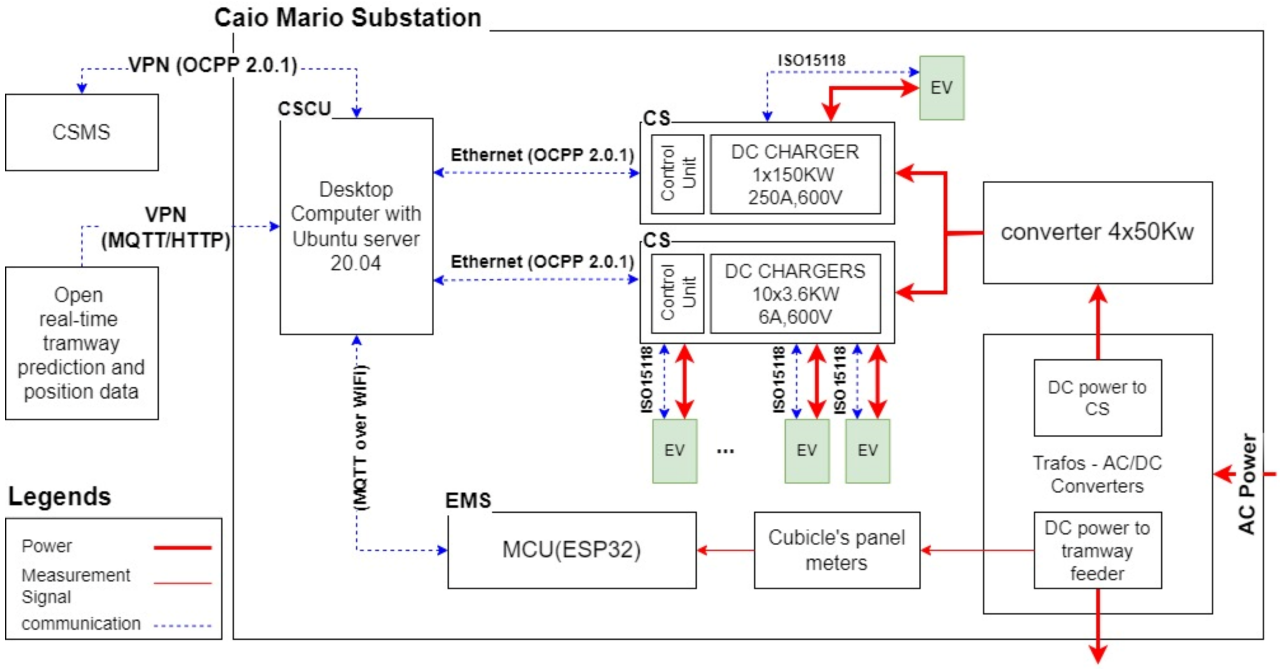

Figure 7: Detailed scheme of the communication levels of UC4.

UC4 Final modelling and engineering results

Throughout the last few months, an impressive progress was made not only concerning the preparation of the commissioning of the civil and electric works, but also on the engineering development of the charging infrastructure. Progressively the hardware was starting to be delivered by the suppliers, after months of shortages and delays.

At this stage of the development, the low power chargers are almost ready, with the beta prototypes already functioning and subject of real load testing as soon as the vehicle simulation tool will be delivered to Prima Electro.

Since the low power chargers converters are subject to the 50kW modules functioning, advanced testing regarding one 50kW module has been going on smoothly and without many issues. As soon as Iveco's specially prepared truck will be available – as it is shared by many different projects – it will be tested at its peak power rating of 50kW.

The core of UC4 Caio Mario charging hub are the 4 50kW modules that operate the chargers by conveying the power extracted by the substation. Manufactured and engineered by Prima Electro with the support of Politecnico di Torino, they will power all the charging points (10 low power + 1 ultrafast). The architecture of the charging infrastructure will be modular. More precisely, there will be 4 DC power modules each of 50 kW (2x25kW), with flexible architecture and fully configurable. Bidirectional topology

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able to implement V2G ancillary services enabling power sharing and smart management of distributed stored energy.

Complete features:

• Isolated DC input battery charger;
• Bidirectional topology (V2G ready);
• Customizable input voltage range;
• Dynamic configurable output voltage range (400 V or 800 V battery);
• High efficiency over the whole operating range;
• Air cooled (standalone system);
• Input pre-charge system for hot plugging DC Link connection;
• Emergency button for maximum safety of operation.

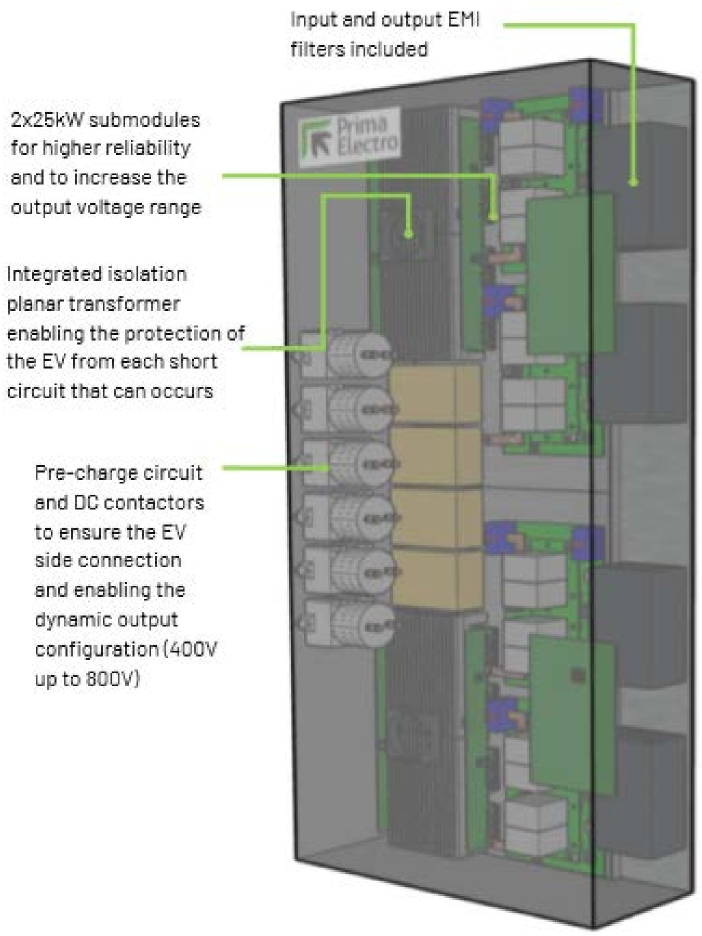

Figure 8: Render of one of the 50kW modules.

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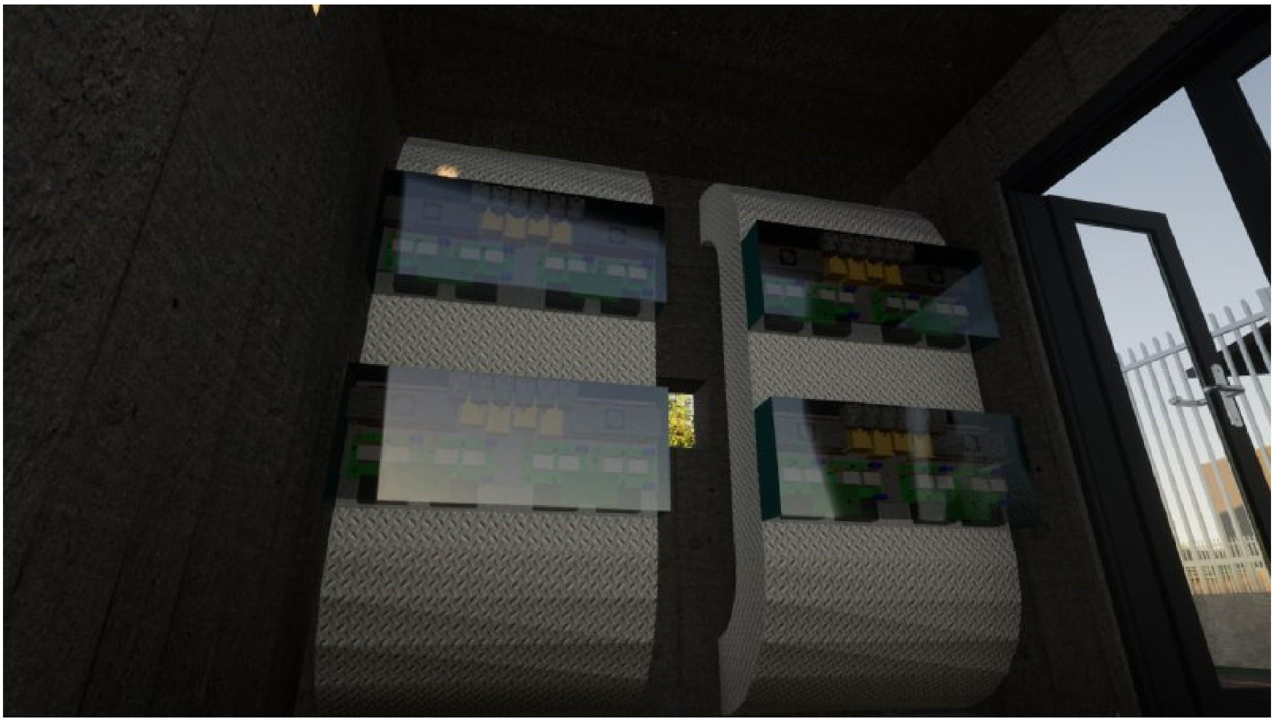

Figure 9: Inner view of the new building that will be housing the modules. To be noted is their passive ventilation system that provides necessary cooling to the system.

As previously mentioned, there will be five 2x3.6kW CCS2 low power DC chargers dislocated among the parking places near the substation. Their demonstration as native DC low power chargers - a true innovation – will be the focus of the early experimental activities. The power electronics component will be located in small manholes under the ground exactly between the parking lines, in order to serve 4 parking places with just one manhole installation. The plug will be a standard CCS2, with a 4m+ cable length in order to guarantee maximum accessibility.

Complete features:

• Engineered from scratch by Politecnico di Torino and Prima Electro;
• Isolated DC input battery charger;
• Converters are embedded under the ground for sleeker design;
• Bidirectional topology (V2G ready);
• High efficiency over the whole operating range;
• Ethernet and CAN communication;
• Air cooled (standalone system);
• Input pre-charge system for hot plugging DC Link connection;
• Emergency button for maximum safety of operation.

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Figure 10: Render of the low power converters in beta 2 prototype stage.

In terms of final aesthetics of the low power charging points, various different options were analysed. The most appreciated and the definitive winner was the one that referenced Turin’s famous and beloved drinking fountains called “Turèt” (small bull in piedmontaise dialect, as “toro”, from which Torino has its name, is “bull” in italian).

Here is a pic of a case prototype, with yellow and blue lighting (City of Turin’s official colors):

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Figure 11: Image of the low power chargers' case shaped as a "Turèt" fountain.

In parallel with the activities necessary for the development of UC4, a further step was taken in the direction of monitoring the power source that is the Caio Mario substation: LINKs and Politecnico di Torino developed together a data collecting/sending system installed in the substation.

Through a Raspberry Pi computer connected to the transducers of the rectifiers, we were able to gather the real time consumption data and transform it from analogue to digital. The Raspberry Pi is always connected to the internet via a 4G sim card, and it is able to simultaneously complete the digital data transfer to LINKS' servers. In order to provide a complete understanding of the impact of accelerations and braking activities done by the trams circulating in the part of network powered by the Caio Mario substation, we asked permission to 5T, service subsidiary of the City of Turin and itself project partner, to provide us the real time positioning of the trams, as they are all geolocalized. Lastly, via a Thingsboard interface we are able to check real time current absorption and voltage figures matched with the position of the trams. A predictive model will be developed as soon as the data quantity will be significant enough to produce reliable results.

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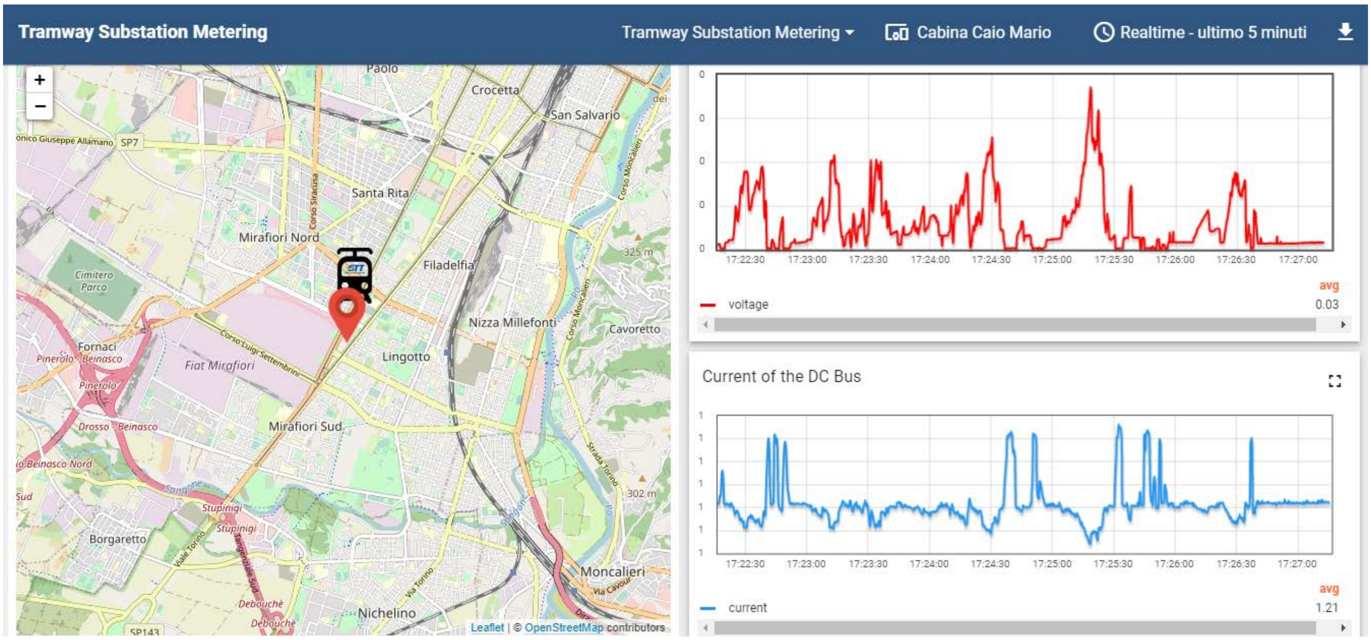

Figure 12: Example of the Thingsboard interface view with voltage and current figures respectively on the right, and the position of a tram near the Caio Mario Park on the left.

- Problems in the process and its solutions.

The UC4 use case, as many other use cases of the INCIT-EV project, had to battle unexpected supply issues. The main components lagging behind in terms of shipment date were - and to an extent still are - the power electronics elements for both the chargers and the circuit breaker for the electric works inside the substation, whose shipping date is yet to be determined by the electric works tender winner.

The communication section of the UC4 was partly delayed due to problems in gathering data of the substation's power consumption, as it is not accurately telematically monitored. The transducers to which the data gathering device set up by Polito and LINKS was connected were damaged and thus only a few weeks ago the current values became reliable. and Smart charging algorithms as well as communication from the Vector modules to the CSCU.

UC4 Expected data to be collected

The main data that the testing activities of UC4 will provide are the following:

- Power quality and delivery band of the low power chargers, i.e. the efficiency of low power DC/DC converters engineered by Prima Electro and Politecnico di Torino;
- Power quality and delivery band of the ultrafast charger;
- Impact of the chargers, especially at full capacity, on the current absorption figures of the substation;
- Interactions between peak-time traffic and peak charging power;

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- Tramway overvoltage mitigation via the stable load of recharging vehicles;
- Communication efficiency data between CSCU and chargers;
- Data regarding the economic figures of the Use Case, i.e. is it potentially cheaper than a traditional solution if applied on a large scale.

Component	Quantity	Comments	Unity
Efficiency	Efficiency of the 50kW modules		[%]
	Efficiency of the low power converters		[%]
Weather conditions	Temperature	Ambient temperature in the substation	[C°]
		Ambient temperature in the new building	[C°]
		Temperature of the DC converters	[C°]
Electrical	AC/DC (auxiliary services)	input voltage	[V]
		input current	[A]
		output voltage	[V]
		output current	[A]
		efficiency	%
	DC/DC (converters and substation)	input voltage	[V]
		input current	[A]
		output voltage	[V]
		output current	[A]
		efficiency	%
Other	Charging time	3.6kW low power chargers	[s]
		150kW high power charger	[s]

UC4 Innovation

There are multiple layers of innovation in UC4, and they are spread among the different activities highlighted in the previous chapters. First, the more tangible and intuitive innovation is the fact that this connection comes directly at a DC level. By exploiting pre-existent conversion infrastructure, the charging infrastructure and architecture is simpler and cheaper, as the conversion burden is handled above their level. Especially the low power DC-DC chargers are, as far as we know, unprecedented, as DC is usually deployed with higher power outputs, starting from the quick "Destination DC" ABB chargers up until the 350kW+ DC ultrafast chargers increasingly more common especially in highways.

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As far as power electronics are concerned, the structures have been adopted that allow more degrees of freedom in the management of semiconductor switching so as to decrease switching and conduction losses, so new modulation techniques have been adopted that allow soft commutations, i.e., natural commutations that have no lossy elements, over the entire range of operation from DC/DC, you know at low and high output voltages at both low load and full power, and at the same time decreasing the peak and RMS current values on the transformers thus going to limit the losses in the copper and at the same time those in the iron.

Previously noted but worth mentioning again is the interaction between the tramway loads and consumption and the charging infrastructure. The algorithms for this interaction are developed by LINKS and are an innovation in the smart charging interactions between charging infrastructure and grid as the fluctuations in the tramway grid are indefinitely more than in a traditional distribution grid.

Furthermore, looking ahead beyond the project's duration, normative issues are being handled with the aid of the partners' legals as well as independent public entities specialized in the energy regulation sector. The developments of this aspect of the project will give a great boost to the assessment of its replication potential beyond the experimental status. In fact, its eventual permanent integration in the IrenGo charging ecosystem coupled with the presumed cost efficiency of the solution bodes well for large scale replication potential.

UC4 Risks

The main risks associated with this use case is of course the interaction between a pre-existing, non-dedicated, voltage-fluctuating grid like the one of Torino's tramways. The smart charging algorithms will have to take care of the fluctuations in the voltage levels that occur thousands of times during a regular working day. Voltage figures range from 500V during peak current absorption to 1200V during sharp, simultaneous braking activity by the trams circulating on the line. The protection systems installed are regular tramway dedicated overvoltage suppressors, so this matter should not have an impact on the infrastructure integrity, but more on the recharging service quality and power availability in peak tramway transit times where the substation reaches its current absorption limits (>4500A).

A risk that has already been taken care of is the one related to the status of the energy absorbed in the charging operation. As it is meant to be dedicated to tramway traction purposes for a public service, it comes with no excise duty and energy taxation. This factor, combined with the fact that this energy is taken after its AC/DC conversion, makes the commercial use of it non regulated, thus the decision to not allow any recharge to the public.

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4 CONCLUSIONS

The installation of 10 CCS2 low power DC charging points (3.6kW), 1 CCS2 Ultrafast Charging point (150kW) will take place in the UC-4 Torino Charging HUB in a Park & Ride Facility as planned. The following activities have been successfully carried through in time:

- Civil works project design, procurement and tendering to the construction company under the guidance of Politecnico di Torino (expected works completion in late M33);
- Electric works project design, procurement and tendering to the electric works firm under the guidance of Ireti (expected works completion by late M34);
- Advanced engineering development of the 3.6kW low power chargers by Politecnico di Torino and Prima Electro;
- Engineering development of the 50kW modules that will power the charging infrastructure in the Park & Ride facility;
- Definition of the communication protocols and architecture;
- Installation of the measuring and data sending device for the real time monitoring of the substation's power absorption.

The development of the charging points is overcoming some initial issues with the supply of the necessary hardware. The 3.6kW chargers are in advanced development status, while the ultrafast charger in its full capability has not been tested yet.

The communication architecture and the interaction between the charging infrastructure and the tramway grid has been defined, helped by the measuring and data sending device finally mounted inside the Caio Mario substation, which helps keeping track of the power consumption of the substation.

The tenders have been assigned and the planning defined with the collaboration of the entirety of the partners, pending the approval of the City of Torino's council who should come before M33.

With renewed confidence, the Use Case development will go as planned with minor delays, and the whole UC4 consortium is eager to start the testing activities before the end of the year, barring unexpected setbacks.

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