An innovative next generation E-mobility infrastructure: the eCo-FEV project

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***Abstract*—Several factors are obstructing the growth of the electric vehicle diffusion. In particular there is a general negative perception about the battery management, the time-travel related to the long time for the recharge and the absence of an hardware and information infrastructure in support of the electric vehicle use. The project eCo-FEV, described in the present work, aims at the creation of a cooperative infrastructure system for the electric mobility. An important technical challenge is also represented by the realization of a prototype of Charge While Driving, a system able to transfer electric energy during the motion through magnetic field induction.**

***Index Terms*—Charge while driving - Electric vehicles - Inductive power transmission - Wireless power transmission - Wireless application protocol - Intelligent systems - Transportation - Cooperative driving**

I. Introduction

Electric vehicle market is shyly growing up in these years, but there are several factors that are preventing its very big expansion related to technological and psychological aspects that influence the common perception about electric vehicles for private transport. On the other way electric mobility is considered a good technology to reduce dependence on fossil fuels and resulting greenhouse gas emissions.

The main critical object is represented by batteries: high costs, high volumes, low power density compared with classic fossil fuels, necessity of frequent stops and long time for the recharge and not well predictable behavior during the travel, are the principal obstacles to the customer approval [1]. All these aspects are emphasized by the absence of a proper infrastructure able to manage an electric vehicles traffic and its related necessity of energy and communication.

The EU eCo-FEV project intends to create an electric mobility platform for the integration of electric vehicles into a cooperative infrastructure systems. This platform allows the information exchange between multiple infrastructure systems including road IT infrastructure, parking infrastructure, public transportation operators and vehicle charging infrastructure providing services of trip planning and assistance that can help to respond to the consumer anxiety about the management of an electric mobility.

An important technical challenge of the eCo-FEV project is also to build a prototype for inductive Charging While Driving (CWD), a system able to transfer energy to the battery of the vehicle during the motion, allowing the reduction of installed battery capacity on board, the reduction of stops for the battery recharge.

Differently from developed solutions [2], [3], [4] based on the public transports sector, the eCo-FEV CWD solution is oriented towards the private transport.

The results of this project, that is seeing the cooperation of several universities, research centers and manufacturers [1], could provide important indications about the possibility to realize new concepts of road and city infrastructures addressed to the development of a full electric mobility.

II. General description of eCo-FEV platform

The general aim of eCo-FEV is the development of an innovative next generation electric mobility (E-mobility) infrastructure able to provide for a cooperation network in which the electric vehicles (EV) can communicate with EV related infrastructure. This cooperative infrastructure enables the information collection from independent infrastructure systems and provides data aggregation functionalities to provide a system of cloud based high quality services for EV users.

The platform renders precise real time information like closer available charging spots, traffic congestion that could prolong the travel time and modify energy consumption, battery information and charge opportunities, management of booking and payment of charging operations. Fig. 1 gives a description of the high level functional architecture of eCo-FEV system. This system is composed by different subsystems here briefly described:

- **Road side system.** This sub-system is composed by the charging infrastructure and communication hardware, application unit hardware and a vehicle gateway to interface with EV electronic systems. The charging infrastructure

[1]The name eCo-FEV is for "efficient Cooperative infrastructure for Fully Electric Vehicles" and its consortium unifies Hitachi Europe, Commissariat à l'énergie atomique et aux Énergies Alternatives (CEA), European Center for Information and Communication Technologies (EICT), Politecnico di Torino, Renault, Technische Universität Berlin, Tecnositaf, Centro Ricerche Fiat, Blue Think, Facit Research, Conseil Général de l'Isère, Energid, Schulz-Institute for Economic Research and Consulting

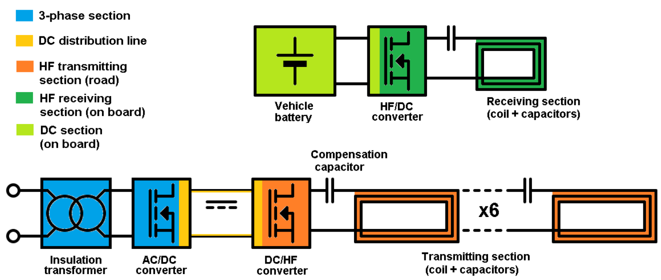

Fig. 2: Scheme of the charging infrastructure for CWD

developed in the Italian test site is oriented only to the so called Inductive Power Transfer (IPT).

- **Vehicle system.** It is the ensemble of communication hardware providing information exchange about system operation, battery status and trip programming. The system includes power electronics hardware to manage the receiving side of the power transfer structure and the battery charge.
- **eCo-FEV backend.** It is eCo-FEV backend is a backend system that includes at least a middleware platform that accommodates a set of functionalities for data collection, data management and data aggregation and one service provider platform that provides EV services to customers.
- **External actors.** Other platforms may also be included in eCo-FEV backend, for instance a platform that manages the ID and contract information of the customer.

In the present paper, the description is focused on Roadside and Vehicle system as underlined also in Fig. 1

III. CWD POWER INFRASTRUCTURE

The proposed prototypal CWD infrastructure is constituted by a sequence of transmitting coils installed on the road surface in which individual coils are sequentially energized through a DC/HF converter as a function of the position of the magnetically coupled receiving coil placed under the EV floor. In this way, the receiving coil is illuminated by a continuous emitting field through an air gap of about 20 cm [5],[6]. An illustrative scheme of the developed architecture is shown in Fig. 2.

An insulation transformer is used to electrically separate the normal three phase distribution line from the section regarding the IPT allowing the adoption of a dedicated IT grounded protection system.

A three-phase AC/DC converter provides for a stabilized DC distribution line that may permit to supply more DC/HF converters. The DC/HF converter, supplied at 650 V is able to supply six coils constituting a CWD Charging Zone (CZ) with a maximum power transfer of 20 kW. A capacitor is placed in series to each coil in order to obtain a resonant system: this allows benefits in therms of reduction of dimensions and costs of power electronics (PE), increase of the efficiency and maximization of the transmissible power.

On board a converter manages the receiving structure and the battery charge. The receiving structure is designed for the maximization of the coupling with the transmitting section but

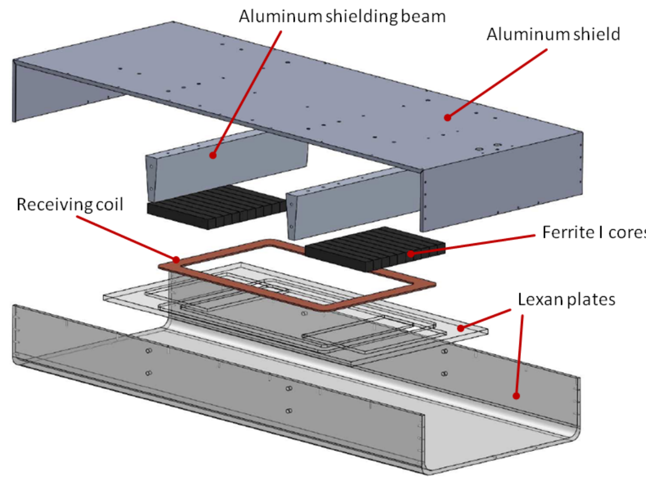

Fig. 3: 3D model of the receiving structure

Fig. 4: Back of the vehicle during the CWD operation. Under the vehicle plane is visible the receiving structure mounted

taking into account all the aspects related to EMC and human protection by magnetic field exposure [7]. Answering to this issue, a shielding system has been developed to confine the magnetic field in a well defined volume under the vehicle. The 3D exploded model of the receiving structure is shown in Fig. 3. The developed structure has been mounted on the rear of the vehicle with the addition of mechanical components apt to guarantee the mechanical robustness and protection against vibrations (Fig. 4)

IV. ICT-COMPONENT OF CWD EVSE

In eCo-FEV project, the CWD power prototype is equipped with an ICT component called the Charging Station Control Unit (CSCU), which meets the ICT requirements imposed by the nature of the system itself on one hand, and by the overall integration in the E-Mobility landscape on the other hand. Due to the dynamic nature of the system, there is a need for a

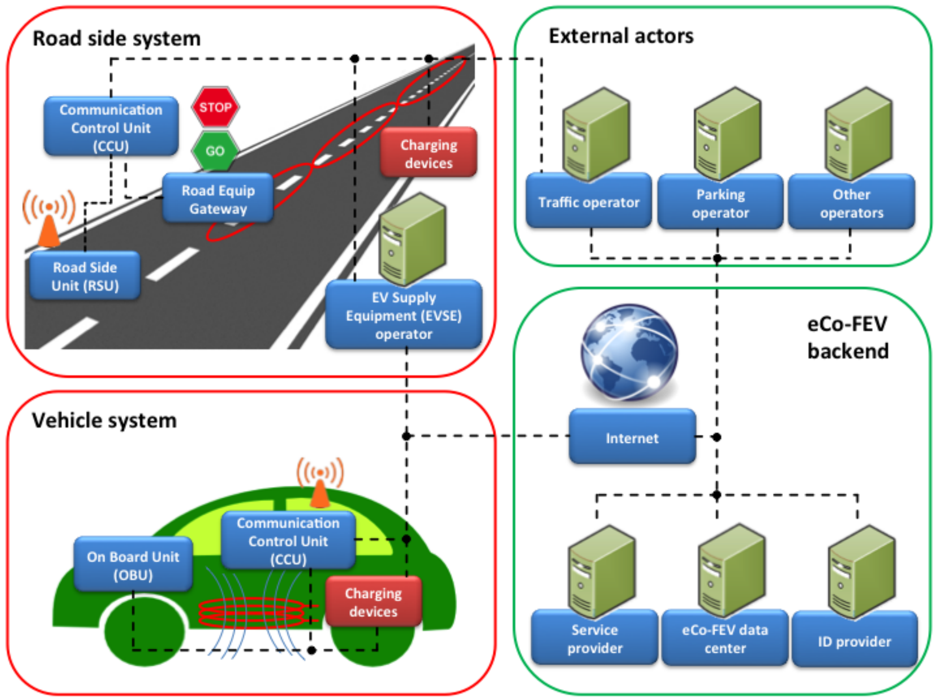

Fig. 1: Functional architecture description of eCo-FEV system. Red boxes contain the components analyzed in this work.

wireless communication between the EV and the EV Supply Equipment (EVSE). This communication is not only needed by the charging process itself, it is also required to manage the charging processes. For the charging process, EVSE and EV need to exchange information regarding the charging parameters. Within the eCo-FEV project, these requirements were the basis for the design of the wireless communication between EVSE and EV. Although the ISO standard ISO 15118 [8] aims at addressing the EVSE-EV communication for the conductive charging cases, its extension in the parts 6 (General Information and use case definition for wireless Vehicle to Grid V2G communication), part 7 (Network and application protocol requirements for wireless communication), and part 8 (Physical layer and data link layer requirements for V2G wireless communication) to cover the wireless charging are still in draft-phase. Thus the experiences and results gained in the eCo-FEV project would make a promising contribution towards shaping the future of CWD-Technology [9]. Since eCoFEV project also aims at providing an ICT Integration of different actors in the e-mobility landscape, for providing different e-mobility services, the CWD-EVSE should be able to authenticate each one of the EVs that are moving dynamically along the coils in the CWD-lane. For each of the EVs, the CWD-EVSE needs to know which one it should provide energy and which one it should not; especially in the case when certain EV has charging service booked or has contractual prioritization. Moreover the EVSE has to keep tracking how much energy has been delivered to the target EV. Last but not least, the CWD-EVSE has to provide monitoring information about the technical and operational status of each coil along the lane. These functionalities are implemented at the CSCU as depicted in Fig. 5 which is an embedded board running Debian based operation system. It is equipped with a CAN-Bus interface to communicate with the power electronics on one hand, and with a Network interface (Ethernet, WLAN, 3G) interface with internet access on the other hand used to communicate with the EVSE Operator. The architecture design for the eCo-FEV system foresees flexibility and modularity for the purpose of enabling various business models. The CSCU can be configured to communicate with any EVSE-Operator using the standard protocols.

The CSCU has the following different functional components:

- **AAA Component**: It is in charge of Authenticating and Authorizing the EV for charging and for accounting the transferred energy. It embeds implicitly the **Booking functional component**.
- **Communication Component**: It handles the communication with the EV and PE.
- **Monitoring Component**: It Monitors the State of the EVSE (PE and CSCU), and reports it to the Back End.
- **ANPR Monitoring Component**: It Monitors the Vehicle Arrival events.
- **The Charging Procedure Control (CPC) Component**: It is in Charge of monitoring and controlling the charging procedure. This component controls and coordinates the operation of the other components.

The different states the CSCU could reside in are the product set of the different sets of states of two state-Machines: the Authorization State Machine (Auth-SM) and, the Charging Procedure Control State Machine (CPC-SM). The Authorization State Machine (Auth-SM) has the following states:

- **Auth_Init** State: Is the state the Auth-SM takes when the Software starts.

- **Auth_Idle** State: In this state the Auth-SM waits for an Event from the EV that it wants to charge. This is considered to be the trigger for our charging session.
- **Auth_Start**: At this point the EV contacts the EVSE using wireless communication indicating that the EV wants to charge. The CSCU starts processing this request in coordination with the EVSE-Operator.
- **Auth_Sucess**: In this state the Auth-SM informs the CPC-SM that an EV wants to charge, which will put the CPC-SM in the State that waits for the EV (to appear on the ANPR-Camera). The Auth-SM also replies to the EV informing that the EV is expected to arrive at the lane.
- **Auth_Rejected**: In this state the CSCU inform the EV that charging cannot be done including the reason.
- **Auth_Error**: In this state error handling is done.

The CPC-SM has the following states:

- **CPC_Init**: In this state the software just starts and checks the status of the PE if everything is ok (no PE errors CSCU internal errors) the CPC-SM transits to the state CPC_Idle.
- **CPC_Idle**: The CPC-SM remains in this state until it receives an Event from the uth-SM announcing that an EV wants to charge. In this case, the CPC-SM transits to the state CPC_Waiting.
- **CPC_Waiting**: When the CPC-SM reaches this state, it means that an EV in the proximity wanting to charge. The EV should be expected to appear on the ANPR camera soon. When an ANPR Event, with the expected plate number occurs, the CPC-SM transits to the state CPC_Arrived.
- **CPC_Arrived**: In this state the expected EV has appeared on the ANPR-camera, and is now near the coils. The CPC-SM sends a trigger to the PE over the CAN Bus.
- **CPC_Charging**: In this state the EV is over the coil and there is some power transfer.
- **CPC_End**: In this state the CPC-SM ends a charging session. The latest at this point the total transferred energy should be captured.
- **CPC_Error**: this state is for error handling. At entrance in this state, the reason for the error is determined and countermeasures are undertaken until the error is gone.

This separation of the state machines allows serving many EV, by using the Authorization state machine to reply to the authorization request as fast as possible and assigning a charging procedure control for each EV that has been authorized.

V. Communication with the IPT CWD hardware: state machine of the charging infrastructure

The eCo-FEV charging infrastructure introduce an actor responsible for the booking and the economic management of electric energy providing for the recharge, a Charging Station Control Unit (CSCU) responsible for the communication control of all the actors of the charging area, a low level controller dedicated to the PE integrated in a Single Board RIO (sbRIO of by National Instruments shown in Fig. 6) and a control unit on vehicle board that interface with the PE on board and

Fig. 5: CSCU with the CAN interface

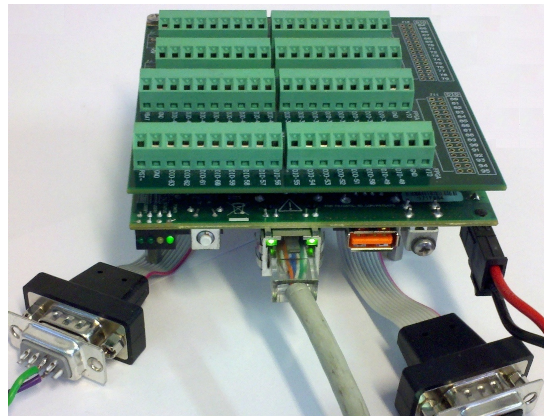

Fig. 6: Aspect and connections of the sbRIO board

communicates the information about the entire vehicle system using COHDA devices. CSCU and sbRIO realize a distributed multi-master control based on a CAN field bus. The charge procedure starts with a first phase of booking. During the EV approach to the recharge area, it gives information about its characteristics and for authentication and authorization to access to the area. The authorization gives the start for the PE activation. The presence of the vehicle and its distance to the charging zone are constantly monitored because the time-space line of each recharge phases is dictated by the information about the vehicle position. To better explain the time-space line, it is possible refer to Fig. 8 and the following explanation list:

- FAR. No vehicle is approaching: normal execution of tests about PE health are performed.
- FAR BEFORE. A vehicles requested to recharge: procedure for authorization starts and this state does not change if the vehicle is out of the COHDA communication range (this means that the vehicle is not in proximity of the charge area).
- NEAR BEFORE. The presence of the vehicle is detected by COHDA: the vehicle is approaching to the charging area. The authorization, authentication and accounting process starts in the CSCU.
- AAA. The vehicle is authorized. After the authorization, the system is waiting for the vehicle arrive. An Automatic Number Plate Recognition (ANPR) camera detects the ID of each vehicle that is direct in the Charging Zone: the transition to the next stage occurs only if the detected ID corresponds to the ID of the authorized vehicle (Fig. 7).

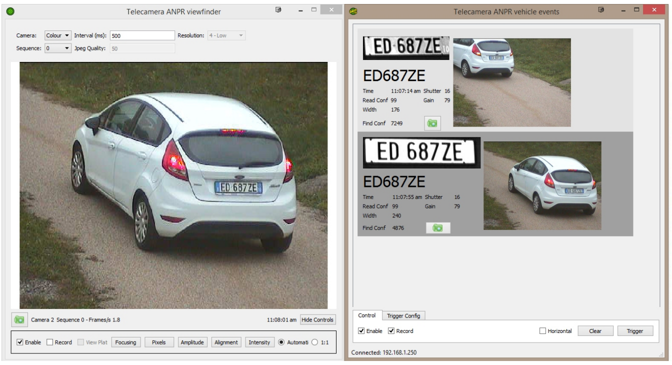

Fig. 7: Screenshot of the ANPR camera software during the ID recognition

- WFV (Wait For Vehicle). The vehicle is arriving in the Charging Zone.
- CWD. The vehicle is above the Charging Zone. The PE on ground identifies the actual presence of the vehicle and transmits power
- EOC (End Of Charge). The recharge procedure is complete: no receivers are above the transmitter coils or the vehicle requested the stop of the power transmission.
- NEAR AFTER. The vehicle passed the Charging Zone but remains detected by the COHDA. There are data exchanges between sbRIO and CSCU about the recharge process.
- FAR AFTER. The vehicle is out of the COHDA detection range (the vehicle exit the charging area) .

Of course, the procedure provides an error handling of all expected malfunctioning or not correct behaviour of the EV driver or system components in order to guarantee the safety.

Although the charging infrastructure communications are based on a CAN bus, for its simplicity and its aptitude to put easily in communication the different actors of the system, this protocol is actually not easily scalable and an increase of the dimension of the CWD infrastructure, with a related increase of the number of Charging Zones and the number of vehicles, needs for the adoption of a different communication standard faster, more stable and apt to cover bigger distances.

VI. Layout of a CWD charging lane

As described in previous III, the transmitting coils, supplied by a DC/HF unit, form a Charging Zone that can be replicated in relation with a proper DC distribution line. This means the possibility to provide the installation of different CZs for CWD along a roadway.

This kind of installation could be translated in a range extender for the EV's battery or in a high reduction of battery capacity installed on board and recharge necessity eliminating two of the most important barrier to the EVs diffusion. Referring to Fig. 9, it is possible to imagine to install a series of coils forming several CZs of length L_{CZ} with an inter distance L_{NCZ} in a dedicated lane on a highway as an example. It is possible to select an appropriate ratio between L_{CZ} and L_{NCZ} able to provide an energy balancing of the consumed power of the electric vehicle an the power

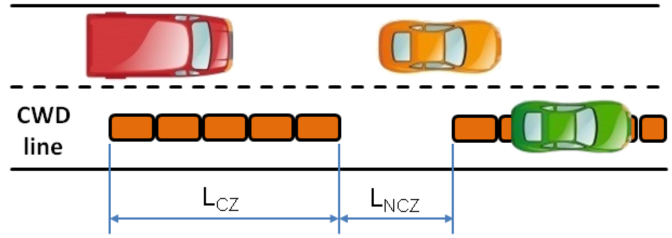

Fig. 9: Example of CWD lane layout for a roadway

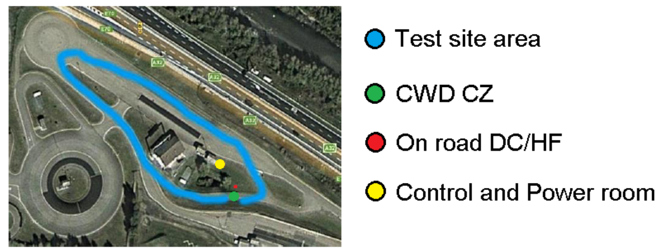

Fig. 10: Map of the Italian test site of eCo-FEV

transferred through IPT CWD during the crossing above the CZs on the road. Naturally, the design of a CWD lane needs to consider also other factors as the speed of the vehicle during the cross of the CZ, the behavior of the EV driver.

Generally, a correct design procedure should consider that to minimize L_{CZ} means minimize the installation and maintenance costs, but that a high length L_{NCZ} could means to reduce the admissible vehicle speed and go against the acceptance of the time travel. A reference work about this aspect can be [10].

VII. Test site and future developments

The eCo-FEV platform has been successfully tested and the CWD system is going to be tested in the Italian test site in Val Susa, Piemonte (Fig. 10) with the cooperation of Politecnico di Torino, Technische Universität Berlin, Hitachi Europe, Tecnositaf and Centro Ricerche Fiat. The entire functionalities and actors of the eCo-FEV infrastructure were installed implementing the management of a CWD system with a single CZ long 6.25 m shown in Fig. 11. The actual installation of the transmitting coils is done without fixed road

Fig. 11: Picture of the vehicle moving over a charging zone

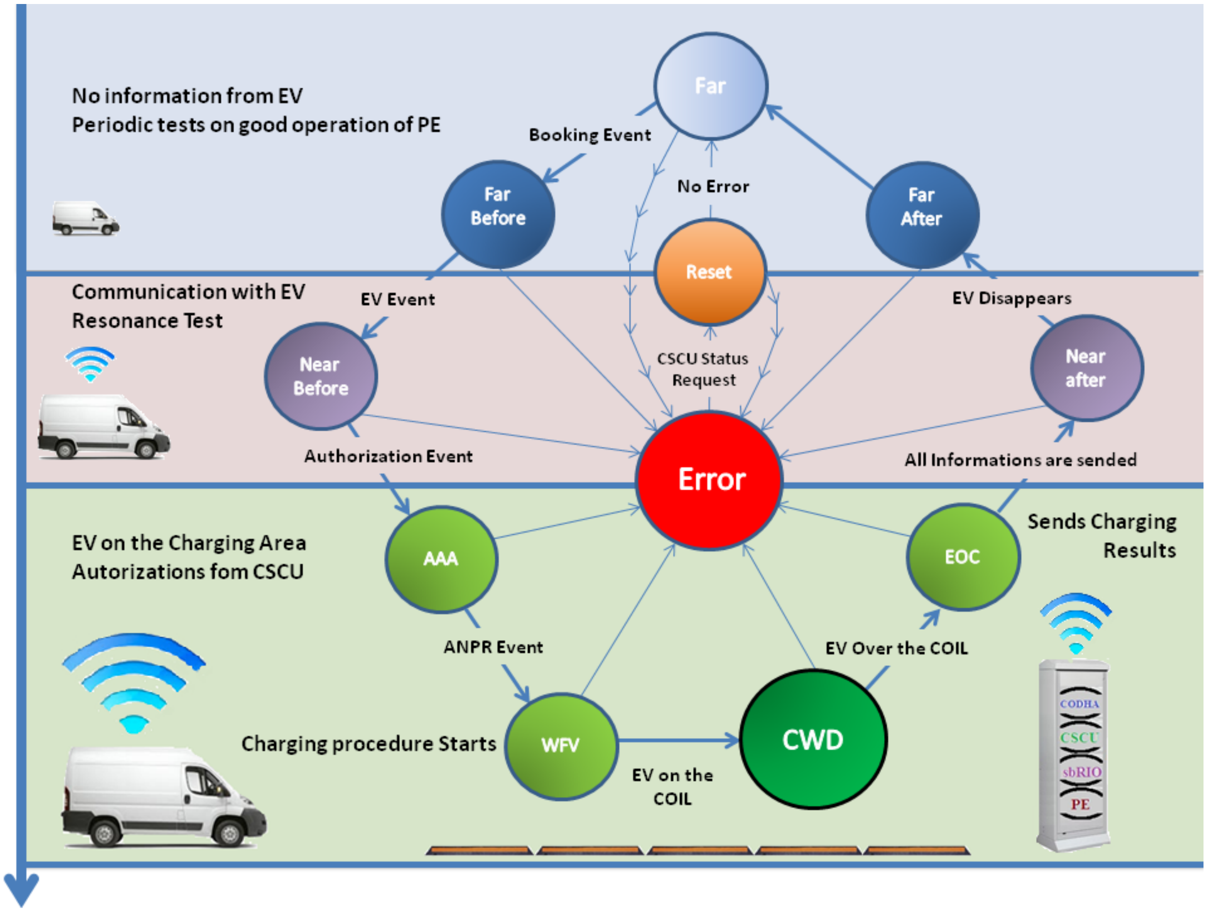

Fig. 8: State machine of the low level control of the charging infrastructure

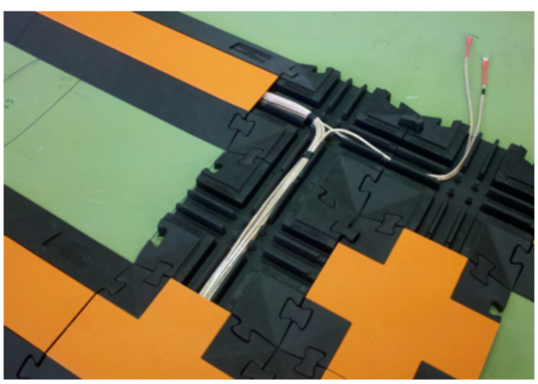

Fig. 12: Insertion of transmitting coil in the floating cable conduit

installation in order to test different possible arrangements and interspacing that can optimize the control and the variations of the emitting field during the charge. This can be done through the use of a floating cable conduit (Fig. 12) that ensure a safe enclosure and protect the coils from the possible collision with the moving vehicle. An outdoor active cabinet is placed on the roadside to contain the power electronic and all the communication devices as the CSCU, the Cohda wireless and the sbRIO (Fig. 13). The first demo test performed in October, demonstrated the feasibility and the well operating

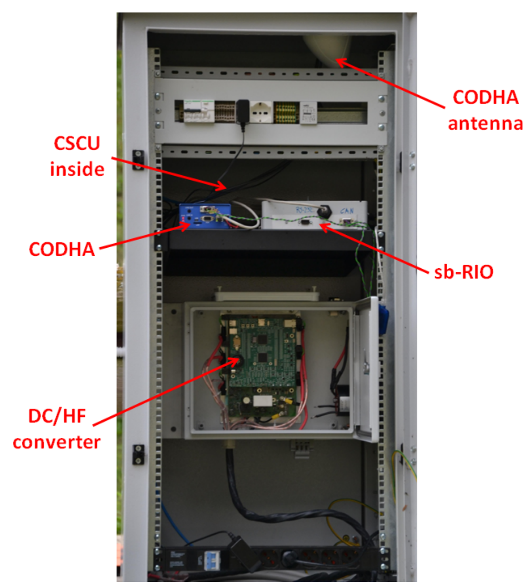

Fig. 13: Shelter installed on the roadside containing the DC/HF converter and the communication devices: CSCU, Cohda and sbRIO

system functionality of the implemented platform providing indications about the critical aspect to be improved as the error handling of the PE control that, in this first rough implementation, simply leads to the stop of the charging operations. In the next future, research efforts will be directed in the direction of the optimization of the CWD system and the management of the PE operations in order to obtain an efficient transmission an a strong capability to fast react against the possible faults that could occur in unpredictable situation of malfunctioning.

VIII. Acknowledgment

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