

Communication Between Electric Vehicles And Charging Stations In The CCS2 Standard: Normative Foundations And A Conceptual Proposal For Embedded Simulation

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Abstract:

The expansion of electric mobility has increased the demand for safe, interoperable, and cost-effective charging solutions. In this context, communication simulators between electric vehicles and charging stations are valuable tools for research, development, maintenance, and system validation, as they enable the reproduction of the charging process without requiring a physical vehicle. This article discusses a conceptual design for an embedded communication device for charging simulation based on the CCS2 standard, integrating a processing and control unit, a signal conformance interface, a CCS2 connector, and a human-machine interface. The proposal is based on IEC 61851, ISO 15118, and IEC 62196 standards and aims to contribute to reducing testing costs, increasing experimental flexibility, and strengthening electric vehicles' charging infrastructure.

Key Word: *Electric vehicles; Charging stations; CCS2; Embedded systems; ISO 15118; IEC 61851.*

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I. Introduction

The ongoing energy transition has encouraged the adoption of technologies aimed at reducing emissions, improving energy-use efficiency, and decreasing reliance on fossil fuels. In this context, electric vehicles play a strategic role, representing a viable pathway for the partial decarbonization of the transport sector and for the integration of mobility, electrification, and smart energy systems. The growing adoption of electric vehicles has been supported by government incentives, environmental regulations, advances in batteries, and increased public awareness of the environmental impacts of conventional transport systems [1], [2].

The expansion of the electric vehicle fleet has been accompanied by increasing demand for charging systems capable of addressing diverse usage profiles. Charging can occur in residential, commercial, or public settings, as well as at fast-charging stations, each with distinct technical, operational, and economic requirements. Studies on charging behavior indicate that residential charging remains one of the most prevalent options among electric vehicle owners, highlighting the need for adequate infrastructure and reliable vehicle-to-station communication and connection systems [3].

Despite the global expansion of electric mobility, charging infrastructure remains a limiting factor for the large-scale adoption of electric vehicles. In Brazil, the charging station network is still under development, with a predominance of semi-fast stations and a limited number of direct-current fast-charging stations [4], [5]. This scenario highlights the need for technological solutions to support the development, maintenance, and validation of charging systems, particularly in a market that is still maturing.

In this context, communication simulator devices for electric vehicles and charging stations emerge as valuable tools for reducing costs and improving testing reliability. These devices enable the controlled reproduction of communication processes involved in charging process, including physical connection, basic signaling, parameter exchange, authentication, authorization, energy transfer control, and session termination. As a result, charging station behavior can be evaluated without requiring the use of a real vehicle in every test.

This article discusses the normative and technical foundations of communication between electric vehicles and charging stations based on the CCS2 standard and presents a conceptual proposal for embedded architecture to simulate this process. First, the context of charging infrastructure and the role of simulators are outlined. Next, the main applicable standards, the proposed device architecture, the control signals, the communication protocols, and the potential applications in research, development, and maintenance activities are described.

II. Electric Mobility, Charging Infrastructure, And Simulation Needs

Electric Mobility and Charging Infrastructure

The diffusion of electric vehicles depends on a combination of technological, economic, regulatory, and infrastructural factors. Although advances in battery technology and the gradual reduction in vehicle costs are irrelevant to drivers, the availability of charging infrastructure remains a key condition for large-scale adoption. The lack of reliable charging points may increase users' perception of risk, limit the practical autonomy of vehicles, and hinder market consolidation [3], [6].

The development of charging infrastructure must account for different power levels, connector standards, charging modes, and installation environments. Alternating current charging, typically associated with residential or semi-fast chargers, is suitable for scenarios in which the vehicle remains parked for extended periods. In contrast, direct current fast charging requires higher power, more complex communication process, and stricter safety requirements, making it particularly relevant for highways, logistics corridors, commercial fleets, and high-turnover locations [7], [8].

In Brazil, the Brazilian Electric Vehicle Association (ABVE) reports the existence of approximately 21,061 charging stations installed in February 2026 [4]. Although this figure indicates progress compared with previous years, it also suggests that the country remains at an early stage in the deployment of a widespread charging infrastructure. The projected evolution of charging stations in Brazil, presented in Figure 1, reinforces this growth trend and highlights the need for supporting technologies, including testing tools, validation equipment, and simulation devices.

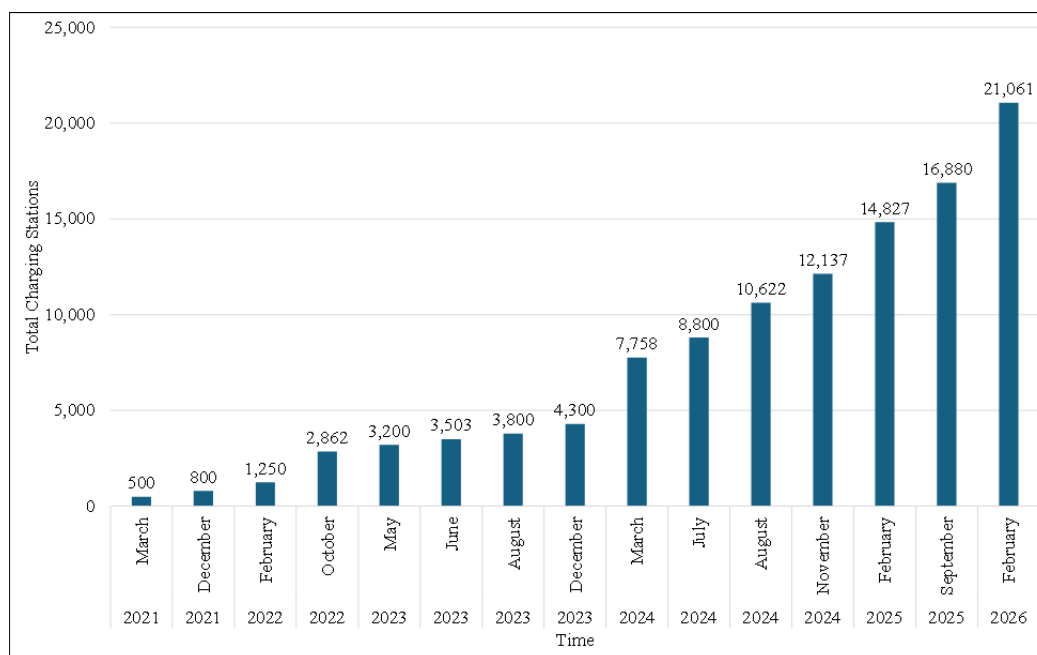


Figure 1. Total number of charging stations in Brazil (Adapted from [4]).

The expansion of charging infrastructure also depends on the technical standardization of charging systems. In the Brazilian context, Type 2 and CCS2 connectors have become prominent, especially in applications related to alternating current and direct current charging. The CCS2 standard is specially relevant because it enables both AC and DC charging within a single physical interface, promoting interoperability between vehicles and stations from different manufacturers [9].

Relevance of Simulators for Electric Vehicle Charging Systems

The proper operation of a charging station depends not only on its ability to supply energy to the vehicle, but also on a sequence of communication and verification steps preceding energy transfer. These steps include connection identification, safety validation, parameter exchange, definition of operational limits, and synchronization between the vehicle and the station. In direct current fast-charging systems, this communication becomes even more critical, as the vehicle actively participates in controlling charging parameters [10], [11].

Testing with real vehicles may be constrained by factors such as cost, availability, model compatibility, and operational risks. In practice, this approach is not always feasible because it requires access to specific vehicle models, compatible charging interfaces, controlled test conditions, and safety procedures capable of preventing damage to the vehicle, the charging station, or the operator. Moreover, reproducing

specific fault conditions, communication events, or operating states in field environments is often not feasible, since such scenarios may depend on abnormal operating conditions that are difficult to induce safely and repeatedly using real vehicles. In this context, communication simulators provide a technical alternative for bench testing, firmware development, conformity assessment, and equipment maintenance.

A communication simulator can emulate the expected behavior of an electric vehicle during its interaction with a charging station. This enables the evaluation of whether the station correctly identifies the connection, responds to control signals, executes standard-defined states, and maintains communication within specified parameters. This approach is particularly useful during the development phase, as it allows inconsistencies to be detected prior to testing with real vehicles.

In addition to research and development applications, simulators are also relevant for maintenance activities. Service providers and technicians can use these devices to diagnose communication failures, validate repairs, test connectors, and investigate abnormal behavior. As a result, simulation contributes to cost reduction, improved operational safety, and increased reliability of charging infrastructure.

III. Embedded Architecture, Normative Requirements, And Communication Protocols **Conceptual Architecture of the Embedded Device**

The conceptual architecture of the proposed communication device is organized into modular functional blocks, including a processing and control unit, a signal conformance interface, a physical connection interface, a serial communication converter, and a human-machine interface. This modular structure facilitates firmware design, signal validation, and hardware/software integration. The adoption of an embedded architecture also enhances portability and reduces costs compared with commercial solutions based on dedicated computing platforms.

The processing and control unit (PCU) is responsible for data processing, execution of control commands, and overall system coordination. In the reference implementation, this unit is based on a development kit equipped with the Texas Instruments TMS320F28377D microcontroller [12]. The use of an embedded platform provides precise control over timing, peripheral interfaces, and the execution of communication routines, which are critical aspects for charging simulation applications.

The signal conformance interface (CSI) adapts the signals generated by the control unit to meet the communication requirements between the vehicle and the charging station. This block is essential because the interaction requires compliance with both physical and logical standards. In the reference architecture, this interface is implemented using the CODICO WB-Carrier Board PEV, designed for applications within the ISO 15118 framework [13]. Figure 2 presents the WB-Carrier Board PEV, representing the signal adaptation and communication interface adopted in the proposed architecture [13].

The system integration interface (SII) corresponds to the physical connection with the charging station through a CCS2 connector. Although the conceptual device is not intended for energy transfer, the use of a compliant connector is required to reproduce the mechanical coupling and control signals present in a real charging condition. Therefore, ensuring electrical and mechanical compatibility is a fundamental aspect of the proposed system.

The human-machine interface (HMI) complements the architecture by enabling system monitoring, command execution, and real-time observation of test behavior. This interface can be implemented using a notebook and communication software, allowing interaction with the embedded firmware and visualization of system states. As a result, the architecture provides flexibility for testing, parameter adjustment, and future experimental evaluations.



Applicable Normative Requirements

The proposed communication device for charging simulation must be aligned with the main normative requirements governing the interaction between electric vehicles and charging stations. These standards define not only electrical and mechanical aspects but also procedures related to communication, safety, interoperability, and control. Therefore, compliance with these standards is essential for a simulator to accurately reproduce the expected behavior of real systems.

IEC 61851 establishes general requirements for conductive charging systems for electric vehicles, addressing aspects related to power supply, control communication, operational safety, and charging modes. IEC 61851-24 defines digital communication between direct current charging stations and electric vehicles, making it directly relevant for systems designed to simulate DC charging control processes [10], [11].

ISO 15118 complements this framework by defining the communication interface between electric vehicles and the power grid. These standards address high-level communication, including use of cases, network and application protocols, as well as the physical and data link layers. Its application is especially relevant in CCS2 systems, where communication between the vehicle and the station involves processes such as initialization, authentication, authorization, parameter exchange, and session termination [14] – [16].

IEC 62196 establishes requirements for plugs, socket-outlets, connectors, and vehicle inlets used in charging systems. Within the CCS2 standard, IEC 62196-3 is particularly relevant, as it defines connectors for direct current charging and combined AC/DC configurations. This standard ensures dimensional compatibility, interchangeability, and safety of the physical components involved in the connection between the vehicle and the station [17], [18].

The integration of these standards demonstrates that the design of a simulator cannot be limited to the implementation of an isolated communication protocol. The device must simultaneously consider the operational charging sequence, physical control signals, safety requirements, high-level communication architecture, and connector specifications. This integrated approach is necessary to ensure that the tests performed with the simulator are technically consistent with real charging station.

Communication between Electric Vehicles and Charging Stations

Communication between an electric vehicle and a charging station occurs at different levels, combining basic signaling, safety verification, and digital communication. In the initial stage, the station identifies vehicle presence, verifies cable connection, and confirms the minimum conditions required to proceed. This phase is essential to prevent improper energization, grounding faults, or incompatibilities between the cable, vehicle, and station.

Within the CCS2 standard, three signals play a central role in the physical and logical interface: Proximity Pilot (PP), Control Pilot (CP), and Protective Earth (PE). The PP enables detection of cable presence and current-carrying capacity, allowing the station to adjust its operational limits accordingly. The CP provides basic signaling between the vehicle and the station, using voltage levels and pulse-width modulation (PWM) to indicate connection status, availability, and charging states. Protective Earth establishes the grounding reference required for electrical safety.

Following basic signaling, direct current fast-charging systems rely on high-level communication to establish and manage a charging session. This process may involve steps such as Signal Level Attenuation Characterization (SLAC), used to assess communication channel conditions, and the SECC Discovery Protocol (SDP), used for charging station discovery and logical connection. Subsequently, vehicle-to-grid (V2G) communication enables the exchange of detailed information between the vehicle and the station [13], [16].

This communication structure is required because, in direct current charging, the vehicle defines key charging constraints. Parameters such as maximum voltage, allowable current, state of charge, and safety conditions are essential for controlled energy transfer. Therefore, a communication simulator must accurately reproduce these processes, enabling the evaluation of charging stations with respect to their logical behavior and compliance requirements.

Communication Protocols Used in the Embedded System

The future implementation of an embedded device requires the use of communication protocols capable of integrating its different functional blocks. These protocols operate both in the internal communication between the microcontroller and auxiliary interfaces and in the organization of the data exchanged during the simulation. Among the protocols relevant to the proposed architecture, SPI, SCI, and HDLC stand out.

SPI communication is used in embedded systems for synchronous data exchange between a master device and one or more slave devices. Its structure uses signals such as MOSI, MISO, SCLK, and slave selection, allowing data transfer with synchronization control and configurable transmission rates. In the context of the proposed architecture, SPI is suitable for communication between the processing unit and the signal

conformance interface, as it enables fast and controlled information transfer [19], [20]. In addition, Figure 3 illustrates a Texas Instruments development platform that can support embedded communication implementations, including applications involving SPI-based data exchange [20].



Figure 3. Texas Instruments controlCARD docking station [20]

SCI communication, in turn, is used for serial data transmission in embedded systems, generally in asynchronous mode. Its typical structure includes a start bit, data bits, an optional parity bit, and stop bits. This simplicity makes SCI suitable for communication between the embedded system and the human-machine interface, allowing commands, status messages, and monitoring data to be transmitted between the microcontroller and the software used by the user [21].

The HDLC protocol operates at the data link layer and organizes information into frames, including fields such as flag, address, control information, and frame check sequence. Its function is to increase transmission reliability by enabling frame delimitation, error control, and organization of transmitted data. In a communication simulation application, this type of structure is relevant because it allows the data packets exchanged between system elements to be represented in an organized manner [22], [23].

The combination of these protocols contributes to the robustness of the proposed architecture. While SPI and SCI enable physical communication between the embedded modules and the user interface, HDLC contributes to the logical structuring of the data. Thus, once implemented, the device will be able to operate in an organized manner, allowing information flow control, process monitoring, and consistent reproduction of the communication stages.

Potential Applications and Advantages of the Proposed Architecture

The embedded communication architecture has potential applications at different stages of the development and operation cycle of charging stations. In research and development activities, it can be used as a basis for validating firmware, testing communication sequences, and evaluating the response of stations under different simulated conditions. This possibility is relevant because it allows failures to be anticipated and adjustments to be made before integration with real vehicles.

In maintenance activities, a simulator based on this architecture can assist in diagnosing communication failures, identifying connector-related problems, verifying the station response, and validating repairs. The use of a portable and customizable device would make this process more practical, especially in environments where access to compatible electric vehicles is limited. Thus, the tool would have the potential to reduce diagnostic time and increase the reliability of stations in operation.

Another potential advantage is related to cost. Commercial simulation solutions may have high acquisition costs and depend on dedicated software or computers. The proposal of a system based on embedded electronics allows costs to be reduced, implementation flexibility to be increased, and the device to be adapted to different testing scenarios. This characteristic is especially important for research institutions, academic laboratories, and companies in the early stages of operation in the charging market.

In the Brazilian context, the relevance of this type of tool is amplified by the still emerging stage of the charging infrastructure. As new companies, station models, and operating standards emerge in the market, the need for devices capable of supporting technical validation and equipment maintenance increases. Therefore, the proposal of an embedded simulator can contribute not only to academic research but also to the development of national expertise in the field of electric mobility.

IV. Conclusion

The expansion of electric mobility requires the simultaneous development of vehicles, batteries, charging stations, technical standards, and validation tools. Although electric vehicles have shown significant

growth on a global scale, charging infrastructure still represents one of the main challenges for their consolidation, especially in countries such as Brazil. In this scenario, communication simulation devices can play a strategic role by enabling testing, maintenance, and validation of stations without the direct use of real vehicles.

This article discussed the normative and technical foundations associated with communication between electric vehicles and charging stations based on the CCS2 standard, in addition to presenting a conceptual proposal for an embedded device to simulate this process. The proposed architecture is based on a modular structure composed of a processing and control unit, signal conformance interface, CCS2 connector, communication converter, and human-machine interface. This organization makes it possible to conceive a system capable of reproducing essential stages of the communication process, including basic signaling, logical interaction with the charging station, and monitoring of system states.

The normative foundation demonstrated the importance of the IEC 61851, ISO 15118, and IEC 62196 standards for the development of solutions compatible with safety, communication, and interoperability requirements. In addition, the analysis of the SPI, SCI, and HDLC protocols showed that the operation of this type of device depends on the integration of embedded communication, data structuring, and compliance with the signals used in the charging process. Thus, the proposal is not limited to the development of an isolated circuit or software, but involves a systemic approach to hardware, firmware, communication, and standardization.

As a potential contribution, the proposed architecture may reduce testing costs, increase experimental flexibility, and support maintenance and validation activities for charging stations. Future work should include the complete implementation of the prototype, laboratory tests with different charging station models, and validation of the communication sequence under normal and fault conditions. Therefore, the development of embedded simulators can contribute to the consolidation of charging infrastructure and to technological progress in electric mobility in Brazil.

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