Smart Testing of Smart Charging

Consistent Test Case Coverage for Electric Mobility

With the increasing diversity of electric vehicles and charging station systems, interoperability between components and conformance to standards are ever more important. In order to test these issues, identify causes of charging interruptions, and test reliability and robustness against various disturbances, consistent test case coverage with an open test environment is required.

The Charging Process According to IEC 61851 and IEC/ISO15118

Four modes are defined in IEC 61851 [4] for conductive charging of electric vehicles.

> In Mode 1, the vehicle is charged with a single-phase power supply with a maximum current of 16 A without a pilot signal.
> In Mode 2, the charging operation uses a single-phase to three-phase power supply with a maximum current of 32 A and a pilot signal.
> In Mode 3, charging takes place with a single-phase to three-phase power supply with a maximum current of 63 A and a pilot signal provided by the charging station.
> Mode 4 describes DC charging with up to 400 V / 125 A.

While the Mode 1 charging operation does not involve communication between the vehicle and the charging infrastructure, charging in Modes 2, 3, and 4 always involves low-level communication based on pulse width modulation (PWM) via the Control Pilot (CP) connection. If the vehicle and charging station support high-level communication, the corresponding signal is modulated to the PWM signal of the CP based on the HomePlug GreenPHY standard. This is defined as power line communication (PLC) and is only possible in Modes 3 and 4 as described by IEC/ISO15118 [3]. Every PLC-based charging communication requiresis PWM-based communication, in principle. Therefore, a complete test system must handle both communication modes.

Function of the Components Involved

From the vehicle perspective, the functionality of the charging station essentially consists of the components described in **Table 1. Table 2** presents the functionality of the vehicle from the perspective of the charging station.

Charging station functionality	Realized through
Communication signal on the CP	Frequency signal based on pulse width modulation (PWM). The PLC signal is modulated to the PWM signal, if necessary
Maximum possible loading of the charging line	So-called proximity signal (PP), which is coded by a resistance between PP and PE dependent on the cable cross-section in the connector
Provided current	Coding by the duty cycle of the PWM signal
High-level communication capability	Duty cycle of 5%. The duty cycle in the range 3% – 7% is reserved exclusively for this purpose
Participant in PLC communication	Communication of more complex information, e.g., charging profiles, billing models, authentication
Power	1- to 3-phase AC circuit, between 100 V and 240 V AC, depending on country. Alternatively: DC voltage via separate cables

Table 1: Functionality of the charging station that the vehicle recognizes directly or indirectly.

Vehicle functionality	Realized through
Display of the plug connection	Resistance between CP and PE that lowers the CP level from 12 V to 9 V
Display of the connector interlock	Additional resistance between CP and PE that lowers the PWM signal from 9 V to 6 V
Display of required cooling	Resistance between CP and PE that lowers the PWM signal from 6 V to 3 V
Participation in PLC communication	Communication of more complex information, e.g., charging request, account data, authentication
Power reduction	Agreement of a profile by means of low-or high-level communication

Table 2: Functionality of the vehicle that is visible for the charging.

Test of the Charging Communication

In order to prove that charging is functioning properly at all levels, a special measuring and testing system is needed. It must be able to analyze and emulate both the load circuit and the communication signals, such as the Control Pilot and the PLC signal. In addition, creation, display, and if necessary manipulation of the message contents of the PLC are required. The ability to inject errors into the electric signals completes the test system. This includes both internal short circuits and short circuits to battery voltage/ground as well as variations of the resistances in the vehicle and charging station that take part in the CP communication. Finally, a complete test system must be able to measure and analyze the load circuit (AC or DC) in terms of current and voltage, and disturb it in a defined way.

Test Modes and Requirements for a Test System

For component tests and analyses of robustness, a test system must provide all interface variables in conformance with standards and with defined injected errors to each component to be tested.
For the charging communication channels shown in **Figure 1**, the possible issues to test include:

- Control Pilot signal with incorrect characteristics on the PW component (e.g., level, resistance values, duty cycles, time sequences) and PLC component (e.g., structure of communication, communication conforming to standards, and defined faulty messages)
- Proximity Pilot including incorrect coding resistance

For the component test or robustness test of an EV charging electronic control unit (EV-ECU) with simulated EVSE **(Figure 2)**, the following must also be provided:

- Vehicle wiring system voltage with overvoltage/undervoltage, ramp characteristics, erratic disturbances
- Vehicle communication (e.g., CAN) with message errors and electrical errors
- AC or DC load signal with all types of voltage disturbances
- Grid Simulator for emulation of various grids around the world (different voltages, frequencies, mains with disturbances, etc.)
- Consumption of the DC charging power, if necessary
- For an EVSE test, the vehicle is simulated with all limit values **(Figure 2)**. Also required are:
- Connection to a real or emulated power utility system (gridemulator)
- Simulation of the www environment, if necessary

For execution of interoperability tests, the test system is inserted between the charging station and the vehicle **(Figure 3)**.

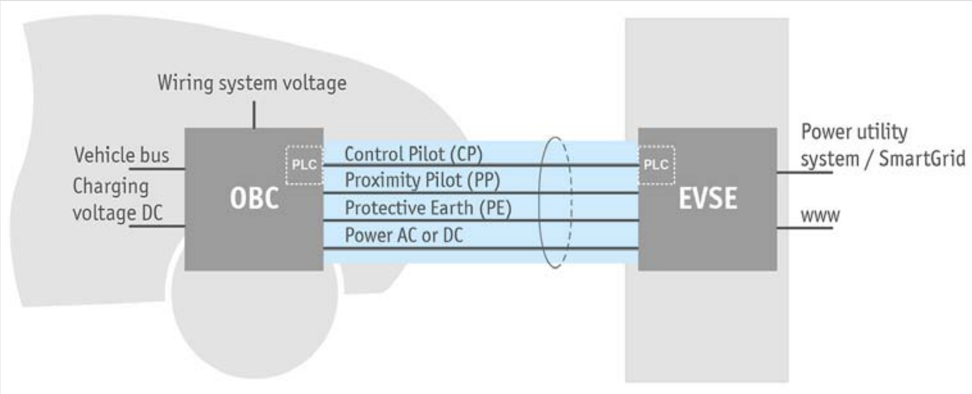

Figure 1: Interaction of charging ECU (OBC – Onboard Charger) and charging station (EVSE).

There are two possible modes of operation: in pure passive mode, only measurements are possible in the electrical signals of CP, PP, and load circuit. In pure gateway mode, where analysis and manipulation of the PLC messages in high-level communication mode is targeted, it is necessary to disconnect, intercept, and modify as necessary the CP line since the messages exchanged are encrypted when the vehicle-charging station connection is established. In addition to measuring and influencing the communication and load channels, a test system must have an execution unit, recording unit, monitoring unit and ideally an authoring and managing unit for test cases. There is already a large demand for systematic tests [2] today. In order to address this issue, IEC/ISO15118 [3] will provide Parts 4 and 5 for standardized test cases in the future.

Overall Test System

To cope with the complex demands on an overall test system, a modular test system architecture was selected that meets all necessary requirements, while allowing realization of subtasks through targeted reduction of the system setup **(Figure 4)**.

The central software element is the CANoe tool of Vector Informatik GmbH with Ethernet option. CANoe takes over the following tasks: test execution, simulation of PLC communication, provision of measurement and analysis data of the vehicle and charging communication and all electrical characteristics, and control of the hardware components involved. It enables all relevant measurements and signals to be provided with uniform time stamps and to be processed, evaluated, and saved. The creation and management of test cases, whether user-created [2] or standardized, are completed in vTESTstudio of Vector Informatik [7]. The presented interconnection options enable test systems for subtasks to be derived from this architecture.

For simulation of the environment of the charging ECU and/or charging station, the presented system uses a combination of the EV Charging Analyzer / Simulator (EVCA) of comemso GmbH [5] as well as the VT System of Vector Informatik [6]. Both the EVCA and the VT System are able to uncouple the PLC signal of the high-level communication from the CP signal and to route CANoe over Ethernet. With the help of the Smart Charging Communication (SCC) add-ons, all necessary analysis and manipulation possibilities are available in CANoe [1].

The EVCA and the VT7870 module of the VT System provide the circuitry for CP and PP required according to IEC 61851-1 [4], including the possibility to inject errors **(Figure 5)**.

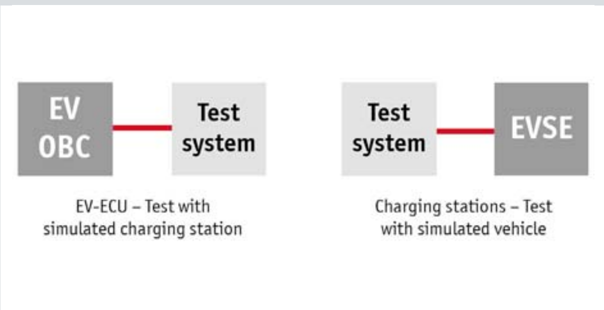

Figure 2: Possible component tests.

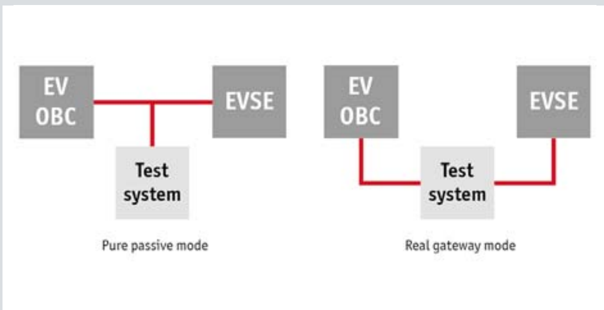

Figure 3: Possible modes of a "Man-in-the-middle" operation for interoperability tests.

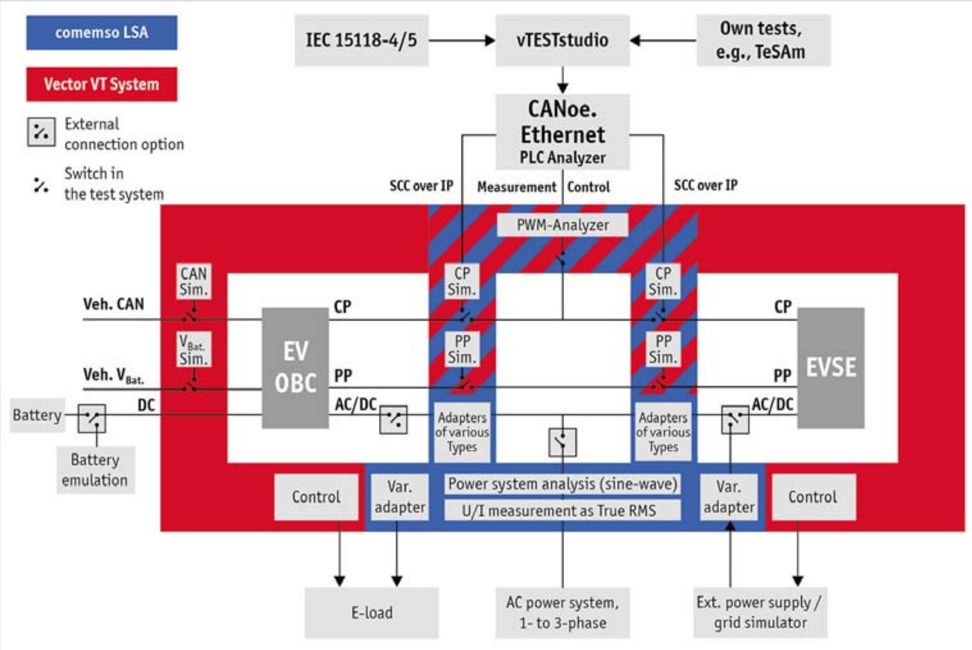

Figure 4: Interaction of charging ECU (OBC – Onboard Charger) and charging station (EVSE). overlay on video image in the Multi-media Window.

The VT System also represents the interface for vehicle communication and enables simulation of the vehicle power system and, if necessary, the control of an electronic load or external power supply. The EVCA of comemso GmbH is also able to detect all disturbances of the complex CP and load signals in real-time while simultaneously detecting the sources of the disturbances. Because the pilot signal together with the modulated PLC signal can violate the specifications for the pilot signal in the standard, specially developed analog filter circuits are required to achieve interaction-free separation of the high-frequency PLC signal from the pilot signal. For analysis of the CP signal, the EVCA uses a specially developed measuring procedure in which up to 150 different errors and permutations thereof can be measured in each period.

In addition, the current and voltage of the load circuit is measured precisely as true RMS on all three phases with the EVCA. Additional power supply system analysis for each of the three phases and each sine-wave period identifies asymmetrical mains utilizations as well as mains disturbances that can cause electromagnetic interferences of the communication signal.

While charging communication is based on Ethernet, all variables measured with the EVCA are forwarded to CANoe via a separate CAN channel. Only through the common and time-synchronized measurement and visualization of the load circuit, CP signal, and PLC signal, related disturbances and – if necessary – causes and effects can be identified.

For field use, the mobile version of the comemso EV Charging Analyzer / Simulator (EVCA) and Vector CANoe. Ethernet with vTESTstudio are used **(Figure 6)**. This provides test case consistency from the prototype stage to the series product both in the lab and in the field.

Figure 5: Test system components for SCC tests relating to IEC 61851 and IEC/ISO 15118.

Figure 6: Test system combination for mobile use.

Summary

The test system architecture presented in this article enables systematic testing of components involved in conductive charging according to IEC 61851-1 [4] and IEC/ISO 15118 [3] for robustness, conformance to standards, and interoperability. The open vTESTstudio and CANoe test environment provides fundamental transparency and reproducibility of the test sequences. The modular architecture and the combination of the comemso and Vector tools allow operation with the real environment or a fully simulated environment and any intermediate stage in between as well as operation in automated test cycles. With this analytical approach at all levels, maximum test depth is made possible – the cornerstone for robust and harmonized components that will ultimately satisfy E-mobility customers.

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Literature:

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Links:

Homepage Vector: www.vector.com

Homepage comemso GmbH: www.comemso.com

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