CHALLENGES AND RELATED SOLUTIONS FOR PERIODIC VERIFICATION OF DC ELECTRIC VEHICLE CHARGING STATIONS

Daniel HERBST
Graz University of Technology – Austria
daniel.herbst@tugraz.at

Martin FUERNSCHUSS
Graz University of Technology – Austria
martin.fuernschuss@tugraz.at

Peter REICHEL
OVE Austrian Electrotechnical Association – Austria
p.reichel@ove.at

Felix LEHFUSS
AIT Austrian Institute of Technology – Austria
felix.lehfuss@ait.ac.at

Christian Auer
KS Engineers – Austria
christian.auer@ksengineers.at

Ernst SCHMAUTZER
Graz University of Technology – Austria
schmautzer@tugraz.at

ABSTRACT

For the periodic verification of DC electric vehicle charging stations (EVCSs) currently no standardised verification and test procedures or associating methods and protocols have been established. This belongs to the incomplete standardisation work as well as the ongoing developments of EVCS. In the course of this paper, first important approaches for possible procedures for the periodic verification of DC-EVCSs, which are already installed in the field, are presented. On the one hand, appropriately applicable sequences from existing AC test routines will be used, and on the other hand, new test procedures required in addition for DC charging stations are presented. Furthermore, a mobile high performance test device demonstrator including its functional scope is shown. Still existing questions and challenges with regard to the mentioned topic round off the article.

INTRODUCTION

The ongoing rising demand of electrical vehicles for individual transport requires a denser charging infrastructure which can only be achieved by installing more charging stations. In non-public areas like households, AC (alternating current) electric vehicle charging stations (EVCSs) with three-phase charging powers up to 22-44 kW are common. In public areas, DC (direct current) charging is by reason of the higher charging power up to 350 kW and the associated shorted charging time is also common. Latest developments indicate DC charging stations with rated charging power up to 500 kW are close to market maturity. For electrical driven heavy-duty vehicles, DC charging stations with charging power in the MW range, are in development.

Like every electrical equipment or installation, EVCS on the one hand have to fulfil safety levels in order to protect users from electric shocks and on the other hand provide the operator with legal certainty with regard to system responsibility. For the fulfilment of these requirements, periodic verifications of installed EVCSs are essential.

Corresponding periodic verifications for AC-EVCSs are nowadays uniformly regulated or standardised. Commercially available installation testers (protective measure testers) as well as corresponding test adapters (e.g. Type 2 inlet to 4 mm safety sockets and/or type F socket including a switch for selecting the charging status) are in use in order to fulfil a standardised test protocol. Among other things, the intended function of installed residual current devices (e.g. type B or type A-EV with 6 mA DC fault current detection) are tested. The methodology applied is similar to the verification of a conventional CEE three-phase socket outlet, whereby the tests mentioned are similar in test procedures for guaranteeing the protection against electric shock of humans, livestock and for the protection of goods.

For DC-EVCSs currently neither standardised verification procedures nor associating methods and protocols are established. This belongs to the incomplete standardisation as well as the ongoing development of DC-EVCSs.

STANDARDS AND LEGAL ASPECTS

As mentioned in the introduction, there are currently no specific standards or regulations regarding to periodic verifications of DC charging stations on national or international level. Nevertheless, it is useful to present the current state of standardisation in the form of a summary of the existing standards relating to the topic in question. Furthermore, an interpretation of the necessity of a periodic verification is presented based on the example of the Austrian legal situation. Table 1 below presents a summary of the current standardisation documents and the regulation by law applicable in Austria.

Table 1: Exemplary standards and legal documents related to the periodic verification of DC-EVCSs.

Short description/ number	Long title	Range of validity
IEC 60364 series	Low voltage electrical installations	int
OVE E 8101	Low voltage electrical installations	AUT
IEC 61851 series	Electric vehicle conductive charging system	int

Short description/ number	Long title	Range of validity
IEC 62196 series	Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles	int
IEC 61893 series	Charging cables for electric vehicles for rated voltages up to and including 0,6/1 kV	int
DIN VDE V 0122-2-300	Conformance Test Specification IEC 61851-23, Annex CC	GER
IEC 61439 series	Low-voltage switchgear and controlgear assemblies	int
ÖVE/ÖNORM E 8701 series	Inspection after repair and modification and repeat tests of electrical appliances	AUT
ETG 1992	Federal law on safety measures, normalisation and typification in the area of electrical engineering	AUT
ESV 2012	Regulation on protection of workers/employees against the hazards of electric current	AUT
ETV 2020	Regulation on safety, standardisation and typification of electrical equipment and installations	AUT
int…valid international, AUT…valid in Austria, GER…valid in Germany		

Usually a DC-EVCS is a stationary electrical equipment with CE marking which is part of an electrical installation. As a result of this, periodic verifications of a DC-EVCS in the sense of OVE E 8101, part 6 (compare IEC 60364, part 6) would not be mandatory. However, since mentioned DC-EVCS are usually installed and operated in public places by companies (and only rarely in private areas), the operator has a corresponding duty of care towards their employees (and the public). According to ESV 2012 (AUT, based on EU directives), this also includes the periodic verification of electrical equipment (e.g. according to ÖVE/ÖNOM E 8701 (AUT)).

CONCEPTS AND METHODS FOR PERIODIC VERIFICATION

Based on the periodic verification methods established for AC charging stations, first approaches of an implementation for DC-EVCSs are discussed in [1-3]. At DC charging stations electrical faults may occur like insulation faults, short-circuits between DC+ and DC- or earth faults between DC+ and protective earth (PE) or DC- and PE. The proper operation can also be disturbed by interruptions of communication signals/lines, DC+ resp. DC- or PE.

In a first step the behaviour of a DC-EVCS is analysed with regard to the following fault emulations resp. tests:

- Test of normal operation (normal charging sequence);
- Short-circuits between DC+ and DC-;
- Earth faults between DC+ and PE as well as DC- and PE;
- Interruptions of communication signal(s);
- Measurement of switch-off times in the event of a fault;
- Measurement of switch-off times in the event of an intentional charge interruption;
- Measurement of electrical losses (energy efficiency);
- Measurement and analysis of grid reactions and system perturbation.

MINIMUM REQUIREMENTS FOR DC-EVCS

With regard to the automatic disconnection of a DC charging station in the event of a fault, different minimum requirements or limit values can be already found in the standards. In the following, recommendations are summarised together with the corresponding standards.

Interruption of DC power lines

With regard to the interruption of DC power lines, no limit values can be found in the regulations resp. standards. However, a maximum permissible break time < 400 ms (< 400 V, HD 60364-4-41) is recommended.

Interruption of the Protective Earth (PE) conductor

In this case a DC-EVCS must switch off within a break time ≤ 100 ms during a CCS charging process according to IEC 61851-1:2017 section 6.3.1.2 [4].

Electrically isolated/separated systems

According to IEC 61851-23:2014 section 6.4.3.2 [5], a break time ≤ 10 s must be observed when interrupting the PE conductor in an electrically isolated resp. separated system.

Electrically not isolated/separated systems

According to IEC 61851-23:2014 section 6.4.3.2 [5], a break time ≤ 5 s must be observed when interrupting the PE conductor in an electrically not isolated resp. not separated system.

Interruption of the Control Pilot (CP) conductor

In the event of an interruption of the CP conductor, a DC-EVCS must switch off within a break time ≤ 100 ms during a CCS charging process according to IEC 61851-1:2017 section 6.3.1.2 [4].

Earth fault between DC+ (or DC-) and PE

In accordance with OVE E 8101:2019 + OVE E 8101/AC1:2020 section 411.3.2.001.AT [6], a DC charging station must switch off within a break time < 5 s in case of an earth fault between the power line DC+ (or DC-) and the protective earth PE.

Short-circuit between DC+ and DC-

Due to the lack of information regarding the maximum permissible break times in the event of a short circuit between DC+ and DC- in standards IEC 61851-1:2017 [4] and IEC 61851-23:2014 [5], the recommended method is to use the break times according to table 41.1 from OVE E 8101:2019 + OVE E 8101/AC1:2020 section 411.3.2.2 [6].

Short-circuit between PE and CP

In the event of a short-circuit between the protective conductor and the control pilot, a DC-EVCS must switch off within a maximum permissible break time < 3 s in accordance with IEC 61851-1:2017 section 6.3.1.2 [4].

Overload

In case of overload, a DC charging station according to prEN IEC 61851-23-2:2018 [7] shall switch off within a maximum break time < 1 min at 1.3 times the rated current ($1.3 \cdot I_N$).

Other possible faults

Among others, faults like longitudinal arc faults (serial) within a power line (DC+ and/or DC-) as well as worn contacts or line to line arc faults (parallel) from DC+ to DC- are imaginable. These can occur either in the charging cable or at the terminals of the charging plug and, in addition to a potential risk of electric shock, also represent a source of fire. However, in the area of the detection of such arc faults research is still being carried out.

MOBILE HIGH PERFORMANCE TEST DEMONSTRATOR

For initial testing purposes, a demonstrator was developed and built in the course of a research project [8], which can emulate the most essential functions of an electric vehicle as well as a certain part of the above-mentioned tests and verifications. At the current state of development, this is capable of starting and performing a charging process at a DC charging station using CCS (Combined Charging System, European charging standard) up to 120 kW. The demonstrator together with its optically connected (fibre optic) control unit is shown in Figure 1.

Figure 1: Test demonstrator with control unit.

In principle, this device generates a load in order to emulate the battery voltage of an EV, so the charging station operates in the same way like a connected EV.
Once communication has been successfully established, any charging power (depending on the power range of the charging station) up to 120 kW can be provided by means of the control unit. The demonstrator charges its implemented batteries for control voltage supply with a part of the charging energy delivered by the DC-EVCS. The remaining part is converted to heat via braking resistors. Due to the aforementioned integrated batteries and the concept developed, the demonstrator can emulate a charging procedure and the corresponding tests resp. verifications almost independently of a grid connection for power supply and is capable to feed back the charging energy into the grid. The now developed verification concept also allows scalability of the charging power and thus offers the possibility to adapt a corresponding test device for the periodic verification of DC-EVCS to the respective required power.
Figure 2 shows the test-setup consisting of the demonstrator, the control unit and the DC charging station under test. In this case, measurements were carried out on a DC-EVCS with a maximum charging power of 50 kW at 150 Vdc to 950 Vdc resp. 0 Adc to 125 Adc with two DC outlets (CCS and CHAdeMO) as well as an AC type 2 outlet with 43 kW (3-phase 400 Vac, 50 .
Additionally, in the course of [1], a measuring distributor was developed and constructed as an adapter and test solution, which can be connected as a device in the middle between a DC charging station and an electric vehicle. The benefits of the measuring distributor are the access of all necessary signals on the one hand and the ability carrying out initial tests with regard to line interruptions, earth faults and short-circuits on the other under guarantee of the safety of persons.

Figure 2: Test setup consisting of the demonstrator (left), the control unit (centre) and the DC charging station to be tested (right).

This measuring distributor, shown in Figure 3, was also temporarily integrated into the test set-up and was used to evaluate the test results of the demonstrator.

Figure 3: Measuring Distributor which can be connected between a DC-EVCS and an electric vehicle for measuring purposes as well as for initial tests (e.g. line interruptions, earth faults and short-circuits) with accessories.

Figure 4 shows an exemplary plot of the measurement data evaluation based on a resistive earth fault with 1 kΩ between DC+ and PE at 400 Vdc and 125 Adc (= maximum charging power of the tested CCS-DC-EVCS of 50 kW). In detail the DC charging voltage (orange) and the corresponding charging current (magenta) as well as the voltage of the contactor simulating an earth fault can be seen. The time (~ second 4.0) at which the contactor is switched and thus the earth fault is initiated as well as the times at which the charging current (~ second 10.7) and the charging voltage (~ second 11.0) are switched off by the EVCS are marked. This results in break times of ~6.6 s for the charging current and ~6.8 s for the charging voltage, both of which are slightly above the maximum limit of 5 s defined in [6].

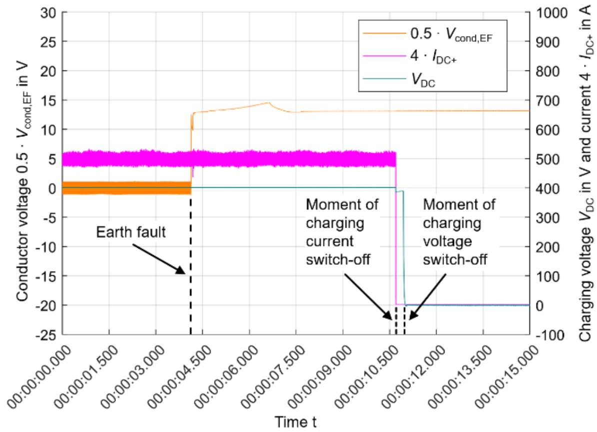

Figure 4: Example resistive earth fault (1 kΩ) between DC+ and PE at 400 Vdc and 125 Adc.

Table 2 summarises a selection of different emulated fault cases with the corresponding break times for the charging current as well as the charging voltage.

Table 2: Selection of different fault cases including the corresponding measured break times.

Type of fault	Break times	
	Current	Voltage
	ss.hhh	mm:ss.hhh
Interruption DC+	0.001	54.227
Interruption PE	< 30.000	< 01:35.113
Earth fault 100 kΩ	06.434	06.640
Earth fault 1 kΩ	06.565	06.834

For example, it can be seen that in the event of an interruption in the power line (e.g. DC+), the current flow is interrupted immediately (< 1 ms) after the occurrence of the fault, but the voltage takes just under a minute to decrease due to existing capacities. In addition, the tested DC-EVCS has similar break times in the case of a resistive earth fault with 1 kΩ (see also Figure 4) than with 100 kΩ.

SUMMARY AND OUTLOOK

The periodic verification of DC electric vehicle charging stations with regard to long-term protection against electric shock is not yet clearly defined in standards. Nevertheless, different standards and regulations at national and international level form a basis on the one hand with regard to the necessity of verifications and on the other hand, for the stipulation of minimum requirements with regard to maximum allowable break times.

This contribution summarises the applicable standards as well as regulations and provides an overview of the correspondingly derived minimum requirements matching a proposal of possible fault cases. A demonstrator is presented which allows to carry out on site tests under practical load conditions on already installed DC charging stations with a charging power of up to 120 kW.

Furthermore, the presented concept allows for a scaling of the charging power required depending on further development steps. In addition, results of initial tests in the form of line interruptions (DC+ and PE) as well as earth faults (DC+ against PE with 100 kΩ and 1 kΩ) on a DC-EVCS are presented.

The next steps currently taken are to deepen the knowledge gained from the previous work in the form of the further planned research project *ProSafE²* (*Protection, Safety and Efficiency of Electric Vehicle Charging Stations*; a corresponding proposal has been submitted to the Austrian Research Promotion Agency (FFG)). The demonstrator is to be developed further in the direction of high-precision measurement technology, interoperability, user safety (including personal and employee protection) and user-friendliness. In addition, a proposal for widely applicable test routines including a recommendation for a practicable test protocol is to be drafted. Also DC-EVCSs from different manufacturers are to be investigated with regard to their efficiency and possible system perturbations.

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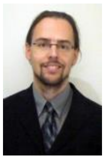
AUTHORS

Daniel Herbst is a PhD student at the Institute for Electrical Power Systems at Graz University of Technology. Main research interests: Low voltage protection concepts, protection against electric shock (protective measures), standardisation, safety of DC-EVCSs, measurement technology in electrical power systems.

Martin FUERNSCHUSS is a PhD student at the Institute for Electrical Power Systems at Graz University of Technology. Main research interests: Earthing, Transients, EMI, EMC, EMF, protection against electric shock, safety of DC-EVCSs, photovoltaics

Peter REICHEL is Secretary General of the OVE Austrian Electrotechnical Association. Prior to that he held several positions in the electro industry

Felix LEHFUSS is research engineer at the Austrian Institute of Technology. His research areas are Hardware in the Loop Simulations, as well as conformance testing and the integration of electric vehicles into the electric energy system and the future Smart Grids.



Christian AUER is project engineer at Kristl, Seibt & Co GmbH (KS Engineers). His main professional interests are EMC and power electronics.

Ernst SCHMAUTZER was a Senior Scientist at the Institute of Electrical Power Systems at Graz University of Technology and is now active as a consultant after his retirement.