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Having a Cutting Point - Testing and Development Environment at TU Dortmund University

Dipl.-Ing Christoph Aldejohann[1], Dipl.-Ing. Willi Horenkamp, Dr. Jan Fritz Rettberg,
Prof. Dr.-Ing. Christian Rehtanz
[1]*TU-Dortmund ie3, Emil-Figge-Str. 70, 44227 Dortmund Germany, christoph.aldejohann@udo.edu*

Abstract

This paper presents the technology and testing platform for interoperable e-mobility, infrastructure and power grids at TU Dortmund University. That environment allows to emulate several power grid states and to analyse the behaviour of charging station and EV regarding to both electrical and ICT aspects. Using this technology platform we developed an alternative method for Residual Current Detection with DC components in electrical vehicle charging. Standard methods are not very well suited for these requirements, because they are very expensive and need a manual reset. The method which is presented in this paper detects the fault current by using an AC/DC summation current transformer in the electric vehicle. The fault current is announced by a fault state. A control unit in the charging station detects the fault state which is transmitted by using the control pilot. The cut-off is done by the already existing charging contactor which is included in the charging station. The fault state is transmitted by using the control pilot. The here presented protection method has a comparable security level to typically used protection devices. It allows cost savings by a factor up to 50. It can be used also for cut-off by detecting an isolation failure.

Keywords: Residual Current Detection (RCD), control pilot, electric vehicle (EV) charging, DC fault current

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1 Introduction

The Test Centre for Interoperable Electro Mobility - Infrastructure and Power Grids (TIE-IN) at TU Dortmund University, in cooperation with industrial partners, has the objective to build up a competence and innovation centre for electric mobility infrastructure and grids. Core of this competence centre is a laboratory including a grid emulation test bench, a power electronic development platform, a motor test bench, a chassis dynamometer and ICT in order to emulate and test the whole chain between the grid, the electric vehicle (EV) and the required communication. The laboratory concept is designed in such way, that also new appliances developed by industry can be tested under various conditions.

The power electronic development platform contains a real time control unit with analogue and digital interfaces, power electronics hardware, measurement equipment usable also for high frequencies, battery emulation equipment and different kinds of loads and motors. The control unit is based on a dSPACE system, FPGA- and DSC Hardware flexible for all kind of power electronic hardware available on the market or new developed.

Besides testing of appliances and equipment the research goal is the development of high efficient multifunctional power electronics to improve the interaction between the power grid and the EV. The focus is on new topologies (e.g. four-leg), new semiconductor materials, new control schemes and the delivering of Power Quality and ancillary services for the grid.

Also, TU Dortmund University provides a testing and development environment to simulate several power grid states. That allows to analyse the behaviour of charging station and EV regarding to both electrical and ICT aspects. Voltage curves up to a cut-off frequency of 70 kHz with 230 resp. 400 VAC can be generated by this device. Figure 1 shows the block diagram of the testing and development platform.

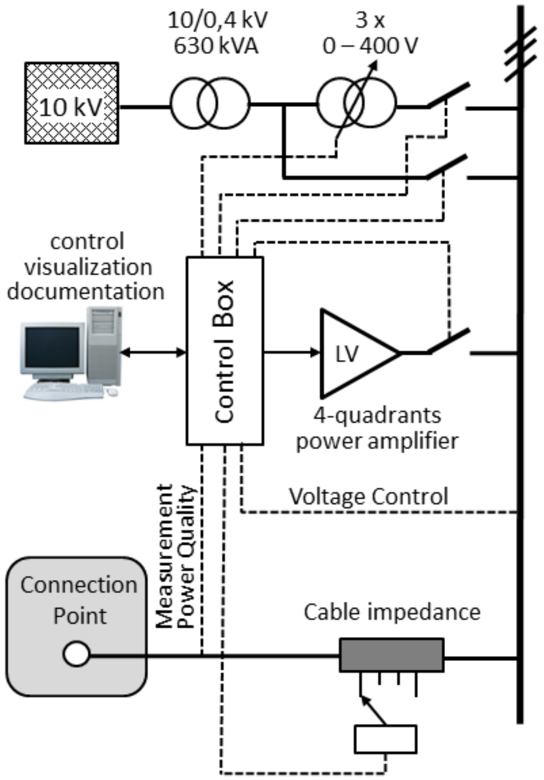

Figure1: Testing and development environment

All test results are controlled, visualized and logged via a central processing unit. A terminal block is used as main control device and allows the hardware interconnection according to requirements. Both the central processing unit and the main control device are connected with the real time hardware within the testing and development environment. This real time hardware operates the requested processes to simulate the voltage curves. It also controls the variable transformer, the power switch and the simulated network impedance. A graphical user interface with the function of a signal editor is developed especially for testing of charging devices and generates the requested voltage curves.

In the following we will point out a use case of the testing and development platform. We show on what terms a possible fault of the charging rectifier contains a direct current component in fault current and how the charging socket can be switched off safely in that case.

2 Possible fault currents with charging rectifiers

If there are consumers with power electronics such as charging rectifiers for EVs, besides the 50-Hz-component constant components of higher frequencies or mixed frequencies can occur in fault current in cases of error. Corresponding to European standards one has to use a type A Residual-Current Circuit Breaker (RCCB) for branch circuits. However, subject to the circuit topologies of the EV’s charging rectifier a safe switch-off is not guaranteed by these RCCBs. But multicurrent sensitive type B or type B+ RCCBs can be used to ensure a safe switch-off. Because type B or B+ RCCBs are much more expensive than type A ones, several standard setting bodies discuss the different possibilities to disconnect an EV from the power grid in cases of constant components in fault current. [1] [2] On the one hand the usage of multicurrent sensitive RCCBs as one possibility to do that is refused by system operators resp. charging point operators because of higher costs. On the other hand there is the alternative solution to outlay charging rectifiers in a way that does not allow direct components or high-frequency fault currents to occur at all. However, this option is refused by car manufacturers that do not want additional components inside their cars.

Thus we examine a higher-level question: Which topologies of charging rectifiers do really need an enhanced fault current protection? In this context we analysed all relevant standards and usable fault current protection devices. We paid special attention to the fact that not all described requirements of fault current protection can easily be transferred to charging devices of EVs. Therefore, we considered not only general standards concerning electric strike protection and e-mobility but also norms and standards that bear upon photovoltaics. Furthermore, we validated the examination of possible charging rectifier set-ups by simulations. [3]

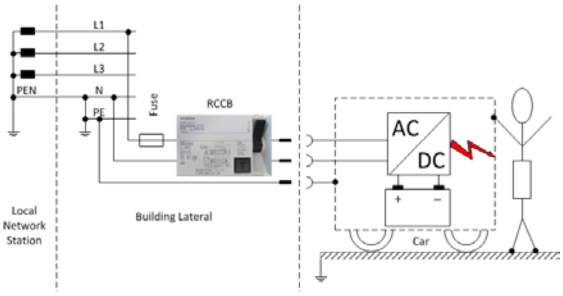

Figure2: Circuit pattern of the EV connection to the grid with functional disorder in electric vehicle

3 Alternative method for Residual Current Detection

Based on these considerations we developed and tested an alternative method. Our method is to record fault current within the EV (charging rectifier). We use the existing control pilot between EV and charging station for switching the power contactor in the EVSE (electric vehicle supply equipment). Amongst other things this provides safety functions, too. The charging states (A-F) are standardized via voltage levels in order to control the charging functions (see IEC 61851-1). [4] Moreover, the communication channel delivers the request to disconnect in case of fault current. Exceeding the critical value of IF ≥ 30mA of fault current causes a state change on the control pilot, e. g. changes state C (charging released) to state E or F (error states). These state changes are recognized by the circuit of the charging station and so the power contactor in the charging station and thus the charging socket are de-energized. The following oscillogram shows the disconnection of the charging station via control pilot in case of fault current with constant component.

The pilot signal is generated from the charging station controller according to IEC 61851-1. By the duty cycle of the PWM signal, the maximum allowable charging current of the charging station is defined. The upper voltage level defines the current state of charge (A-F). The change of the charging state is induced by loading the pilot signal in the EV by means of a resistor. On the EV the detection of the fault current is done by an AC/DC summation current transformer. The pilot state is forced to a failure state (e.g. state E) in case of a limit violation of the fault current. In the EVSE the actual state is monitored. A detection of a fault condition leads to an immediate interruption of the control of the charging contactor. The charging station is de-energized.

The fault current may be indicated by the states E, F or a new introduced state G which is between state E and F. Various state sequences are possible which make a mistake identified and release the charging station again. The principle is the same. The charging process is carried out as usual. In case of a fault current detection the EV sets the pilot control in an error state, for example state E. The state is kept until the plug is removed. Pulling the plug can be obtained by monitoring the proximity wire or by detection of the state A. Consecutively the charging station can be set free for the next charging process. An example for a suitable state diagram is shown in Figure 4.

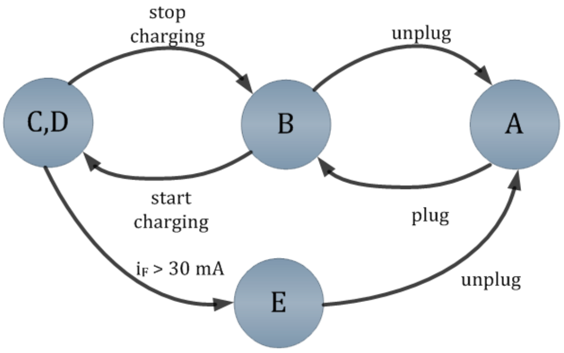

Figure4: State diagram for announcing a fault condition

Based on our results we developed recommendations regarding fault protection subject to particular circuit technologies. The use of this current fault protection method requires a standardization regarding to the de-energization period of the main contactor in the EVSE. A sufficient switch-off time should also be observed even in a parallel circuit of a diode.

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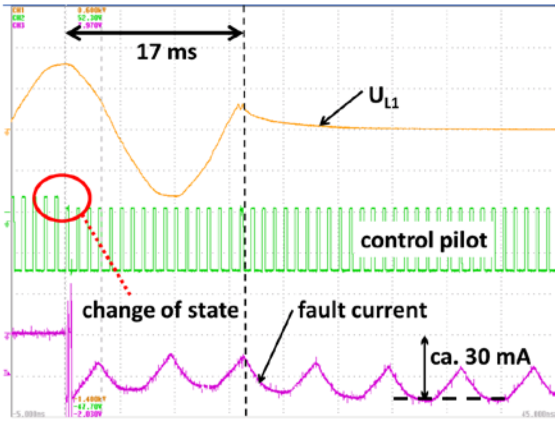

Figure5: Oscillogram of disconnection via control pilot

The system was implemented circuitry-wise. The standardization process is much easier for a circuitry-wise implementation than a software solution based on a microcontroller. An auxiliary supply is needed for the residual current detection and the control pilot monitoring. In case of failure of the auxiliary supply the error condition is taken and the EVSE is de-energized automatically. Thus the system is intrinsically safe. There is no difference concerning this matter to a RCD type B. The DC fault detection is also depending on voltage in this safety device.

4 Advantages of the alternative RCD method

The above described fault current detection method has some advantages. The existing charging system can be extended by a further safety precaution without great effort. Manufacturers of the vehicles may choose on their own the charging topology and the necessary safety precautions. An adjustment of the charging stations' protection functions is not required for country-specific and future security requirements. It is sufficient to integrate them into a car. This control pilot protection system allows to switch off the EVSE in a sufficiently short time period in both cases, DC content in the leakage current, as well as for isolation. In contrast to a protection system, which the contactor has integrated in the vehicle, also the charging cable is de-energized immediately. Furthermore the tripping of the protective device requires no manual reset by a technician, like a classical RCD without remote control requires so. The method is in contrast to an RCD type B very cheap. Financial savings by a factor of 20-50 are realistic and offer a comparable security level to a RCD of type B.

The pilot control monitoring system in the EVSE may be integrated by an auxiliary module at the current status, to which both, the pilot wire and the control line of the charging contactor are connected. The circuitry can also be integrated into a charging station controller. If a software implementation can be standardized, an adaptation of the existing firmware of charging controllers is conceivable.

It is possible to replace the RCD type A completely by this alternative protection system. Therefore the RCD in the EVSE would be replaced by a summation current transformer and could be integrated into the protection system. The error detection could drive the load contactor directly. The system would have the same properties as the error detection in the vehicle and thus it also would be intrinsically safe.

5 Conclusion

A RCD of at least Type A is required at charging mode 1 by standard IEC 61851-1. The manufactures should ensure an elimination of DC components for that one phase charging mode. It should allow using almost every plug for charging EVs. In contrast to charging mode 1 a control pilot is used in mode 2 and 3. In these modes a DC component in the fault current should also be avoided. However by using a three-phase bridge DC components in the fault current are more likely to occur due to the B6 rectifier in the input circuit.

For charging mode 2 and 3 an alternative method for residual current detection and cut off was shown. It can be used for all possible rectifier circuits. The required fault detection mechanism can be modified for a specific topology. However, the proposed principle is not standard compliant. It has to be examined as far as the proposed method provides the same security level as a RCD of type B or B+.

A residual current device has to include supervising and protection of the vehicle, the charging connection and also the charging cable. Therefore a method of monitoring the protective earth is provided in IEC 61851-21. In case of an interruption or an increased resistant of the protective earth the EVSE has to be disconnected.

Besides the mentioned DC components in the fault current frequencies components higher than the line frequency can occur. In this case the protection device has to operate without any restrictions and has to detect it reliably.

The examinations have been done at the test facility at TU Dortmund. It allows investigating charging devices in terms of different power grid situations.

Acknowledgments

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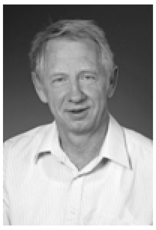
Authors

Christoph Aldejohann received the diploma degree in Electrical Engineering in 2012 at TU Dortmund University, Germany. He is currently working toward the doctor of engineering degree in the department of Electrical Engineering at the TU Dortmund. His research interests are in the field of power grid perturbations, power electronics, power quality and electric mobility.



Willi Horenkamp was the head of the electro technical laboratory at the institute of energy systems, energy efficiency and energy economics at the TU Dortmund. His research interests are the integration of decentralized energy conversion systems, smart Metering, power quality and electric mobility. Membership in national Standardising committees

Dr. Jan Fritz Rettberg received a doctor's degree in technology and innovation management at TU Dortmund University. Afterwards he joined the ie³ Institute of Energy Systems, Energy Efficiency and Energy Economics as executive of the Northrhine-Westphalian Competence Center for E-Mobility, Infrastructure and Power Grids at TU Dortmund University. Besides other projects with a number of industrial partners he directs the main project of the Competence Center to establish a technology and testing platform for interoperable e-mobility, infrastructure and grids (TIE-IN).

Christian Rehtanz, received his diploma degree in Electrical Engineering in 1994 and his Ph.D. in 1997 at the TU Dortmund Univ., Germany. From 2000 he was with ABB Corporate Research, Switzerland and from 2003 Head of Technology for the global ABB business area Power Systems. From 2005 he was Director of ABB Corporate Research in China. From 2007 he is professor and head of institute of energy systems, energy efficiency and energy economics at the TU Dortmund Univ. His research activities include the network integration of new technologies like HVDC, FACTS, storages and electric vehicles.