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EVIAN

Electric Vehicle Intelligent Charging Technology R&D Combined with Electricity Network Adaptation and Battery Lifetime Factors

Technical Report

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Abbreviations

AC	Alternating Current
DC	Direct Current
EV	Electric Vehicle
EVIAN	Electric Vehicle Intelligent Charging Technology R&D Combined with Electricity Network Adaptation and Battery Lifetime Factors
EVSE	Electric Vehicle Supply Equipment
NERC	North American Electric Reliability Corporation
RMS	Root Mean Square

Nomenclatures

Symbol	Unit	Description
f	Hz	Current supply frequency
P	W	Active power
Q	var	Reactive Power
U	V	Current supply voltage
U_N	V	Nominal voltage
U_C	V	Supply voltage agreed between the grid operator and the grid user
$\cos(\varphi)$	-	Power factor

Preamble

This technical report is an outcome of the EVIAN-Project funded by the German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung - BMBF)

The aim of project EVIAN (Electric Vehicle Intelligent Charging Technology R&D Combined with Electricity Network Adaptation and Battery Lifetime Factors) is to intelligently integrate charging systems or electric vehicles with energy recovery into the power line. The requirements for the power grid and the connected vehicle battery must be determined and taken into account. In order to be able to feed energy back into the grid, information must be exchanged and communicated between the vehicle, the charging station and the grid operator. This project identifies the parameters necessary to communicate such information between the participating systems. Therefore, a communication strategy is developed which takes into consideration the existing standards and protocols. In the case of alternating current (AC) feedback from the electric vehicle to the grid, the parameters related to the network quality are essential but not yet defined such as regenerative feedback which could be used for local reactive power compensation. Another aspect of the communication strategy arises as soon as the car can communicate with the charging stations on either a wired or a wireless physical layer. The transition from wireless to wired communication needs to be designed and implemented. With the additional data and information of such a combined communication, the grid operator can better predict, plan and stabilize the load, as the energy required by the electric vehicles within a specific area can be ahead and more accurately estimated.

1 Introduction

The technology of wired charging of electric vehicles is described in various national and international standards, e.g. IEC 61851 [1], GB/T 18487 [2], SAE J1772 [3]. On the other hand, the standards do not describe or fully investigate topics such the energy feedback into the grid, the wireless (inductive) charging and the transition from wireless to wired communication when the electric vehicle arrives at the charging point.

One aspect to reach the aim of this project is to define the communication between electric vehicle (EV) and electric vehicle supply equipment (EVSE) for energy feedback of AC current.

The following results are based on the project EVIAN outcomes and the summary of several students' term papers [22] [23].

2 Grid and Feedback Parameters

The grid and feedback parameters for bidirectional AC charging are described in this chapter.

First standards about the electricity feed-in and grid quality are described. The EVIAN project scope is to investigate China, Germany and USA grid quality and requirements for electricity feedback. The important parameters are derived from these standards and transferred to an information exchange matrix that represents the communication between the electric vehicle and the charging station. Three different communication use-cases are identified and used as possible options for deriving the parameters. The necessary difference in the information flow is shown based on these options.

The list of standards is presented in the following section 2.1. The standards are not mentioned separately in sections 2.2 to 2.9.

2.1 List of Standards

Table 1 contains the standards that apply to the different markets.

Table 1: List of Standards

Property	China	Germany	USA
Nominal voltage	GB/T 156-2007 [4]	(DIN) EN 50160 [13] (DIN) EN 50549-1 [14] VDE AR-N 4105 [16]	ANSI C84.1 [18]
Voltage deviation	GB/T 12325-2008 [5]		
Nominal frequency / frequency deviation	GB/T 15945-2008 [9] NEA Nr. 211 [12]		ANSI C84.1 [18] IEEE 1547-2018 [20]
Effective power regulation	(information is unavailable)		IEEE 1547-2018 [20] NERC PRC-024-2 [21] (regional diff.)
Reactive power regulation	GB/T 33593-2017 [11]	(DIN) EN 50549-1 [14] VDE AR-N 4105 [16] VDE AR-N 4100 [17]	IEEE 1547-2018 [20] (regional diff.)
Voltage imbalance	GB/T 15543-2008 [8]	(DIN) EN 50160 [13] VDE-AR-N 4100 [17]	(information is unavailable)

Property	China	Germany	USA
Harmonics	GB/T 14549-1993 [7]	(DIN) EN 61000 [15]	IEEE 519-2014 [19]
Interharmonic frequencies	GB/T 24337-2009 [10]	(in discussion)	(information is unavailable)
Fast voltage change	GB/T 12326-2008 [6]	(DIN) EN 61000 [15] (limits) DIN EN 50160 [13] (definition)	IEEE 1547-2018 [20]

2.2 Nominal Voltage / Voltage Deviation

The following values and permissible deviations apply to the nominal voltages in the countries described in Table 2.

Table 2: Voltage Limits

China	Germany	USA
220 V +7% / -10% (1-phase)	230/400 V ±5% (fast change)	120 V ±5%
380 V ±7% (3-phase)	230/400 V ±10% (slow change)	
(exceptions for remote areas)	230/400 V +10% / -15% (remote areas)	

In Germany, the guideline for voltage dips (≤ 1 min, dip 10 to 60%) is a few 10 to 100 per year, for short supply interruptions (≤ 3 min, voltage < 1% U_C) a few 10 to several 100 per year and for random long supply interruptions (> 3 min, voltage < 1% U_C) some 10 to 50 per year.

According to DIN EN 50549-1, the generating plant must be able to operate continuously when the voltage at the grid connection point is in the range between 85 % U_N and 110 % U_N. Outside this range, the immunity limits specified in DIN EN 50549-1 for the passage of undervoltage events and overvoltage events must be complied with.

2.3 Nominal Frequency / Frequency Deviation

The following values and permissible deviations apply to the nominal frequencies in the countries described in Table 3.

Table 3: Frequency Limits

China	Germany	USA
50 Hz ±0,2 Hz 50 Hz ±0,5 Hz (remote areas) (both for 99.5% of the time)	In general: 50 Hz ±1% (49,5 Hz … 50,5 Hz) (during 99.5% of a year) 50 Hz +4% / -6% (47 Hz … 52 Hz) (for 100% of the time) Grids without a synchronous connection to an interconnected power grid: 50 Hz ±2% (49 Hz … 51 Hz) (during 95% of a week) 50 Hz ±15% (42.5 Hz … 57.5 Hz) (for 100% of the time)	According to ANSI C81.4: 60 Hz ≈ ±1% (59,3 Hz … 60,5 Hz) (implementation within the NERC grid varies greatly) According to IEEE 1547-2018, the operating range of power generating systems is: 58.8 Hz ≤ f ≤ 61.2 Hz.

According to DIN EN 50549-1, generation plants in Germany must be able to operate continuously in the frequency range between 49 and 51 Hz. In the frequency range from 47 Hz to 52 Hz, the generation system should be able to operate until the decoupling protection is triggered. Therefore, the generating plant must be capable of operating at the frequency ranges and duration specified as minimum requirements in the standard.

2.4 Effective Power Regulation

The following limits apply to the effective power regulation in the countries described in Table 4.

Table 4: Limits for Effective Power Regulation

China	Germany	USA
(Information is unavailable)	Outside the limits of 47.5 Hz < f < 51.5 Hz: The system has to be switched off within 200ms. 50.2 Hz < f < 51.5 Hz: Adjustment of the effective power of the system with a gradient of 40% per Hertz.	Limits to immediate shutdown vary between NERC associations. 61.2 Hz < f ≤ 61.8 Hz as well as 57.0 Hz ≤ f < 58.8 Hz: Adjustment of the effective power of the system based on the equations given in IEEE 1547-2018.

According to DIN EN 50549-1, a generating plant has to be robust against frequency drop at the grid connection point and may reduce the maximum active power as little as possible. The permissible active power adjustment due to an underfrequency is defined in this standard. In the event of overfrequency, the active power must be adjusted in accordance with the requirements of the standard.

2.5 Reactive Power Regulation

The following limits apply to the reactive power regulation in the countries described in Table 5.

Table 5: Limits for Reactive Power Regulation

China	Germany	USA
The power factor of asynchronous generators must be adjustable in the range from 0.98 (capacitive) to 0.98 (inductive). The power factor of synchronous generators must be adjustable in the range from 0.95 (capacitive) to 0.95 (inductive).	Depending on the system power and whether it is a storage or generator: cos (φ) fixed by the network operator, cos (φ) (P) - characteristic, Q (U) - characteristic	cos (φ) fixed by the network operator, cos (φ) (P) - characteristic, Q (U) - characteristic

In Germany and according to DIN EN 50549-1, generation systems must generally be capable of operating with effective factors ranging from effective factor = 0.90 underexcited to effective factor = 0.90 overexcited.

In the case of different generation technologies with different requirements in a generation plant, each unit must provide voltage support through reactive power according to its specific technology. Compensation by one technology to meet the general requirements of the plant is not expected.

For additional grid support, an optional extended capacity of reactive power may be supplied by the generating plant if this has been agreed between the distribution system operator and the plant operator.

2.6 Voltage Imbalance

The following limits apply to the voltage imbalance in the countries described in Table 6.

Table 6: Limits for Voltage Imbalance

China	Germany	USA
Under normal operating conditions, the asymmetry factor of the negative sequence voltage should not exceed 2% and should not exceed 4% in the temporary time range. For each user connected to the common connection point, the unbalance factor of the negative sequence voltage of the point must generally be 1.3% and temporarily not more than 2.6%.	The voltage imbalance may usually be 2%, in special cases up to 3%. According to VDE-AR-N 4100, a power difference of the three outer conductors of a maximum of 4.6 kVA must not be exceeded.	(Information is unavailable)

2.7 Harmonics

The following limits apply to the harmonics in the countries described in Table 7.

Table 7: Limits for Harmonics

China	Germany	USA
The permissible values for harmonics can be found in the specifications of the GB/T 14549-1993 standard.	In (DIN) EN 61000 the permissible harmonics are shown in a table and differ depending on the rated current (devices up to 16 A rated current and devices with more than 16 A up to 75 A rated current).	In IEEE std 519-2014 the permissible harmonics are shown in a table.

2.8 Interharmonic Frequencies

The following limits apply to the interharmonic frequencies in the countries described in Table 8.

Table 8: Limits for Interharmonic Frequencies

China	Germany	USA
The permissible values for interharmonic frequencies can be found in the specifications of the GB/T 24337-2009 standard.	Values for the interharmonic frequencies are currently being discussed.	(Information is unavailable)

2.9 Fast Voltage Changes

The following limits apply to fast voltage changes in the countries described in Table 9.

Table 9: Limits for Fast Voltage Changes

China	Germany	USA
The permissible values for voltage fluctuations depend on the frequency of occurrence and are described in the GB/T 156-2007 standard.	Fast voltage changes must not exceed a value of 3% in relation to the rated voltage.	The voltage must not exceed a change of 3% of the supply voltage per second.

(DIN) EN 50160 defines a rapid voltage change as "a single rapid change in the RMS value of a voltage between two successive voltage values with a specific but not fixed duration".

3 Parameters to Exchange Between EV and EVSE

In this chapter the derived parameters that have to be exchanged between EV and EVSE in order to enable high-quality AC feedback are described.

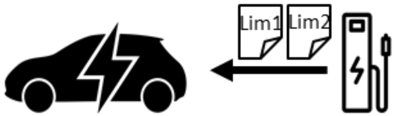
3.1 Communication Strategies

After consulting with experts in this field including some of those in the ISO 15118 committee; three communication strategies are defined for the communication of the feedback parameters:

- Communication Strategy 1: Transmission of a Country/State Identifier
    - EVs have the feedback parameters stored
    - Many different sets of parameters in Europe
    - Other parameter sets for China and USA
- Communication Strategy 2: static Transmission of feedback parameters
    - EVSE transmits feedback/grid parameters to EV before energy transfer starts
- Communication Strategy 3: Dynamic Transmission of Feedback Parameters
    - Dynamic transmission of all feedback/grid parameters between EV and EVSE.

The pros and cons of each strategy are summarized in Table 10.

Table 10: Communication Strategies

Proposal	Pros	Cons	
Use-Case 1: Transmission of a Country/State Identifier	• Simple communication between EV and EVSE	• Change in parameters requires controller update • No dynamic adaption to current state of the grid possible	
Use-Case 2: Static Transmission of Feedback Parameters	• Change in parameters does not require a controller update	• No dynamic adaption to current state of the grid possible	
Use-Case 3: Dynamic Transmission of Feedback Parameters	• Change in parameters does not require a controller update • Dynamic adaption to current state of the grid possible	• Complex communication between EV and EVSE necessary • Communication between EVSE and grid operator may be necessary	

3.2 Communication Matrices

The matrices described in Table 11 contain the parameters that have to be exchanged between EV and EVSE for energy feedback in general and for either one of the three Communication Strategies.

Table 11: Communication Matrices

General Parameters			
Parameter	**Unit**	**Direction EV ←→ EVSE**	**once (1) periodic (∞)**
Energy Feedback y/n	boolean	→	1
Departure time	timestamp	→	1
Grid parameters ok	boolean	←	∞
Requested energy for charging	kWh	→	∞
Requested energy for feedback	kWh	←	∞
Available energy for feedback	kWh	→	∞
Available energy for charging	kWh	←	∞
Requested power for charging[1]	kW	→	∞
Requested power for feedback[1]	kW	←	∞
Available power for feedback	kW	→	∞
Available power for charging	kW	←	∞
Available reactive power[2]	kvar	→	∞
Control range cos(φ)	min/max or characteristic	→	1
Max DC injection[3]	-		

Communication Strategy 1: Grid parameters stored in EVs controller			
Parameter	**Unit**	**Direction EV ←→ EVSE**	**once (1) periodic (∞)**
Country code	string	←	1

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[1] Recommended as a profile.

[2] For requested reactive power see communication strategies below.

[3] We recommend to standardize the limit globally instead of transmitting it.

Communication Strategy 2: Static transmission of grid parameters

Parameter	**Unit**	**Direction EV ←→ EVSE**	**once (1) periodic (∞)**
Min/Max supply voltage	V	←	1
Min/Max supply frequency	Hz	←	1
Max harmonic voltages	list of limits	←	1
Max harmonic currents	list of limits	←	1
Max power difference outer conductors	kVA	←	1
(Effective power adjustment)[4]	characteristic	←	1
Fixed required cos (φ) [5] [6]	1	←	1
Q(U) for cos (φ) [5] [6]	characteristic		

Communication Strategy 3: Periodic transmission of grid parameters

Parameter	**Unit**	**Direction EV ←→ EVSE**	**once (1) periodic (∞)**
Min/Max supply voltage	V	←	1
Min/Max supply frequency	Hz	←	1
Max harmonic voltages	list of limits	←	1
Max harmonic currents	list of limits	←	1
Requested current outer conductor L1	A	←	∞
Requested current outer conductor L2	A	←	∞
Requested current outer conductor L3	A	←	∞
Requested cos(φ) [5]	1	←	∞
Requested reactive power [5]	kvar		

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[4] Not necessary if the charging station requests power for feedback (see general parameters above).

[5] either/or

[6] Germany: Min/max values of cos (φ) have to be observed for energy consumption as well.

4 Conclusion

There are different standards around the world for feeding the energy back to the grid. Those standards must be applied and taken into consideration when feeding back the energy from electric vehicles. However, they always describe the same physical quantities. It can be seen from the communication strategies that the more dynamic and complex the communication, the greater the possibilities of influencing the grid. We prefer communication strategy 3 because it offers maximum flexibility. It allows to react to new requirements and business cases in the future and it provides the best opportunity to stabilize the grid. In order to realize the full set of features of strategy 3 in the future, the charging station has to be capable of communicating with the grid operator.

References

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[4] Standard voltages (GB/T 156-2007)

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