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Fast charging emulation system for electric vehicles

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Abstract

Current implantation of electric mobility systems requires the use of fast charge stations. It is necessary to establish a methodology and some test standards in order to characterize the quality of the energy transferred by these stations to the vehicle, and the impact caused by them in the supply grid. To achieve this goal, a methodology is proposed, using a flexible power electronics system which allows simulating the behavior of an electric vehicle (EV) while it is being charged. By using this system it is possible to verify the proper operation of the charge equipment, facing it to different charge profiles during an unlimited number of operations, in a safe way, and not having the need for an actual vehicle.

Keywords: *EV quick charge, e-mobility, electric vehicle emulator, dc fast charge impact in electricity grid*

1 Introduction

Consolidation of EV as a means of transportation requires the installation of fast charge stations which allow performing emergency charges and thus increasing the current range of those vehicles. This chargers supply the batteries in the EV with DC current at a high power level. The paper focuses on charges classified as 'DC fast chargers' or QC (UNE-EN 61851-23). Power range for these systems goes from 20 to 55 kW, making it possible to perform a full charge in a short time, in the range of tenths of minutes.

However, large intermittent consumption may have a significant negative impact in the supply grid, as reflected in [1] [2]. It is necessary to analyze the quality of this equipment, and to study the possibilities of associating additional systems which soften consumption peaks or reduce grid impact [3] [4] [5]. A thorough analysis of a specific charger requires the use of actual EVs, which is a non-ideal situation, since the specific curve of the battery in the vehicle imposes restrictions in charge profile and duration.

2 EVE: Electrical vehicle Emulator

The *Electrical Vehicle Emulator, or EVE,* is a power electronics system whose main function is emulating the consumption created by the charge of the batteries in an EV, in both the charger and the electric network. The EVE makes it possible to visualize the power transfer in the charge point, verifying the system quality, reliability and safety.

Figure 1 shows a standard charge characteristic of a commercial EV model.

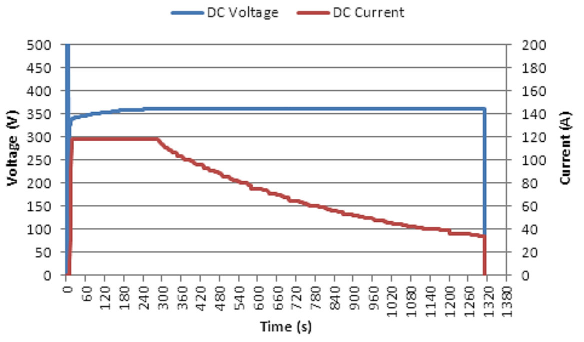

Fig. 1 Standard VE charge curve

As a general rule, voltage range in currently available compact EVs goes from 350 to 400 V, and it never exceeds 500 V. However, battery maximum current rate depends on their technology and configuration. That is the reason why the used charge protocol establishes the maximum value for this parameter. This paper adopts the Japanese fast charge protocol CHAdeMO as reference [5], which specifies a range of 50 to 500 V for battery voltage, and current up to 125 A. This protocol covers a wide operational range, from low to high power (62,5kW), and it is desirable to have a system capable of testing the charger within all the operating range established by this standard.

EVE allow testing QC under different battery characteristic curves, emulating the operation of diverse commercial models. This prototype is capable of operating at fixed or variable power during long time periods, in extreme conditions outside the usual range of operation.

Thus, the EVE enables a most exhaustive characterization of fast charge systems, making it possible to perform comparisons between two chargers, or to a predefined standard. Moreover, it is possible to perform validations of the correct operation of the communication protocol between the vehicle and the charging equipment. Figure 2 shows a general view of the developed EVE system.

Fig. 2 EVE general view

2.1 EVE processing unit

The control of the power electronic stages, the management of the EV charge protocol, and the Exchange of information with the Human Machine Interface (HMI) has been implemented in a Digital Signal Processor (DSP), a high performance controller. Figure 3 shows a simplified scheme with the main functional modules of the system.

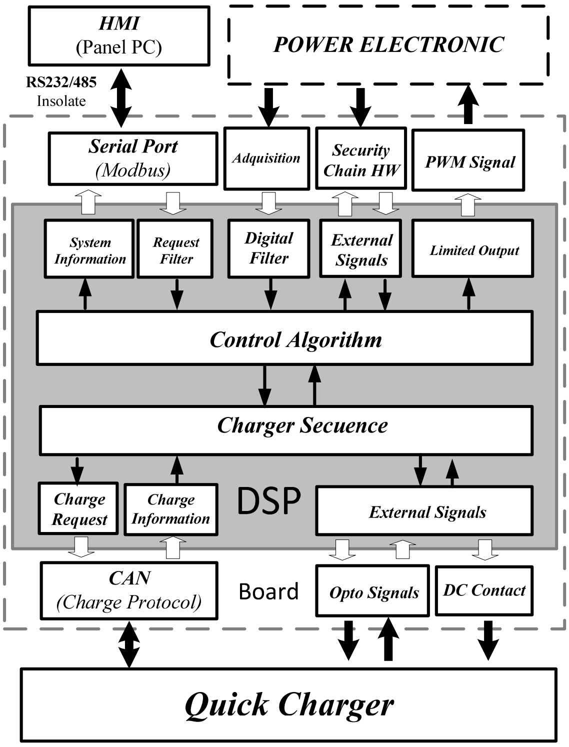

Fig. 3 EVE block diagram

The gray square contains the functional blocks implemented into the DSP, and the dashed contour represents the system control board.

The system operates as follows: using the HMI the user introduces the main parameters, the charge characteristic curve, and confirms the start of the charge process.

The HMI transfers the charge reference parameters to the DPS unit. Next, it is verified whether the EVSE is capable of performing the charge in accordance with the reference values set in the EV. After a successful verification, the charge process starts, and during this period, the HMI allows the emulation of the behavior of some alarms and signals monitored by the QC.

2.2 Power electronics

The power electronic stages used inside the EVE make it possible to dynamically set the values of desired voltage (V_{DC}) and current (I_{DC}) desired in the input of the system. The absorbed energy is dissipated in a set of resistors, providing total flexibility to act as an independently variable load.

The use of storage systems is not suitable, since they impose a fixed operating voltage point, hindering significant voltage fluctuations. The use of a power electronics topology allowing regeneration prevents the analysis of the QC impact on the grid if there is a single connection point [6]. Figure 4 shows the general power scheme of the EVE.

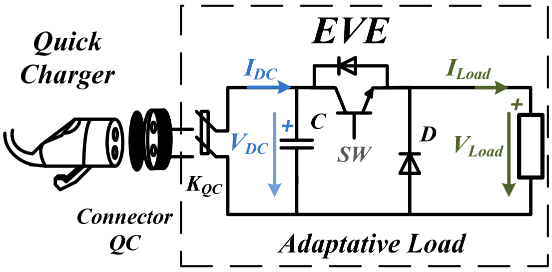

Fig. 4 EVE power scheme

A capacitor set has been included at the input of the system, decoupling the absorbed current from the one sent to the load. Capacitor pre-charge is performed using the grid, allowing the simulation of different initial charge conditions.

The solid state device (SW) is in charge of regulating the bus discharge to keep the desired voltage level, sending the energy to the load. The desired wide operational range of the system: from 0 V to 600 V and from 0 A to 150 A, makes it necessary to establish an adaptive charge, which has been implemented controlling the SW duty cycle.

The most restrictive value for this charge corresponds to the lowest voltage and highest current point, requiring a very large dissipation capability, and thus, a significant volume for the load. Besides, it is necessary to favor continuous conduction, avoiding pulsating current as long as possible [7].

2.3 Control algorithm

The control of the system consists in the regulation of bus voltage, taking as reference the V_{DC} value set by the HMI. Extracted energy will be determined by the SW duty cycle, always ensuring the circulation of I_{DC}, also a reference set by the *HMI*. This switch operates at a frequency of tenths of kilohertz.

2.4 HMI

The main goal of the EVE is allowing qualified personnel to perform behavior and operation tests of the QC, ensuring the integrity of both systems.

As previously noticed, the EVE includes a touchscreen interface that allows the manual supervision of the power transfer and the behavior of the system, making it possible to simulate any failure considered in the CHAdeMO protocol, for instance, battery failure, such as overvoltage, overcurrent, overheating, or the disengagement of the hand brake during the charge process. The generation of this fault signals makes it possible to verify that the QC complies with the technical safety specifications imposed by the charge protocol.

The EVE accepts files containing the characteristic charge curve to be tested, and generates other files that include those magnitudes and some other significant data recorded during the test.

Figure 7 shows the EVE user interface. It provides the concatenation of test for a charge curve, for different random State of Charge (SOC) points.

V Setpoint 351,4
V Measure 351,3
V CAN 0
I Setpoint 20,925
I Measure 0,0473
I CAN 0
4
Vbus sp 55
Ibus sp 2
Capacity sp 50
1 Sheet
C:\CHARGE_CURVE\Peugeot\Peugeot Lion 5min.xls
0 Protocol CHAdeMO
20,9 Initial Current
351, Initial Voltage
0,04 Initial Capacity
05 Time
400 Max battery voltage
375 Target battery voltage
15,6 Total battery capacity
329 Max charging time

Fig. 5 Concatenated charge EVE interface, V and I.

3 Tests and verification

As stated in the introduction, one of the more relevant aspects of the EVE is the ability to perform tests that would not be possible using a conventional vehicle. QC tests can be classified into two groups: the ones analyzing the behavior of the charger regarding the EV, and the ones regarding the grid. Next, an example of each test type is presented. The first one shows a consecutive charge test, and the second one analyzes the charger impact on the grid.

3.1 Consecutive charge test

The proposed example consists in emulating three consecutive charges of a commercial EV. The charge curve was obtained performing measurements on an actual charge of the EV. The charge profile used during the test is introduced in the system using the HMI, figure 5. Figure 6 shows a process of three concatenated charges, in the upper side it can be seen the V_{DC} voltage, reference voltage in red, the EVE voltage in dark blue and the QC voltage in soft blue. In the lower side can be seen de I_{DC} current, reference current in red, EVE current in dark green and QC current in soft green. In the figure, the precharge process is included. Figure 7 shows the absorbed power profile and the corresponding battery charge percentage for the equivalent operation point in the actual model.

The charge has been monitored using a high performance oscilloscope. In figure 8, a complete charge can be observed in the top part of the image, while the bottom part shows the start of the charge process, which is the point of maximum power. Emulated battery voltage is shown in yellow (V_{DC}) and current is represented in purple (I_{DC}). Pulsating voltage in the load is drawn in blue (V_{load}) and current in green (I_{load}).

Figure 9 shows an instant close to the end of the charge process, which implies minimum power. Reduces levels of I_{DC} are observed, which result in minimum duty cycle for the SW (V_{load}) and consequently low load current values.

Figure 10 shows the transition between consecutive charge curves. QC response time to a step current reference change can be obtained from this transition.

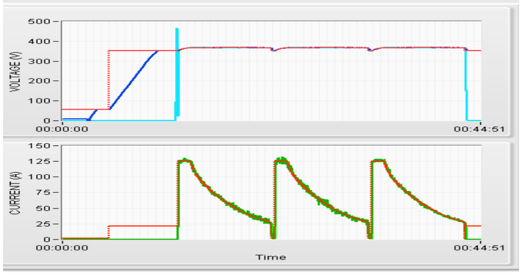

Fig. 6 HMI EVE concatenated charge, V_{DC} & I_{DC}.

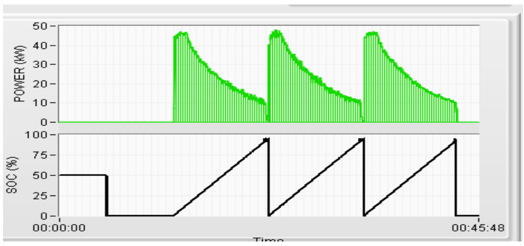

Fig. 7 HMI EVE concatenate charge, Power & SOC

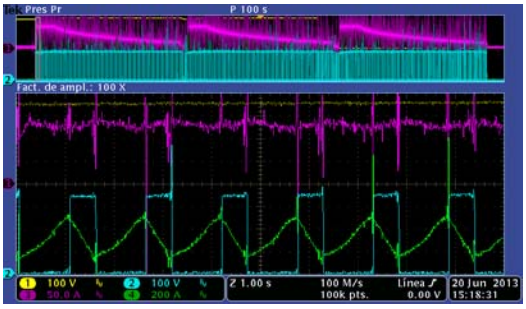

Fig. 8 Zoom V_{DC}=350V and I_{DC} =125A.

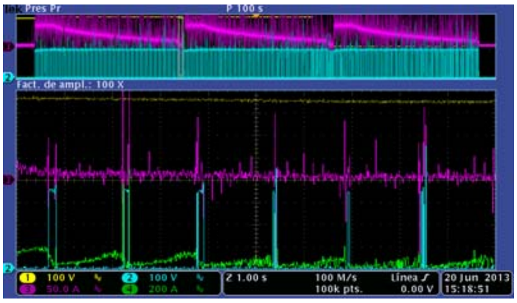

Fig. 9 Zoom V_{DC}=370V and I_{DC} =20A.

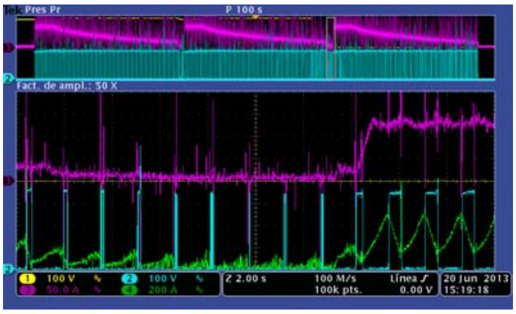

Fig. 10 Current step response zoom.

3.2 Grid impact study

As previously stated, it is important to know the impact of QC on the grid, in their different operational conditions. Table 1 summarizes some of the more relevant parameters that must be analyzed to obtain a proper QC characterization.

Table. 1 Significant grid parameters

Group	Parameters	
Charger output parameters	DC voltage	(4)
	DC current	
	DC power	(1)
Grid quality parameters	AC power	
	AC voltage (phase)	
	AC current (phase)	
	PF (phase)	(2)
	Cos(φ) (phase)	
	Active power (per phase)	
	Reactive power (per phase)	
	Apparent power (per phase)	
	THD i [%]	(3)
	Current harmonics	
	THD v [%]	
	Voltage harmonics	
	Frequency	

Some relevant parameters, such as AC-DC efficiency, power factor (2) (regulated by IEC 61851-23) or harmonic level (3) (EN 61000-3-12), are interesting for the analysis of the QC impact on the grid. It is also necessary to characterize the QC output current (4), measuring key parameters such as maximum ripple, or the response to sudden reference changes, ensuring compliance with the charge protocol used.

By using a data logger connected to the grid and the files generated by the EVE it is possible to perform an efficiency and quality analysis of the charge. The next figures show a fragment of the experimental results obtained during a test. A whole charge using an actual EV has been recorded and, using the obtained data via CAN, the same process has been repeated using the EVE.

Figure 11 presents some of the parameters proposed in the table, and the results obtained during the emulated charge for each magnitude. It shows V_{DC} and I_{DC} on the EV side and the power ($Power_{AC}$), current (I_{RMS}) and RMS voltage (V_{RMS}) on a grid phase (U). EVE emulation error is shown in red in all the figures, representing the accuracy with which the actual commercial EV curve (blue) is replicated by the EVE (purple).

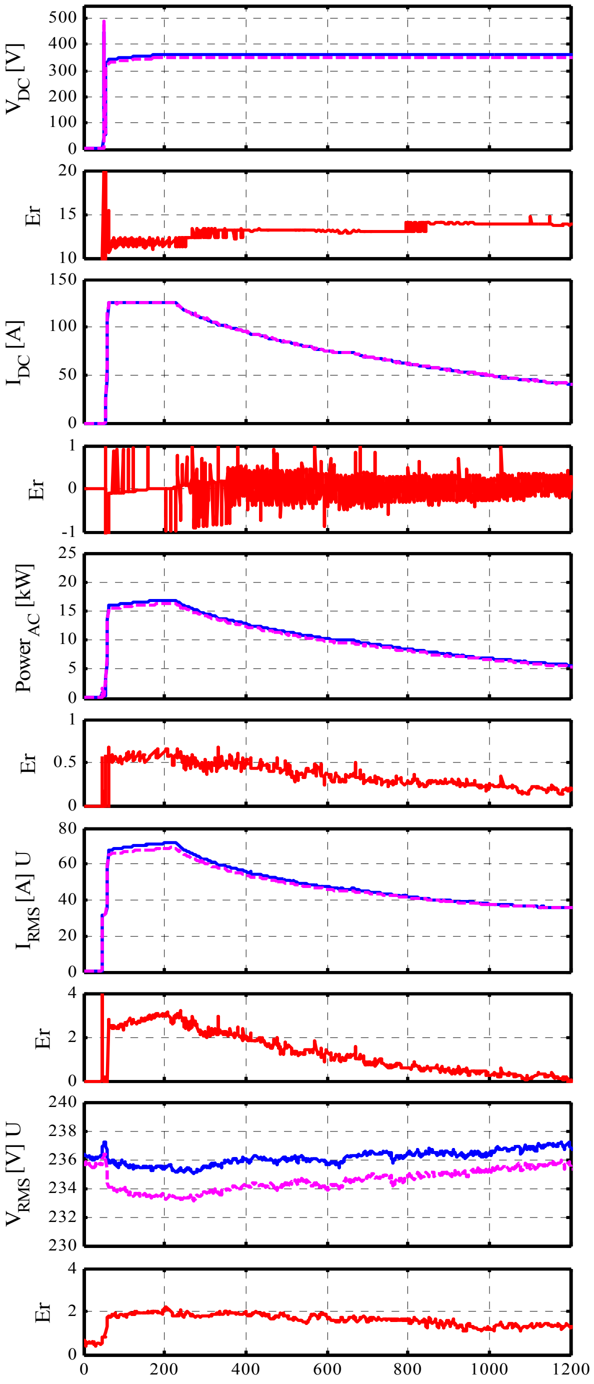

Fig. 11 Comparison of the more relevant magnitudes during the charge of the EV (blue) ant the EVE (purple), and the error (red).

Recap

Considering the need to analyze, verify and certify the quality with which QC transfer power to EV and their impact on the grid, it is insufficient to establish methodologies and standards based on the use of actual EV. CIRCE proposes the use of an Electric Vehicle Emulator, or EVE. Along the paper, the main general design guidelines for the prototype are presented. The prototype makes it possible to perform more exhaustive QC tests, characterizing their behavior in a more concise manner. Finally, two test types are proposed, one for the vehicle side and another one for the grid side, aimed to verifying its operation and its validity within the scope of application of the proposed solution.

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