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An automatic test system for the characterization of quick charging stations for electric vehicles

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Abstract **– In the latest years, policies toward the diffusion of electric vehicles received a lot of attention in many countries. Important efforts of researchers and engineers are focused on the development of high performance quick charging stations, that allow a significant reduction of charging time without negative effects on the battery systems. In this paper a suitable automatic test system is proposed. It makes possible the experimental characterization in realistic conditions of a quick charging system complying with CHAdeMO [1] protocol. In the paper test system features are described and some experimental results presented and discussed.**

I. INTRODUCTION

The experimental characterization of static converters is a fundamental step needed for validating their performance and comparing experimental results with design specs and simulation data. As an example, by means of an exhaustive series of tests it is possible to draw diagrams describing the converters behavior under realistic conditions, in order to identify possible critical components[1-3].

In this paper, we present an automatic test system for the characterization of quick charging stations for commercial electric vehicles, based on the CHAdeMO Standard requirements [4-6]. Its implementation is part of a Research Project conducted by the University of L'Aquila (Department of Industrial and Information Engineering and Economics) in cooperation with the ENEA, the Italian National Agency for New Technologies, Energy and Sustainable Economic Development.

The proposed system is an automatic digital measurement station [7-10] based on a PC equipped with a multifunction DAQ board and some transduction units for conditioning voltage and current signals. A data-logging system has been also included for the simultaneous measurement of temperatures. An ad hoc program has been developed in the NI LabVIEW environment to manage the system and perform data acquisition and processing.

The test system has been applied for an exhaustive performance evaluation of a CHAdeMO (CHArge de MOve) quick charging station for commercial electric vehicles.

The paper is organized as follows. Section II reports a brief description of CHAdeMO standard; the automatic test system is described in Section III; Section IV briefly describes features of both the quick charger station under test and an electric vehicle adopted as electric load. Section V illustrates the testing procedures and Section VI reports some experimental results. Finally some concluding remarks and suggestions for future research are examined in Section VII.

II. THE CHADEMO STANDARD

One of the major concerns with quick chargers is related to their contribution to battery deterioration and capacity decrease [4], mainly because of possible both high voltage and temperature values that can be reached during the charging process, that produce an acceleration of electrodes' decay.

The most critical parameter to be checked is the battery temperature, that could increase due to internal power losses operating with a high charging current. Recent electric vehicles have been equipped with a battery management system, that monitors the parameters of each battery cell, in addition to the overall battery, with the aim of preventing these problems. Basically, charging unit and battery management system communicate during the charging process in order to set appropriate voltage level and current intensity. These values are obtained starting from the battery actual characteristics and their residual charge conditions, in order to obtain the fastest charging speed by assuring the necessary safety level.

According to CHAdeMO standard a quick charger

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performs the charging by controlling the supplied current during all the process. It receives information about the battery initial conditions from electric vehicle via CAN bus and sets internal parameter for an optimal fast charging. The CHAdeMO is a Japanese Industrial Standard (JIS) technical standard; the principal European (IEC) standards concerning this protocol and the charging of electric vehicles are: IEC EN 61851-1, 61851-21, 61851-22, 62196, 61439-7 (draft) and EN 60364-7-722 [11-16].

The CHAdeMO standard defines only the interface geometry, without any additional specification for the AC/DC conversion circuits and performance, that can be freely defined by manufacturers [4, 5]. From the electrical point of view, a quick charger implementing the CHAdeMO protocol can supply up to 500 V and 150 A, by means of a standard JARI [6] connector, whose interface is depicted in Fig.1. The interface pin-out is described in Table 1.

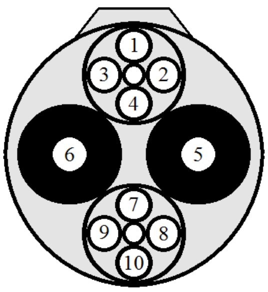

Fig.1.CHAdeMO JARI D connector interface

Table 1. CHAdeMO connector pin-out description

Pin	Description
1	Groundwire
2	Charger start/stop 1
3	-
4	Charging enable/disable
5	Power supply +
6	Power supply -
7	Connection check
8	CAN bus high
9	CAN bus low
10	Charger start/stop 2

III. THE AUTOMATIC TEST SYSTEM

Basic measurement quantities for characterizing a battery charging stations are voltage, current and most of all the power (and energy). Today's commercially available power measuring instruments present a variety of sizes and configurations because of the different application area and customer requirements. To be applied to testing a quick charging system, a measuring system should allow the users to perform multichannel data acquisition for extended periods of time, both in stationary and dynamic conditions.

Our goal was the implementation of a cost-effective and flexible digital system with suitable data processing and user interface. As shown in the block diagram of Fig. 2, the system hardware consists of a PC, linked via USB to a data acquisition (DAQ) board. Voltage and current transduction are performed by Hall-effect transducers [17]. Temperatures are measured by a data logger.

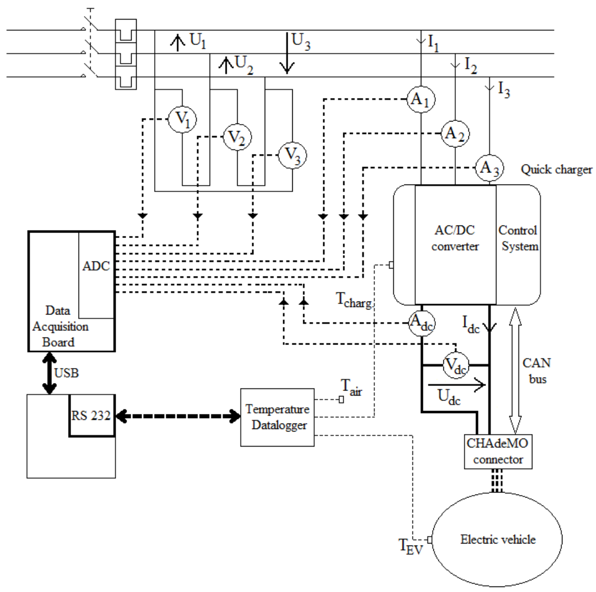

Fig.2. Block diagram of the automatic test system.

The host PC controls the acquisition task, processes data and stores them for further off-line analyses. The main features of the DAQ NI USB-6255 board are: i) 40 differential analog input channels with 16-bit resolution; ii) maximum sampling frequency of 1.25 MS/s single channel, 750 kS/s multi-channel (aggregate); iii) input ranges ±10, ±5, ±2, ±1, ±0.5, ±0.2 and ±0.1 V; iv) timing accuracy 50 ppm of sample rate; v) CMRR (DC to 60 Hz) 100 dB; vi) crosstalk (at 100 kHz), adjacent channels, -75 dB; vii) crosstalk (at 100 kHz), non-adjacent channels, -90 dB; ix) USB communication.

For the transduction of the input AC voltage waveforms, a set of three LEM LV-100 voltage transducers has been adopted; they guarantee a frequency bandwidth of DC-150 kHz, an accuracy of 0.7 % @ 25 °C, a response time of 20-100 µS and an insulation level up to 6 kVrms for 1 min. @ 50 Hz. For the measurement of output DC voltage, a LEM CV 350 voltage transducer has been chosen; it can measure up to +/- 500 V, with a bandwidth of DC-300 kHz, an accuracy of 0.2% @ 25 °C, a response time 0.3 μs, and an insulation level up to 6 kVrms for 1 min. @ 50 Hz. The transduction of both input and output current waveforms has been carried out by means of four LEM LT 300, whose main features are: i) measuring range +/- 500 A; ii) bandwidth of DC-150 kHz; iii) accuracy of 0.5% @ 25 °C, iv) response time < 1 μs.

A Fluke Hydra 2625A data logger has been used to acquire the temperatures reached by both quick charger and electric vehicle; the ambient air temperature has been also measured. Three J thermocouples have adopted, guaranteeing a 0.1 °C resolution and +/-0.39 °C accuracy.

The measurement software has been developed in the NI LabVIEW Environment; it performs a continuous data acquisition @ 20480 Sample/s on 8 differential channels, according to the requirements of IEC Standards [18-23]; the monitoring of the temperatures is performed @ 0.1 Sample/s via RS 232 with the data logger. The data acquisition duration can reach 1 hour, so the generated TDMS file size, containing the acquired voltage and current waveform, can be up to 4 Gbyte. The acquired data are processed offline; the measured trends concern: i) input AC active power; ii) input AC apparent power; iii) input AC power factor; iv) input AC V_{THD}%; v) input AC I_{THD}%; vi) input 3-phase voltage harmonics; vii) input 3-phase current harmonics; viii) output DC voltage; ix) output DC current; x) output DC power; xi) conversion efficiency; xi) supplied energy; xii) temperatures.

IV. THE QUICK CHARGER UNDER TEST

The quick charger under test is the model EQC – 50 Endesa by Circutor [24] (Fig. 3); its main features are: i) input voltage of 400 Vrms, three phase plus neutral; ii) rated input power of 77 kVA; iii) input frequency of 50/60 Hz; iv) maximum output power in DC mode of 50 kW; v) maximum output DC voltage of 500 V; vi) maximum output DC current of 125 A; vi) maximum output power in AC mode of 22 kW; vii) maximum output AC voltage of 400 Vrms; viii) maximum output AC current of 32 Arms; ix) class B accuracy according to EN 50470-3 [25] for the active energy measurement; x) class 2 accuracy according to EN 62053-23 [26] for the reactive energy measurement; xi) optional harmonics filter for 5^{th} and 7^{th} components; xii) CHAdeMO protocol compliance.

The quick charger has been tested by performing a set of charging procedures on a commercial electric vehicle, a Nissan Leaf [27] characterized by the following main features: i) 24 kWh lithium-ion (Li-ion) battery; ii) 80 kW AC synchronous electric motor; iii) maximum power of 80 kW @ 3000 rpm; iv) maximum torque of 254 Nm; v) maximum speed of 144 km/h; vi) city MPGe 126, highway MPGe 101 [25] ; vii) zero tailpipe (exhaust) emissions.

Fig.3.The testing system, the quick charger and the electric vehicle during a test in the ENEA Laboratory.

V. THE TESTING PROCEDURES

Three typologies of testing have been implemented for the quick charger experimental characterization. As a first step, the performance measurement in steady state conditions has been carried out, with the quick charger supplying constant voltage and current values. The measurements have been performed at several battery charge levels, with the aim to evaluate input voltage and current waveform distortions vs the output power.

As a second step, we carried out some tests in dynamic conditions: voltage and current waveforms have been acquired at both constant DC voltage and constant DC current charging conditions. For both these charging methods, particular attention has been given to the acquisition and analysis of voltage and current transient phenomena.

Finally, an overall evaluation of the charging processes in realistic conditions has been implemented, for investigating the behavior of the quick charger in terms of efficiency, voltage and current distortion, harmonics, supplied energy and power, starting from different values of the state of charge of the battery.

VI. THE EXPERIMENTAL RESULTS

The following diagrams depict some experimental results obtained during a charging procedure. The initial state of charge of the Nissan Leaf battery system was 54.9%, while the actual duration of the charging process was 1270 s. The process has been controlled by the CHAdeMO communications between quick charging station and electric vehicle battery management system.

As a first remark, the input AC currents show a high level of harmonic distortion, (Figs. 4, 5). The analysis of the current harmonics lead to the conclusion that the AC/DC converter embedded in the quick charging station under test is a naturally commutated converter. Although this typology of converter is characterized by high reliability and good efficiency (Fig. 9), the impact of the current harmonic components that are injected in the mains could involve several undesired effects. The adoption of suitable filtering units and voltage transformers is highly recommended on the AC side, especially when the quick charging system is installed in power mains characterized by high values of fault loop impedances.

Finally, as remarked in Section II, although the CHAdeMO protocol can be suitable to avoid decay of

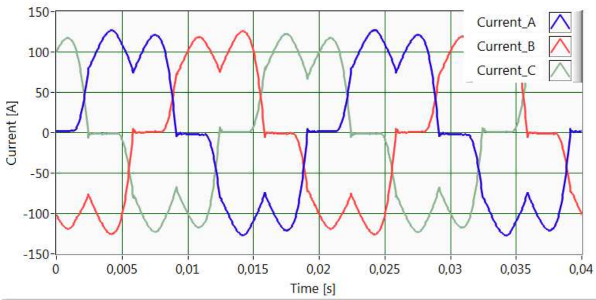

Fig.4. Input AC current waveforms.

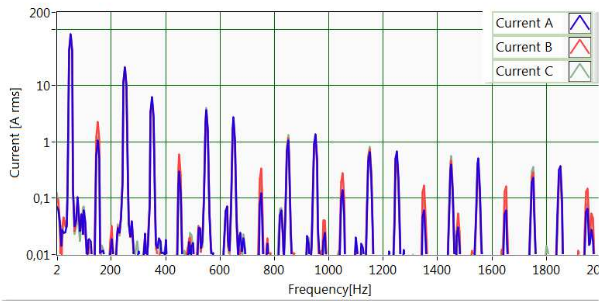

Fig.5. Input AC current spectra.

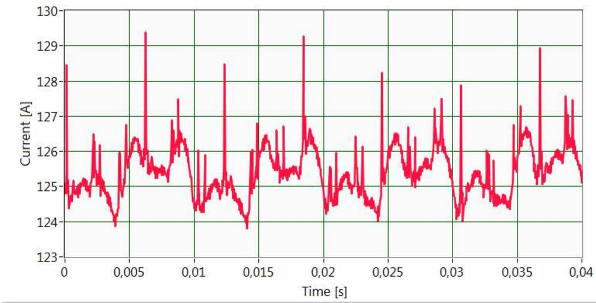

Fig.6. Output DC current waveform.

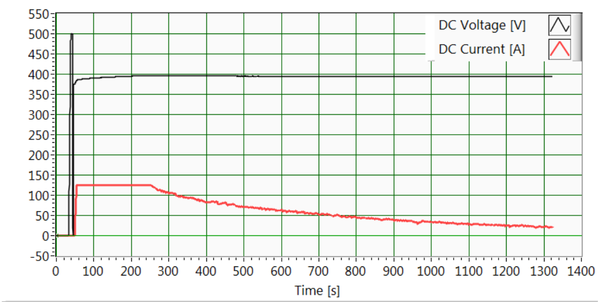

Fig.7. Output DC voltage and current trends.

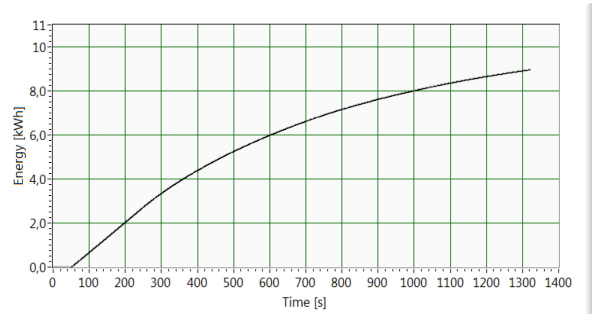

Fig.8. Supplied energy trend..

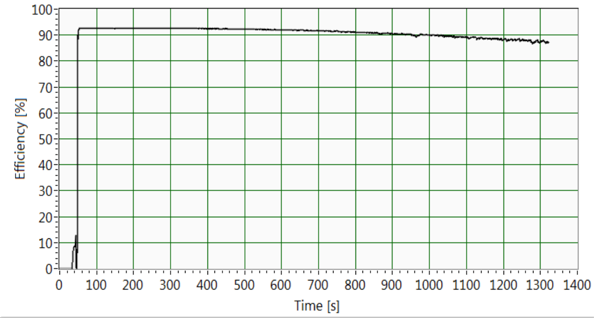

Fig.9. Conversion efficiency trend.

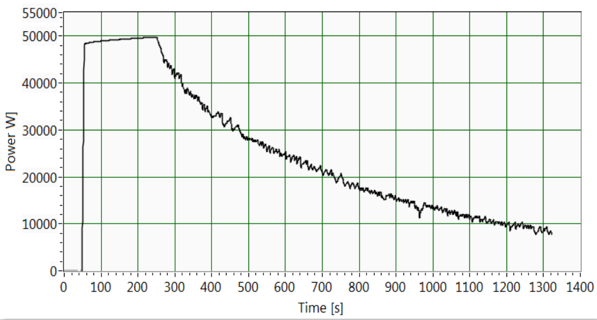

Fig.10. Output DC power trend.

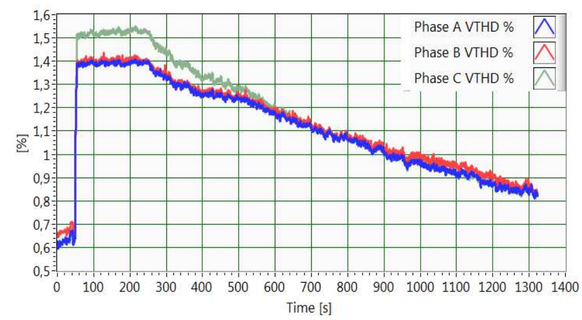

Fig.11. Input AC V_{THD}% trends.

battery system performance during quick charging processes, it doesn't fix any requirement from the electrical point of view, so, a CHAdeMO complying quick charger can involve critical effects on the mains, as shown by the ITHD% trends in Fig. 12.

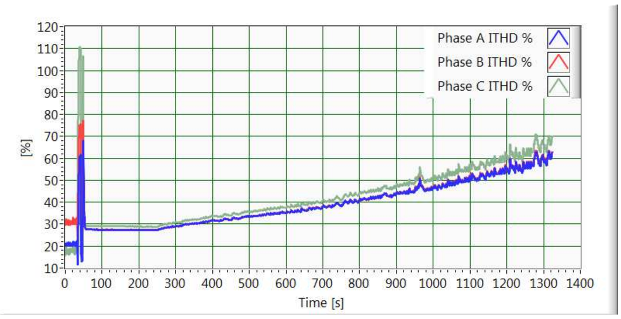

Fig.12. Input AC ITHD% trends.

VII. CONCLUSIONS

In this paper, an automatic test system for the characterization of quick charging stations for electric vehicles has been presented. It has been successfully adopted for the performance evaluation of a quick charging station based on the CHAdeMO standard. The first results obtained during on-field test of the system show encouraging results. In further improvements of this research activity, the analysis of the CAN bus communication between the charging station and the battery management system will be considered in order to better analyze the operating working condition of the charger controller.

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