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Conference on Electronics, Telecommunications and Computers – CETC 2013

Smart Platform towards Batteries Analysis Based on Internet-of-Things

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Abstract

This paper presents a new approach of pre-defined profiles, based in different voltage and current values, to control the charging and discharging processes of batteries in order to assess their performance. This new approach was implemented in a prototype that was specially developed for such purpose. This prototype is a smart power electronics platform that allows to perform batteries analysis and to control the charging and discharging processes through a web application using pre-defined profiles. This platform was developed aiming to test different batteries technologies. Considering the relevance of the energy storage area based in batteries, especially for the batteries applied to electric mobility systems, this platform allows to perform controlled tests to the batteries, in order to analyze the batteries performance under different scenarios of operation. Besides the results obtained with the batteries, this work also intends to produce results that can contribute to an involvement in the strengthening of the Internet-of-Things.

Keywords: Batteries Analysis; Electric Mobility; Interne-of-Things.

1. Introduction

Nowadays, smart grids are emerging as a new paradigm towards power grids [1][2]. In this scenario, with the advances in the electric mobility [3], and in the production and integration of renewables, new research challenges are being opened. The main challenge is related with energy storage systems to smooth the intermittent production

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of renewables, where batteries are the most common solution [4][5]. Taking in account the growing of the energy storage systems area through batteries, it is important the usage of an equipment capable to perform the batteries analysis. This analysis is based in the results achieved from the batteries tests, which are related with different charging and discharging profiles. Although this issue can be ignored for most cases, it is very important to ensure the batteries reliability and performance, and also to prevent failures along their lifetime. Moreover, this equipment can be used to evaluate batteries towards a specific project and to determine the electrical characteristics for their complete characterization under different scenarios of operation. As example, in [6] is presented a reliability and failure analysis of lithium-ion batteries for electronic systems, and in [7] is presented a batteries analysis related with performance. The batteries performance is directly related with the following characteristics:

- Battery Chemistry: Each chemical technology of battery has a specific nominal voltage (as well as maximum and minimum voltage), and charge and discharge curves, even batteries of the same chemistry can have different characteristics according to the manufacturer;
- Temperature: The batteries performance is dramatically influenced by temperatures (when they are used or stored) above or below the limits recommended by the manufacturer;
- Self-Discharge: This characteristic is related with the energy lost when the battery is not in use due to unwanted chemical actions;
- Internal Resistance: The battery internal resistance determines its current carrying capability and the energy lost during operation;
- Charge and Discharge Rates: These characteristics are related with the recommended methods and limits for each battery chemistry, mainly currents, voltages and temperatures.
- Depth-of-Discharge: This characteristic is the battery capacity percentage that has been discharged, expressed as a percentage of maximum battery capacity.

In this sequence of ideas, in this paper is presented a prototype of a smart platform towards batteries analysis, in special batteries applied in electric mobility systems. This platform allows implement controlled tests to the batteries, which consist in different profiles of charge or discharge and that can be applied to different batteries technologies (as example lithium-iron-phosphate, lithium-titanate, or nickel-metal-hydride). Figure 1 shows the architecture of the smart platform, where is illustrated the power flow during the charging (equipment connected to the power grid) or discharging processes (equipment connected to the load). Through these tests it is possible analyze the batteries performance under different scenarios aiming to determine their reliability and performance, as well as estimate the lifetime. The aforementioned platform is based on power electronics in order to analyze the electrical behavior of batteries and is supported on Internet-of-Things (IoT) to control the power electronics hardware. The control and management system of the power electronics platform is based in a microcontroller (DSP from Texas Instruments), which receives a set of commands from an application based on the concept IoT.
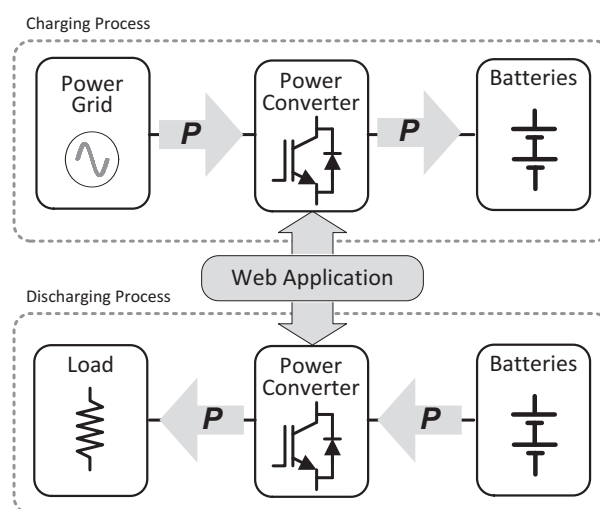

Figure 1. Architecture of the smart platform.

2. Integration with Internet-of-Things

With the presented platform it is possible establish a bidirectional flux of information between the hardware system and the control application. Therefore, it is possible exchange information through the internet, contributing to strengthening the IoT and their introduction in smart grids.

The IoT allows localize, recognize and monitoring appliances, linking them through internet [8]. This new concept in the computing and communication area is also a promising path to the breakthrough in the industry and society [8]. However, it is dependent of the technical innovation in different fields, as Information and Communication Technologies (ICTs), power electronics and wireless communications [9][10]. The International Telecommunication Union defines the IoT as "a technological revolution that represents the future of computing and communications, and its development depends on dynamic technical innovation in a number of important fields, from wireless sensors to nanotechnology" [9].

The IoT paradigm is more evident taking into account the widespread use of mobile phones that are intimate part of everyday life for many millions of people. Consequently, this concept enables new forms of bidirectional communication between people and things [9][10]. The smart grids, including the technological advances in electric mobility, are one of the leading areas to the IoT expansion. As example, in [11] is proposed the use of the IoT in battery charging and swap stations for EVs. Thus, it will be possible access, anywhere, the information related with each device connected to the power grid.

3. Batteries Charging and Discharging Profiles

In this section are detailed described the charging and discharging profiles that are possible implement to test the batteries. For the presented platform it was developed a local application (for control the platform) and an application installed in a web server. Both applications communicate through the web.

3.1. Charging Profiles

In order to perform the batteries charging tests there are four predefined profiles with different algorithms in accordance with the batteries technologies. The batteries charging algorithms are composed by different stages of voltage or current. Although there are several algorithms for the different batteries technologies, following are described the four implemented, which are the most relevant and recommended by manufactures.

The constant voltage charging profile is a charging algorithm based in a single stage. It is imposed a predefined value of constant voltage to the batteries and the current decreases to a predefined value. However, if the predefined value of the current is different from zero, then the batteries are not charged 100%.

The constant current charging profile is a charging algorithm also based in a single stage. It is imposed a predefined value of constant current to the batteries and the voltage increases to a predefined value. However, with this charging profile the batteries are not charged 100%.

The constant current / constant voltage charging profile is a charging algorithm based in two stages. Initially, it is imposed a predefined value of constant current to the batteries and the voltage increases to a predefined value. When this value of voltage is reached, it is imposed a predefined value of constant voltage to the batteries and the current decreases to a predefined value. Depending of the predefined values, with this charging profile the batteries can be charged 100%.

The pulsed charging profile is a charging algorithm based in a single stage, however, this stage is repeated with a predefined frequency. It is imposed a predefined value of constant current to the batteries until the voltage increases to a predefined value. This charging profile is different from the constant current, because it can be applied a greater value of current. However, with this charging profile the batteries are not charged 100%.

3.2. Discharging Profiles

In order to perform the discharging tests there are four predefined profiles. As for the charging profiles there are several algorithms, however, following are described the four implemented.

The constant current discharging profile is a discharging algorithm based in a single stage. It is imposed a predefined value of constant current to discharge the batteries and the voltage decreases to a predefined value, when occurs the end of discharging.

The pulsed discharging profile is a discharging algorithm based in a single stage, however, repeated with a predefined frequency. As for the pulsed charging profile it is imposed a predefined value of constant current to discharge the batteries until the voltage decreases to a predefined value, when occurs the end of discharging.

The free discharging profile is a discharging algorithm without stages. The load is applied to the batteries and the voltage decreases as well as the current. When the voltage reach a predefined value occurs the end of discharging.

The power discharging profile is a discharging algorithm without stages, however the output voltage of the power converter is controlled, forcing to a specific batteries current discharging at constant power. The end of discharging occurs when the batteries voltage reach a predefined value. In this discharging profile is used a fixed resistive load.

4. System Architecture

The presented platform is based in the integration of a hardware system (power electronics) with a local and a remote application with a web interface. There is a communication channel based on available internet where the developed local application is able to exchange data and commands with the remote application and local hardware system. Through the software system the user can define the test to the batteries and control the hardware system.

The hardware system is composed by two power converters, one ac-dc (diodes bridge rectifier) and one dc-dc (bidirectional interleaved buck+boost). For each battery exist a circuit that receive the voltage, current and temperature. These circuits are connect through a RS485 bus and the communication with the DSP is done through RS232. Through the local application is configured the required test that is controlled by the digital control system. During the test, the obtained data is transmitted to the local application. Figure 2 shows the schematic of the presented platform.

According with Figure 2 during the batteries charging the switch S1 in closed and the switch S2 is open. In this case the power flows from the power grid to the batteries through the ac-dc and dc-dc converters. The dc-dc
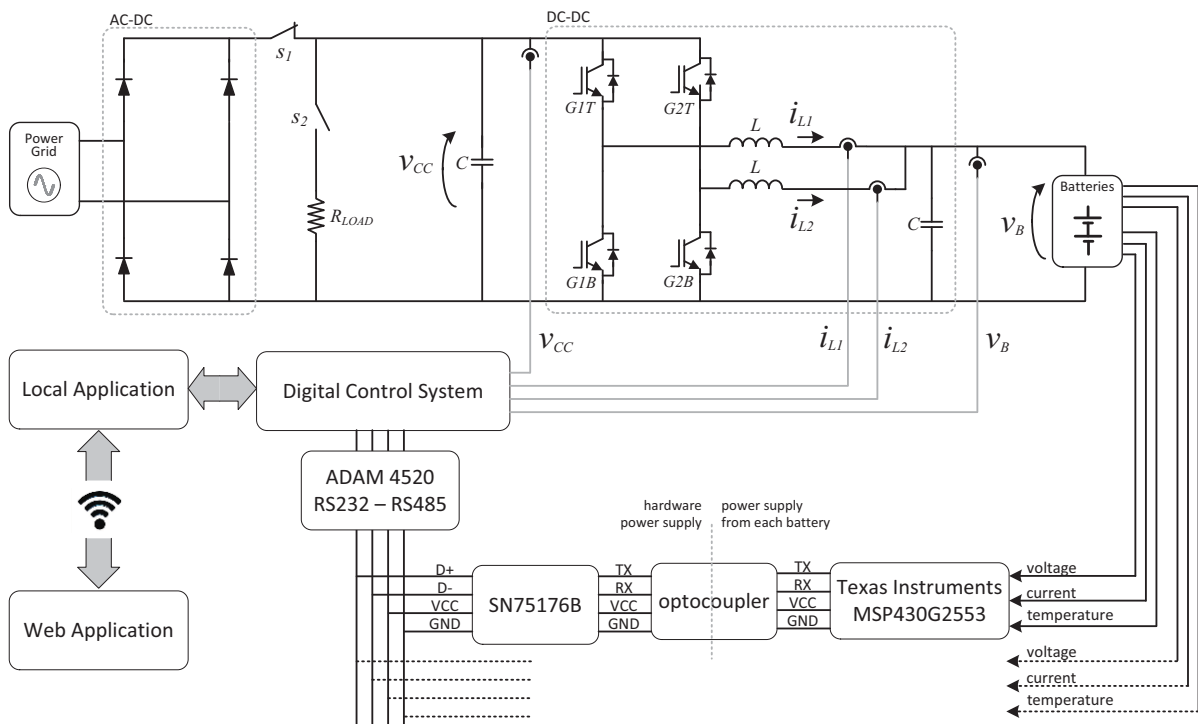

Figure 2. Schematic of the smart platform.

converter operates as buck interleaved converter, i.e., is applied a PWM signal to the IGBTs G1T and G2T and are used the reversible diodes of the IGBTs G1B and G2B. On the other hand, during the batteries discharging the switch S1 in open and the switch S2 is closed. In this case the power flows from the batteries to the load through the dc-dc converter. The dc-dc converter operates as boost interleaved converter, i.e., is applied a PWM signal to the IGBTs G1B and G2B and are used the reversible diodes of the IGBTs G1T and G2T. In this case the ac-dc converter is not used.

4.1. Data Communication

The communication between the web application and the local application is done through web. The communication between the local application and the control system of the hardware system is done through RS232.

The web application has a user menu that allows choosing three main options: (1) charge the batteries; (2) discharge the batteries; and (3) visualize the stored data. In any profile of charge or discharge the user should insert the required values for the test, and then, these values are saved in a file in the web server. The local application is always monitoring new commands received from the web server, and when a change occurs, it will verify what is the required profile (for charging or discharging), and the respective values of the test. Then, this information is transmitted to the control system of the hardware system through RS232 and it is started the test. The voltages and currents required for the test are controlled through the DSP.

During the performing of the charging or discharging profile, the DSP transmits the relevant data (e.g., voltage, current and temperature) to the local application through RS232 with a predefined frequency. These data is stored in a file in the local application. At the end of the charging or discharging profile the DSP informs the local application about this situation and the local application upload the data file to the web server. When it occurs is possible visualize the obtained data in the web application.

4.2. Hardware System

The hardware system is composed by two parts: the power converters (ac-dc diodes bridge rectifier and dc-dc bidirectional interleaved buck+boost converter) and the control system. Figure 3 shows the developed prototype. Table I lists some specifications of prototype hardware.
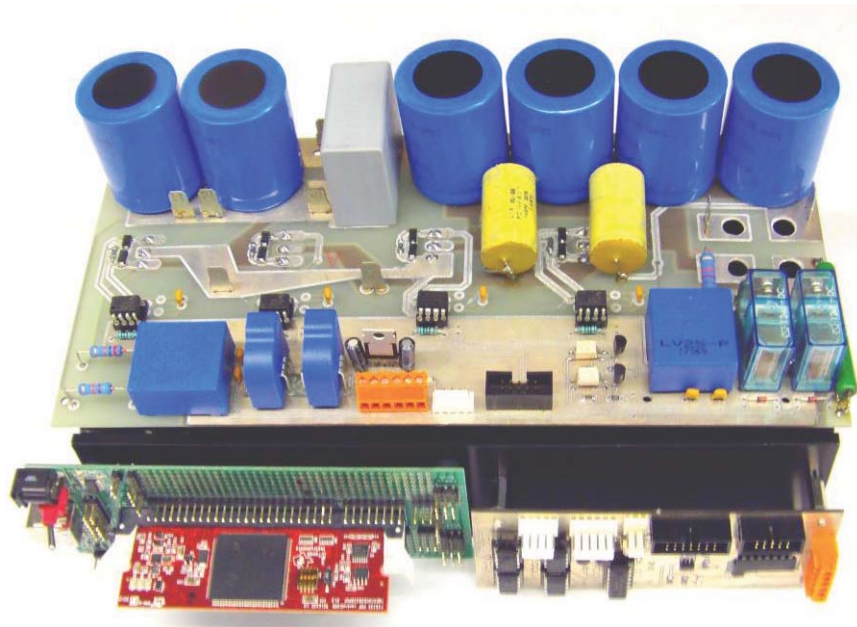

Figure 3. Developed prototype.

TABLE I
PROTOTYPE HARDWARE SPECIFICATIONS

Parameters	Value	Unit
Input ac Voltage	230 ± 10%	V
ac Frequency	50 ± 1%	Hz
Maximum Input ac Current	16	A
Maximum Input Power	3.6	kVA
dc-link voltage	350	V
Output Voltage Range	100 - 300	V
Output Current Range	0 – 10	A
Switching Frequency	20	kHz
Efficiency	> 90%	
Dimensions	250×290×95	mm

Taking into account that the tests can be divided in charge or discharge the batteries, the hardware systems allows operating in bidirectional mode. During the batteries charging test the hardware system is used to convert the ac electrical energy into dc with an appropriate voltage or current level in order to charge the batteries (using the buck converter). During the batteries discharge test the hardware system applies an appropriate voltage or current level to a load in order to discharge the batteries (using the boost converter). In the power converters were used IGBTs from Fairchild, model FGA25N120ANTD.

On the other hand, the control system, which implements the algorithms in both operation modes, is composed by several electronic circuits with analogue and digital signals. The control algorithms were implemented in the DSP TMS320F28335 from Texas Instruments. Their internal ADCs receive the voltages and currents signals provided by the signal conditioning circuit and generate the control signals to the command circuit. The voltage and current signals of the dc-dc bidirectional power converter are obtained through hall-effect LEM sensors (LTSR 15-NP for the current sensors and LV 25-P for the voltage sensors) in the signal conditioning circuit. This circuit also provides protection against overvoltages and overcurrents in both operation modes. The control signals to the IGBTs drivers (HCPL 3120) are provided by the command circuit, which receives the control signals from the DSP and receives the error signals provided by the signal conditioning circuit.

4.3. Software System

The software system is composed by two main parts: the local application and the web application. Through these applications the hardware system can be locally or remotely controlled by the user. The user can access both applications through a login mechanism (username and password). For security reasons the local application is available only in local network. In both applications the user can define the intended test and visualize the obtained data. The local application is running on a common PC at this phase with local network connection to the server and with RS232 communication with the hardware system.

In order to define a test the user has two options. The first consist in configure the intended test in the local application and visualize the obtained data in this application. The second consist in configure the intended test in the web application, and the communication is established with the local application (without user interference) and with the control system of the hardware system. In this second option the obtained data is visualized in the web application.

5. Developed Application

The presented platform is intended to perform a set of tests in batteries, aiming to obtain electric parameters to their faithful characterization. Besides the electric characterization, it is also intended to adequately assess the batteries efficiency, the effect of temperature in the batteries during operation, and determine the State-of-Charge (SoC) and the State-of-Health (SoH).

The local and web applications were developed to allow configure the intended test through a specific charging
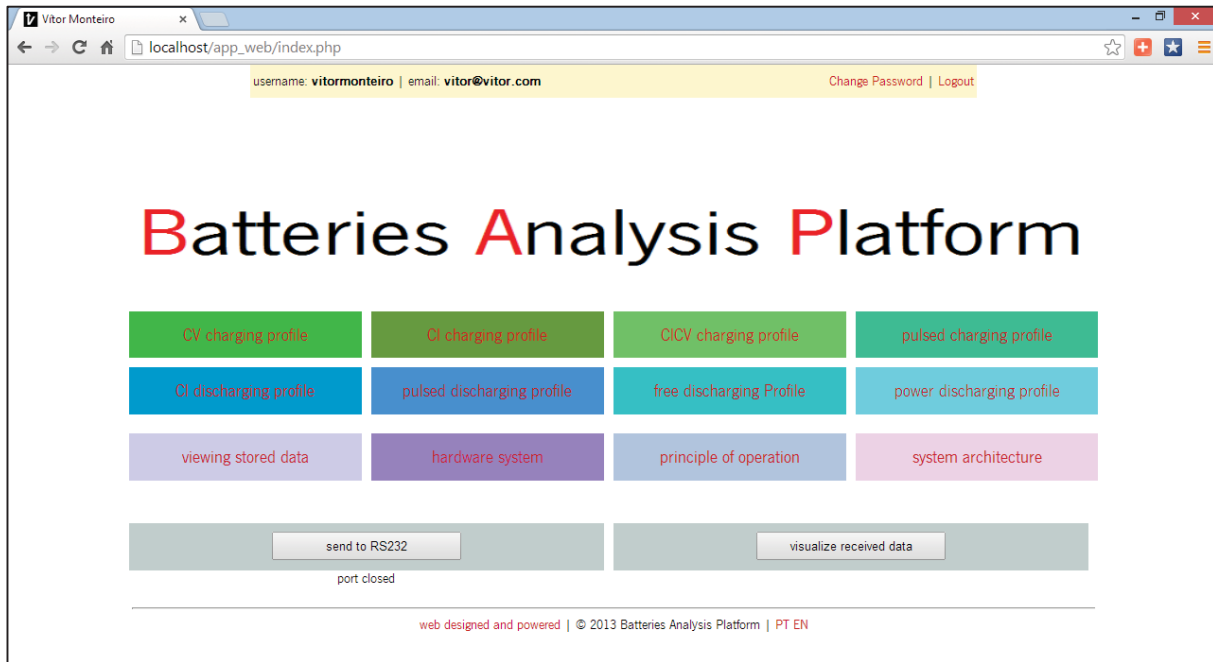

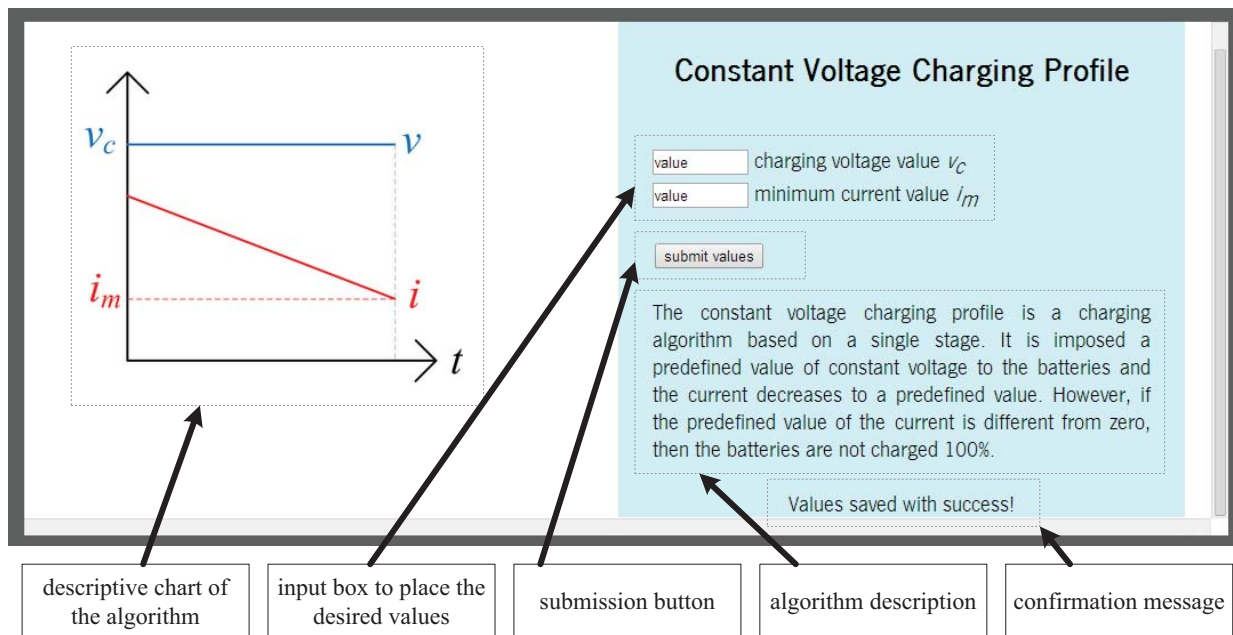Figure 4. Developed web application with the different options.

Figure 5. Screen of the charging profile.

or discharging profiles. When is selected a profile appears a window above the main window. In this new window is shown a figure with the profile characteristics, a set of text boxes to introduce the required values to the test according to the profile, and also a submit button to save the introduced values in a file. In Figure 4 is present the main window of the developed web application with the different options. As example, Figure 5 shows a screen used to configure a charge profile.

6. Conclusion

This paper presents the prototype of a smart platform that was developed to perform batteries analysis. It was developed a power electronics system and a control system related with Information and Communication Technologies. As presented, through this platform it is possible to configure different tests to the batteries according to charging or discharging profiles. These profiles can be configured through a local or a remote application, contributing to strengthening the Internet-of-Things.

The different profiles that can be configured are explained, as well as the development of the local and web applications. The data files transactions between the applications and the control system of the hardware are also explained. In this context, one of the main contributions is the possibility to perform several controlled tests, and to store the obtained data in a web server, aiming to analyze the batteries performance under different scenarios of operation. Through these tests it is possible to characterize the batteries in order to define usage strategies, aiming to optimize their performance, and consequently their lifetime.

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